Noise Effects '98

SYDNEY, AUSTRALIA

7TH INTERNATIONAL CONGRESS ON NOISE AS A PUBLIC HEALTH PROBLEM

VOLUME I

EDITORS

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FOREWORD

These two volumes are the Proceedings of Noise Effects '98, the Seventh International Congress on Noise as a Public Health Problem, which took place in Sydney, Australia, from 22-26 November 1998. The Congress was organised under the auspices of the International Commission on Biological Effects of Noise (ICBEN). The papers contained herein are those which were presented at the Congress and submitted for publication. They are grouped according to the subject matters of the ICBEN International Noise Teams, as follow: Team 1: Noise Induced hearing Loss; Team 2: Noise and Communication; Team 3: Non-auditory Physiological Effects Induced by Noise; Team 4: Influence of Noise on Performance and Behaviour; Team 5: Effects of Noise on Sleep; Team 6: Community Responses to Noise; Team 7: Noise and Animals Team; 8: Effects of Noise Combined With Other Agents; Team 9: Regulations and Standards.

Volume 1 contains papers from Teams 1-4; Volume 2 Teams 5-9. Within each Team, the papers are further grouped according to Keynote Addresses, Invited Papers, and Workshop and Contributed Papers.

Publication of these Proceedings was sponsored by the United States Department of Defence, the U.S. Army, Navy and Air Force, and the National Aeronautics and Space Administration. The Editors wish to thank these sponsors, as well as all contributors, the ICBEN team leaders, and the staff of Tour Hosts Pty Limited, Sydney, especially Ms Denyse Robertson.

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INTRODUCTION

These volumes represent the research papers submitted to Noise Effects '98, the 7th International Congress on Noise as a Public Health Problem, organised under the auspices of the International Commission on Biological Effects of Noise (ICBEN). Since its creation in 1973, at the Dubrovnik conference (the 2nd International Congress on Noise as a Public Health Problem, the first being held in Washington in 1968) ICBEN has become a premier international body in the field of research into the biological effects of noise and their prevention. To cite two examples, ICBEN is acknowledged for its help with the recent review of noise effects by the World Health Organisation (see Berglund & Lindvall, 1995) and is also involved in advising the European Commission on noise effects.

International Representation on ICBEN

A primary attribute of ICBEN which has contributed significantly to its success is its truly international representation. The three office bearers (who, in keeping with equal opportunity across gender, are all female at present) come from three different countries, the President from Sweden, the Secretary from Germany, and the Vice-President from the United States. This international representation is also evident in the Chairs and Co-chairs of the nine International Noise Teams.

Structure of ICBEN

The success of ICBEN may also be attributed to its structure, which allows for no continuing funding of ICBEN itself. As a result ICBEN does not become bogged down in financial concerns, such as annual auditing of accounts. ICBEN does not operate a bank account. The original constitution of ICBEN contains only one article on finances, which simply states: "The officers and the Executive Committee are authorized to solicit funds in support of the activities of the ICBEN." Thus, the office bearers must meet costs from their institutions and from their own resources, selecting for committed persons. This also means, however, that the conferences must be run without any financial support from ICBEN. While this creates a more daunting task at the outset, strong sponsorship has been forthcoming for the conferences, and the present conference is no exception. In part at least, this level of sponsorship arises from the knowledge that the conferences are run as non-profit ventures, and that sponsorship of the conferences does not amount to sponsorship of an ongoing account held by ICBEN.

International Noise Teams

The powerhouses of ICBEN are its International Noise Teams. ICBEN is organized around nine teams: Team 1 is responsible for efforts in relation to noise-induced hearing loss; Team 2 for noise and communication; Team 3 for non-auditory physiological effects induced by noise; Team 5 for effects of noise on sleep; Team 6 for community response to noise; Team 7 for noise and animals; Team 8 for combined agents; Team 9 for regulations and standards. Each team consists of up to 10 experts in the relevant field, with an elected Chair and Co-chair. The chairs are limited to two periods of office to allow for new ideas and fresh approaches to the problem at hand. Team membership is limited to no more than two members from any one country to ensure the maintenance of the international representation of ICBEN. This team structure allows for many of the valuable outcomes of ICBEN and its twice per decade conferences, in the following ways:

1. Research endeavours can be focused, and can avoid unwanted duplication within the team.
2. The team members can be kept abreast of recent developments in their field. This is done in part through correspondence between team members, and partly by means of the summaries of the developments in each field over the preceding five years, which are presented by each team at each conference.
3. While each team maintains a focus on the specific issues of the team, the isolation of teams is avoided by ensuring that each team presents its five-yearly review of research and invited addresses in plenary. In this way members of all teams may witness the advances being made in each of the other eight primary areas of endeavour.
4. The teams themselves are not fixed. The original constitution of ICBEN only states that such teams will exist but does not specify the number or subject-areas of the teams. Indeed, the teams have been changed to meet the growing and changing face of noise research. The most recent change was the addition of Team 9: Regulations and Standards, at the Stockholm conference in 1988.
5. The team structure can allow for international collaboration, and agreements regarding findings, approaches, applications, methods, measurement, and/or reporting. A prime example of this has been the collaborations in Team 6 (Community Reaction) regarding standards of reporting which have been agreed on within the team after considerable discussion, and since published by the team (see Fields et al., 1997).

Collaborative research is also fostered, such as the international research on the wording of questions on reaction to noise, resulting in several papers presented in the present volumes.

Conferences and Proceedings

The five-yearly international congresses on Noise as a Public Health Problem are a centrepiece of ICBEN's productivity. High standards of scientific quality and sensitive application of research to practical solutions are the norm. Shared information and experience raise the knowledge base for all. The polite yet sometimes spirited discussions also serve ICBEN well. The production of quality Proceedings from these conferences has allowed them to maintain an impact rarely seen of conference publications. Indeed, as a measure of awareness of the features of quality conferences shown by the founders of ICBEN, the constitution requires that Proceedings be produced for each conference. This maximises the impact of the conference, advertises the conferences, and increases the motivation to present quality work at such conferences, knowing that a Proceedings will be produced. We can all identify classic papers in our respective fields within previous volumes from this conferences series.

An objective measure of the impact of these conferences lies in the level of scientific citation of the Proceedings. The most recent Proceedings, edited by Michel Vallet, are recorded as having been cited 14 times in the Science Citation Index and the Social

Science Citation Index in the years 1994-1997. It is an unusual achievement for a Proceedings to be cited so frequently in refereed journals.

The conference on which the present Proceedings are based continues to reflect these advantages of the ICBEN structure in many expected ways. The plenary session from each team is programmed. The conference maintains the international representation of researchers and workers on noise effects. The conference boasts papers offered from all continents, as well as from 'Oceania'. International keynote addresses are included. Each team has organised its own sessions from invited and contributed papers, with the results of these decisions being passed on to the local Organising Committee for implementation.

Noise Effects '98 is also innovative. There are sessions based on the joint work of more than one team. Thus we have combined sessions from Teams 3 and 4 (physiological effects and performance), and from Teams 3, 6 and 8 (physiological effects, community response and combined agents), demonstrating fruitful cross-team collaborations. A contributed workshop addressing the economic costs of noise countermeasures is of relevance to deliberations regarding solutions to noise from the perspective of many of the teams (Section 10).

Two other features of the Congress are noteworthy. First, it is appropriate that one quarter of a century after the founding of ICBEN, one of the two people most responsible for its creation, Dixon Ward (who together with Gerd Jansen founded ICBEN) is honoured by the Dixon Ward Memorial Address, one of the two keynote addresses delivered at the Opening Ceremony. This address is presented by Guido Smoorenburg. Second, the global role of ICBEN is emphasised in this conference, the first to take place outside Europe. Previous ICBEN conferences (after the 1973 Dubrovnik conference from which ICBEN arose) have been held in Germany in 1978, Italy in 1983, Sweden in 1988, and France in 1993.

These are exciting times in the field of noise research. The effects of noise on humans and animals is better recognised and better understood than ever before; solutions as expensive as shifting airports to unpopulated areas, or even offshore are being considered and implemented. New approaches, such as positive sound environments are being evaluated; communities are more informed and more reactive to this information (or misinformation) about noise than before (see Carter et al., 1996). Artificial hearing and hearing protection are advancing. Yet, these are also worrying times in terms of the effects of noise. The combined effects of greater industrialisation, greater mechanisation (especially of transport), and greater concentration of populations in noisy cities rather than quiet rural settings has caused greater noise exposure of the population globally than ever before. It is our earnest hope that Noise Effects '98, the 7th International Congress on Noise as a Public Health Problem, and these Proceedings, will contribute significantly to furthering our understanding of the biological effects of noise, and their mitigation.

Norman L. Carter
R. F. Soames Job

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EFECTS OF IMPULSE NOISE ON MAN

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1. IMPULSE NOISE

Background

When one considers either noise-induced hearing loss or noise annoyance then it is clear that impulse noise has always received special attention. For noise-induced hearing loss ISO 1999 (1990) "Acoustics, Determination of occupational noise exposure and estimation of noise-induced hearing impairment" states in clause 1, Scope, that "use of this International Standard for instantaneous sound pressures exceeding 200 Pa (140 dB *re* 20 μPa) and for higher sound pressures should be recognized as extrapolation". This led to the inclusion of a strict 140-dB peak level limit in the European Directive 86/188/EEC on the protection of workers from the risks related to exposure to noise at work.

For noise annoyance, ISO 1996-2 (1987) "Acoustics – Description and measurement of environmental noise – Part 2: Acquisition of data pertinent to land use" states that " if impulse is an essential characteristic of the sound within a specified time interval, an adjustment may be applied for this time interval, to the measured equivalent continuous A-weighted sound pressure level. The value of this adjustment should be stated." ISO 1996-2 (1987) does not specify the appropriate adjustment. The previous recommendation ISO/R 1996 (1971), however, did specify an adjustment of + 5 dB. The appropriate adjustment is still in discussion. Presently, adjustments vary amongst types of impulsive noises and amongst countries between 2 and 12 dB and higher for very high-energy impulses.

At the time both the hearing-impairment and land-use standards were drafted there were only very limited data available on the effects of impulse noise although the need for these data was recognized much earlier. In fact, the congress on Noise as a Public Health Problem of 1973 (where the International Committee on Biological Effects of Noise was established) was organized in Dubrovnik, Yugoslavia, hoping that this meeting place of East and West would provide new data and insights, not in the least on the effects of impulse noise on hearing threshold. W. Dixon Ward, the session arranger and proceedings editor of this conference was personally highly involved in the evaluation of risk of hearing loss from impulse noise.

Intuitively, one may expect relatively strong effects from impulse noise. For noise-induced hearing loss, this expectation is usually based on the notion that hearing loss increases progressively with sound level. The concentration of sound energy in a short time interval might therefore increase the risk of hearing loss to a larger extent than the relatively silent periods between the impulses might decrease this risk. However, the relatively silent periods may provide important time to the ear to recover, which might counterbalance the progressive effect at high sound levels. In a similar fashion, we may assume that impulse noises may be more annoying than noises with about the same amount of energy stretched out over the full time interval. Impulse noise may exceed a threshold (for example a startle threshold or a hearing threshold enhanced by ambient noise) whereas a stationary sound with the same amount of energy stretched out in time may not reach this threshold at all. Consequently, the stationary sound may not cause any annoyance. However, annoyance may be caused by speech interference. When the impulse noise masks the speech completely for only a short period it may be less annoying than stationary noise at the same equivalent sound level interfering continuously with speech perception. The above examples illustrate that one cannot, simply based on educated guessing, decide whether or not the effects of impulse noises will be relatively large. The result of the trade-off between the possibly progressive effect of concentrating the sound energy in a short time interval and the possibly beneficial effect of the relatively silent periods in between the impulses should be assessed experimentally.

Possible experimental approach

Experimental assessment of the community response to impulse noise appears to be quite workable. It has received much attention in the last decades. In addition, annoyance from impulse noise may be estimated on the basis of laboratory experiments in which impulse noises are compared to other types of noises with better known community response. However, experimental assessment of hearing loss due to impulse noise is obviously impossible when one accepts that such an assessment should ultimately be based on permanent threshold shifts induced in human subjects. Analysis of damage risk on the basis of hearing loss data that are available from the times that hearing conservation did not yet receive much attention is complicated by uncertainties in the retrospective assessment of the sound exposure. First of all, it is very difficult to trace down the exact temporal distribution of the sound. Many parameters are involved such as impulse duration, attack and release times of the impulse, the intervals between the impulses and the background noise during these inter-impulse intervals. Moreover, these parameters may depend critically on the exact position of the ear with respect to the sound sources. Impulse noise often arrives at the ear from a few distinct sound sources. These uncertainties in the temporal aspects of the impulse noise exposure, in combination with the uncertainties in the retrospective assessment of the spectral properties of the noise, show that, where the hearing loss data may be quite reliable, assessment of damage risk will often be troubled by uncertainty in the exposure history. In recent research on the risk of hearing loss from large caliber weapon noise we have tried to solve this problem by focussing on small threshold shifts measured immediately after the impulse noise exposure in human subjects. The threshold shifts were not allowed to exceed a level at which any risk of permanent hearing loss would arise. Thus, this approach aimed at assessing a threshold. It did not address the, for hearing conservation purposes less important, issue of finding the full dose-effect relation.

2. ANNOYANCE FROM IMPULSE SOUNDS

History

When in the seventies we started our research on annoyance from shooting noise there were very limited data. Based on studies by Kryter [1], Hediger [2], Meurers [3], and Carter [4] and based on the psycho-acoustics of loudness perception we concluded [5,6] that the rating sound level L_r for impulse noise should equal:

$$L_r = L_{imp} + 10 \log N - 42 \, dB(A) \qquad (1)$$

where L_{imp} represents the level of a single impulse in *dB(A,imp)*, which means A-weighted and with the standardized impulse integration time (imp) of 35 ms, and where N represents the number of impulses per day, $100 < N < 10{,}000$.

By approximation, it was possible to express L_r in the equivalent level of the impulse noise as required by ISO 1996-2. For shooting noise field measurements showed that the 1-s A-weighted equivalent energy levels (the sound exposure levels, *SEL*) were about 9.5 dB lower than the *dB(A,imp)*-values. Calculating the equivalent continuous level L_{eq} based on an eight-hour relevant period for shooting ranges yielded:

$$L_r = L_{eq} + 12 \, dB(A) \qquad (2)$$

Thus, our estimate of the adjustment to the equivalent continuous A-weighted sound pressure level, proposed in ISO 1996-2, became 12 dB for shooting noise.

Laboratory comparisons

As mentioned above, these results were based on a very limited set of data. Therefore, a European study was initiated, including four institutes, to collect more data. In this study, we made the principal decision to base further evaluations of annoyance from impulse noise on laboratory comparisons between impulse noises and road traffic noise. Field studies are subject to high variability related not only to inter-subject differences in susceptibility to noise but also to factors such as the estimated effect of the noise on the value of one's property and the economical relation of the subject interviewed to the source of the impulse noise (*e.g.* the employee of a shooting range). According to our view, laboratory experiments based on the inclusion of a reference noise with a well-known community response would enable a pragmatic evaluation of annoyance from impulse noises. In addition to gunfire noise, the European study included pile driving noise and a synthetic impulse sound consisting of a white noise burst with immediate onset and 87 dB/s exponential decay [6]. The results of these experiments showed that the adjustment proposed in ISO1996-2 tends to depend on level. We concluded that this factor should range from about 13 dB at an indoor L_{eq} of 35 dB(A) to 4 dB at L_{eq} = 56 dB(A). Rice [7] concluded from these studies that the adjustment should be about 10 dB at an indoor L_{eq} of 35 dB(A) to 0 dB at an indoor L_{eq} of 70 dB(A). A later survey confirmed these conclusions [8]. This result suggested that the previous finding of Eq. (2) would hold only for impulse noise at low indoor levels. However, the laboratory studies were performed in a quiet background. The adjustment factor of 10 to 12 dB might also hold for higher impulse sound levels in the presence of ambient noise considering the relative level above the noise rather than the absolute level. Therefore, a follow-up study was initiated including background noise.

In addition to gunfire noise, this follow-up study included metal construction noise [9]. The background noise consisted of a recording of remote-traffic noise, characterized by very small fluctuations in noise level at 35 and 55 dB(A). The impulse noises were presented at L_{eq} = 30-60 dB(A) for the 35 dB(A) background and at L_{eq} = 40-70 dB(A) for the 55 dB(A) background. Using again annoyance ratings in these laboratory experiments, the results for gunfire noise showed, in agreement with the previous results, that the adjustment should decrease with increasing impulse level. For construction noise, the adjustment tended to be smaller and less dependent on level. The decrease in the adjustment for gunfire noise was found, however, over a rather large range of impulse levels, including high annoyance ratings. Focussing on a criterion of 33% of the subjects "very much annoyed" we found an adjustment factor of about 10 dB at an indoor background level of 35 dB(A) and a factor of 5 dB at a background level of 55 dB(A). These adjustment factors held for annoyance ratings up to the 33% criterion, the range pertinent to land use.

The ISO/R 1996 recommendation was based on the notion that community responses to unwanted sounds are determined by the level of the specific noise sources in comparison with the level of the background noise. In particular at high background and impulse sound levels, however, the over-all noise level may be important. Therefore, two ratings were collected: one source specific and one based on the total noise. The results for the 33%-very-much-annoyed criterion showed no significant difference between these two types of noise ratings. In addition, considering the full range of impulse levels, the total-annoyance ratings showed clearly less dependence on impulse level than the source-specific noise ratings (see also [10]). Together with the results for the source-specific ratings up to 33%-very-much-annoyed this suggests the usage of an adjustment independent of the impulse level.

Effect of background noise

In search of the appropriate adjustment for impulse sounds in the evaluation of environmental noise pertinent to land use laboratory experiments do not suffice. In 1995 Vos [8] presented a review of field surveys addressing the annoyance caused by small firearms. The results of the surveys could be compared on the basis of a criterion of 33% highly annoyed. For a Swedish survey he derived an adjustment of 13 dB, for a Swiss study 14 dB, for a German survey 12 dB, and for an Australian study 12 dB. Moreover, two studies on industrial noises gave about the same adjustments. An English survey at a construction site [11] and a Dutch survey around an industrial area [12] both yielded an adjustment of about 11 dB. Finally, in comparing the results of all these studies, there appeared to be no systematic relation between the outdoor equivalent level of the impulses and the required adjustment. Thus, in spite of all the factors that may affect the results of field studies, the results from the above field studies confirm the conclusion drawn before from the ratings in the laboratory experiments below 33%-very-much-annoyed that we do not need to introduce a level-dependent adjustment. For shooting noise from small fire arms and several industrial noises we may conclude that an adjustment of 10 –12 dB is appropriate with impulse levels in the range of L_{eq} = 50-60 dB(A) outdoors (30-40 dB(A) indoors) and noise backgrounds up to about 55 dB(A) outdoors (40 dB(A) indoors). These background levels cover the noise levels in most communities.

Industrial impulse noises

Thus far, the conclusions were mainly drawn from shooting noise whereas industrial impact and impulse noises may constitute an important part of land planning and land use problems. However, this approach is therefore not inadequate. Shooting noise is quite an extreme form of impulse noise. The extremeness helps in finding the range of adjustment factors that may be expected. Moreover, wherever we included non-shooting impulse noises so far we found by and large that the results did not differ from the shooting noises. Inclusion of industrial impact and impulse noises is complicated by an adequate description of the impulsiveness of the sounds. When one feels it is necessary to introduce a range of adjustment factors for sounds characterized from continuous to very impulsive, there should be a method to choose the appropriate adjustment based on a physical measure of impulsiveness. An attempt to derive such a measure was initiated within the CEC Joint Project on Impulse Noise (1986-1990). Forty noises were rated as to their impulsiveness. The ratings were based on four questions: (Q1) annoyance of the total noise, (Q2) its impulsiveness, (Q3) a yes/no decision on whether the noise was clearly impulsive and (Q4) a rating of the annoyance of the impulsive part of the noise [13]. Physical measures based on the variance in the sound energy measured in 10 ms intervals correlated highest with the questions Q2, Q3, and Q4 that included the word "impulsive". Measures based on the difference between the long-term L_{Aeq} and this quantity measured with the standardized "impulse" time weighting and a measure based on the kurtosis of the distribution of the 10 ms energy samples correlated less well. However, the coefficient of the correlation between the three measures based on the variance of the 10 ms energy samples and any of the three questions Q2-Q4 that included the word "impulsive" was limited to about 0.7. The correlation with annoyance is still lower, almost negligible. A recent draft of a revision of ISO 1996-1, ISO/DIS 1996-1-WD2 (June, 1998) "Acoustics-Description and measurements of environmental noise- Part 1: Basic quantities and procedures", prepared by ISO/TC 43/SC 1/WG 45, does not include a physical measure of impulsiveness. Rather than including such a measure, correlated with annoyance to a negligible degree, one prefers to include several explicit categories of impulse noise. The revision proposes to distinguish three categories: (1) highly impulsive noises (e.g. small-arms gunfire, hammering, pile driving, and riveting), (2) high-energy impulsive sound (explosions, sonic booms, military and mortar fire or any other explosive sources where the equivalent mass of dynamite exceeds 25 g), and (3) ordinary impulsive sounds which includes all other impulsive sounds. The high-energy impulsive sounds were not discussed in this survey because they constitute a very specific category of impulses. Moreover, annoyance from these impulses may be determined by other factors than sound, for example the vibration of buildings or even risk of damage to buildings. This means that low-frequency energy becomes very important which leads to other weightings than the A-weighting, namely the C-weighting.

Conclusion

The above categorization of impulse noises is used in a new version of ISO 1996-2, which was accepted by majority vote in 1997. However, the acceptance was accompanied by many comments which are still under consideration. The revision indicates that an adjustment of 12 dB shall be applied for highly impulsive sounds, the types of impulse sounds discussed above. For ordinary impulse sounds, the adjustment shall be 5 dB. Thus, we may conclude that the original ISO/R 1996 recommendation of 1971 proposed a 5-dB adjustment for impulse noise that was withdrawn in the final version of 1987 by lack of data. The data collected since have shown convincingly that the adjustment of 5 dB is too small for highly impulsive sounds. The proposal for the new ISO 1996-2 is to increase this adjustment to 12 dB and to use the 5 dB adjustment for "ordinary" impulse sounds.

3.HEARING LOSS DUE TO IMPULSE SOUNDS

History

Similarly to studies on the annoyance from impulse noise, hearing loss due to impulse noise has been studied largely for shooting noise. Early important work was conducted within Working Group 57 of the Committee on Hearing, Bioacoustics and Biomechanics of the National Research Council of the US National Academy of Sciences (CHABA). The results of their report "Proposed damage-risk criterion for impulse noise (gunfire)", edited by W. D. Ward in 1968, are summarized in Fig. 1 using a definition of impulse duration different from the original one. An essential aspect of these data is that a tenfold increase in impulse duration has to be compensated for by less than a 10 dB (*i.e.* 7 dB) decrease in impulse level in order to satisfy the damage risk criterion. This implies a deviation from a constant (equivalent) sound energy criterion. The CHABA damage risk criterion aimed at less than 10 dB

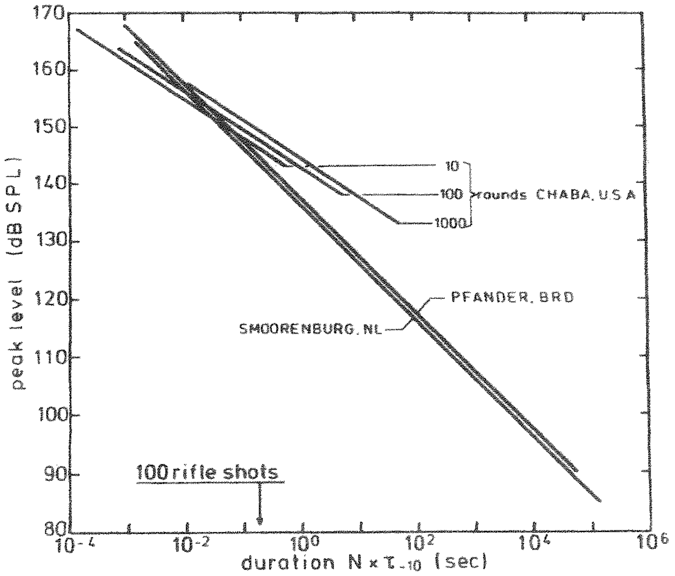

Figure (1) Damage risk levels derived by CHABA, Pfander [15] and Smoorenburg [14]. N represents the number of impulses, τ_{-10} the duration of a single impulse. Figure adopted from ref [14].

threshold shift at 1 kHz, less than 15 dB at 2 kHz, and less than 20 dB at 3 kHz in not more than 5% of the exposed personnel. Fig. 1 also shows that the trade-off between number of impulses and impulse duration was fairly close to a constant product of the two; the lines for different number of impulses nearly coincide.

We [14] extended the work of CHABA by collecting all data available on temporary threshold shifts (TTS) after exposure to shooting and non-shooting noise. The evaluation included wood and metal impacts, sparks, cricket toys and synthetic impulses. However, the sounds were limited to impulses well separated in time, without background noise. Duration of the individual impulses ranged from 0.034 to 90 ms. Impulse numbers ranged from 1 to 4,000 per exposure and the impulse rates varied from one in 50 seconds to 3 per second. The total exposure lasted up to 30 minutes. Acceptable TTS (the fence) was set at 15 dB, averaged across the audiometric frequencies 1, 2, and 3 kHz, to be found in not more than 10% of the people exposed to these noises two minutes after the exposure (TTS_2). This fence allowed compilation of the data without too much extrapolation. The duration measure was based on an idealization of the impulse waveform. The impulse waveforms were fitted to an exponentially decaying ringing impulse and the duration, τ_{-10}, was defined as the time interval at which the envelope had reached a level of –10 dB with respect to the peak of the impulse. Again, this measure was chosen because it allowed pooling of the data available with a minimum of extrapolation. The results showed a trade-off between peak level and total duration $N^* \tau_{-10}$ (N is the number of impulses) of –8 dB per tenfold increase of total duration in the range $N^* \tau_{-10} = 0.001\text{-}1000$ s. This implies a deviation from equal energy like the CHABA result. At $N^* \tau_{-10} = 1000$ s these results for impulse noises appeared to join TTS_2 data for intermittent noise applying the same fence for hearing loss. For intermittent and continuous noise in the range $N^* \tau_{-10} = 1000\text{-}30{,}000$ s (30,000 s = 8 hr), we found a much steeper slope of about -18 dB per tenfold increase of total duration, corresponding to the earlier finding of –5 dB doubling the duration. In summary, these results showed an allowable exposition of $L_{eq} = 85$ dB at the extreme total durations of 0.001 s and 8 hr with positive deviations from this equivalent level up to 12 dB at $N^* \tau_{-10} = 1000$s. After comparing this result to data on permanent threshold shifts (PTS) for shooting noise and stationary noises we concluded that the fence in terms of PTS will not be exceeded if all types of noises, from the single high-level impulses to continuous noise, is limited to $L_{eq} = 85$ dB. This value may be too conservative for certain types of intermittent noise. Our result is presented in Fig. 1 (indicated by SMOORENBURG, NL). Fig. 1 also shows a damage risk criterion proposed at that time by Pfander [15], which was very close to ours.

Critical issues

Over-all exposure limit. The above result shows that an adjustment as used for the evaluation of impulse annoyance is not required for hearing loss due to impulse noise. The limit of to $L_{eq} = 85$ dB holds over the full range, from a few isolated impulses to stationary noise. However, this is true only for this particular hearing loss criterion yielding the $L_{eq} = 85$ dB limit. Hearing loss due to impulse noise increases very progressively with exposure level, in particular in the most susceptible 10% of the population. Therefore, the conclusion that no adjustment is needed for hearing loss due to impulse noise is limited to the $L_{eq} \leq 85$ dB. Countries that have adopted a higher limit for stationary noise should not conclude from these results that the same higher limit can be applied to impulse noise.

140 dB exposure limit. The results have also shown that there is no critical peak level. Thus, the limit of 140 dB in ISO 1999 is not supported by these results. The limit of 140 dB stems primarily from the consideration that the effects of isolated impulses like those from shooting noise were not well known at the time the standard was drafted. In industry, one usually does not find peak levels above 140 dB. Thus, implicitly the standard was limited to industrial noises for which risk of hearing loss was better known.

Angle of sound incidence. In the introduction, we already mentioned that the exact location of the sound source is more important with impulse noise than with most stationary noises. More so than for stationary noise, impulse noise may originate with a single or a few sources. One example of the importance of sound source location is the dependence of the risk of hearing loss on the angle of incidence of the sound. Normal incidence (sound from aside) implies a higher risk (easily to an equivalent of 5 dB) than grazing incidence (sound from ahead). The above evaluation was based on normal incidence.

Acoustic reflex. The acoustic reflex may reduce the risk of hearing loss by attenuating the middle ear sound transfer. This effect, however, cannot well be incorporated in a damage risk limit because it will be limited to very specific temporal distributions of the impulses (or noise bursts). Moreover, the effect itself is limited: the reflex onset is too slow to protect against impulse sounds, the reflex sustains over only a limited period, and the attenuation is primarily in the low-frequency range.

Fence. Above, we have used a fence of 15 dB, averaged over 1, 2, and 3 kHz. This fence was chosen primarily to allow compilation of the available data. We do not propose that such a hearing loss is acceptable. In principle, one could defend that no hearing loss, what so ever, is acceptable. Particularly in view of the progressive increase of hearing loss with exposures above the derived exposure limit of L_{eq} = 85 dB we would rather recommend a limit of L_{eq} = 80 dB. The fence used above is comparable to about 23 dB average loss at 2 and 4 kHz, which implies a loss of about 30 % in speech perception when speech perception is hindered by ambient noise [16,17].

Effect of impulse duration, A-weighting

The early results indicated already that damage risk increases very moderately when the duration of an impulse from shooting or blasting, without reverberation or echoes (the waveform straight from the source, a Friedlander wave) is increased. Such an increase of duration, keeping the peak level constant, implies an increase of only low-frequency energy. In addition to this finding it gradually became clear that many large caliber weapons with much low-frequency energy in the impulse showed less TTS than one might have expected based on the damage risk criterion of Fig. 1 [18]. This suggested that a damage risk criterion based on peak level and impulse duration, thus a damage risk criterion based on the total energy in the impulse, did not suffice. The low-frequency energy contributed less to damage risk than one would expect from the damage risk criterion of Fig. 1. A measure including low-frequency filtering suggested itself. Including A-weighting showed markedly better predictions of the TTS for large caliber weapons [19].

At present, the database suggests that even more low-frequency attenuation than included in A-weighting might give a better fit to the experimental data. This is supported by previous findings [20,21] showing that the frequency range important for damage risk narrows as the exposure shortens. Future evaluation of the data might suggest frequency weighting corresponding to the threshold of hearing (T-weighting) [22]. From a physiological point of view, this would be a very attractive solution because the threshold of hearing represents rather well the effective cochlear stimulus. The A-weighting represents the 40 dB isophone which includes a loudness component probably originating more centrally than the cochlea. Whether or not T-weighting would provide a better damage risk criterion than A-weighting for a broad range of types of impulses cannot yet be concluded.

Since T-weighting is not implemented on sound level meters while A-weighting is and since A-weighting is used for the evaluation of non-impulsive noise with regard to damage risk the pragmatic conclusion should be to include A-weighting. This means that we could use the A-weighted equivalent continuous sound level for all types of noises. An adjustment for impulse noise like we had to include into the evaluation of annoyance is not required. For light firearms, the effect of A-weighting is only -2 to -3 dB. In view of the above conclusion to set the damage risk limit at $L_{eq} = 80$ dB or 85 dB we arrive at a limit of $L_{eq} = 80$ dB(A).

Recent developments

Research on the effects of impulse duration on hearing loss in guinea pigs and recent research on the TTS effects of large caliber weapons have shown that increased low-frequency energy in the impulse might even decrease the risk of hearing loss. This idiosyncratic effect may be related to saturation in the energy transmission of the middle and inner ear. Low-frequency energy driving the ear into saturation might prevent high-frequency energy, more damaging to the ear, to enter the ear effectively. This complicates the evaluation of damage risk due to impulse noise considerably. It suggests that only physiologically based models might afford accurate damage risk assessment and it suggests that simple measures like the A-weighted equivalent continuous level might not suffice. Presently, research along these lines is conducted [23,24]. This research includes the concept of a critical level above which damage risk increases progressively. A final evaluation is not yet available.

4. ACKNOWLEDGEMENT

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PREVENTING NOISE-INDUCED HEARING LOSS: A PERSPECTIVE VIEW FROM THE NEXT MILLENNIUM

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So long as we have tools and machines to perform work, we will have noise that is hazardous to hearing. That is, unless steps are taken to reduce the noise to safe levels. In the latter part of the 20th century we can add communication and entertainment to the list of agents that create sounds hazardous to hearing.

My task is to predict what might be accomplished in the area of noise-induced hearing loss between now and the convening of the 8th Congress. To do that I like to look back 10 years first. And, I would like to evaluate the occurrences of the past decade in three different aspects: Regulations, Science, Technology, Public Awareness and Outcomes.

REGULATIONS:

In the past 10 years Many developing countries have adopted the ACGIH TLV for noise as the foundation for their noise and hearing conservation standards. Others have also adopted procedures from the U.S. OSHA Noise Standard and Hearing Conservation Amendment.

The regulatory environment in the United States has not changed since the last Congress in Nice, France in 1988. The OSHA Noise Standard and Hearing Conservation Amendment have been in effect since 1985, counting administrative stays and actions of the courts. MSHA has yet to release a unified set of noise and hearing conservation regulations for all aspects of mining. OSHA has not issued any regulations for the reporting of noise-induced hearing loss so there is no national registry on noise-induced hearing loss such as there is other occupational illnesses and injuries.

The U.S. Environmental Protection Agency has been out of the noise "business" since 1982 when the Office of Noise Abatement and Control was zero funded by the Reagan administration. While the EPA's regulations are still in effect, there is no office or staff to monitor compliance or to bring enforcement actions. The Noise Reduction Rating that is required on all protectors sold in the U.S. is based on a laboratory method that greatly exaggerates the protection received by workers. Even though the American National Standards Institute has rescinded the standard in favor of a newer standard that better describes real-world outcomes, with no noise program, the EPA has no resources to revise or amend the labeling rule. Yet it must enforce the rule. Copies of EPA documents on noise are no longer available; only those that escaped the shredders survive in the drawers and on the bookshelves of a few collectors.

The 50 states, Puerto Rico, and the District of Columbia have different workers' compensation rules–an automobile worker with noise-induced hearing loss in Wisconsin may receive money, and hearing aids, and vocational rehabilitation while the automobile worker in Michigan or Indiana will receive nothing. If anything, moves are afoot in the U.S. to reduce the scheduled payments and benefits of the workers' compensation system. This is interesting since in the U.S. workers' compensation programs were initially developed to reduce the liability of employers in the tort system where the ill or injured worker would sue the employer directly for recovery and compensation.

There has been no general increase in the technology for or application of noise control in the U.S. because there has been no regulatory pressure to reduce noise. OSHA permits companies where workers receive noise doses of 100 dBA TWA or less to substitute hearing protectors for noise controls. Nor are there any observable noise-control agendas in many other parts of the world. When companies build new facilities, they may or may not design them to be quiet. While many major corporations have instituted "buy-quiet" programs, most medium-size and small companies have not. The building trade workers in the United States have not seen a reduction in the noise levels to which they are exposed. And, new tools such as leaf blowers, pneumatic nail drivers, and dust collectors are extremely noisy.

SCIENCE:

There have been many developments in the past 10 years in terms of what we know about the ear and its response to noise. Briefly summarized we have learned that:

- Ears exposed to lower level noise are 'toughened' against hearing loss from higher level sounds.
- Impulsive noise above a certain level is more hazardous than continuous noise of the same energy and spectrum.
- Continuous noise with embedded impulsive noise is more hazardous than continuous noise alone.
- Aromatic solvents are hazardous to hearing and their effects may be additive or synergistic to those of noise.
- Otoacoustic emissions have not delivered as hoped in giving us an objective look at the cochlea.
- There is a gene in mice that is responsible for age-related hearing loss and mice with the gene are more susceptible to noise-induced hearing loss than mice without the gene.
- Free radicals may have a role in noise-induced hearing loss and free-radical scavengers may be effective in reducing temporary and permanent threshold shift.
- Outer hair cells are motile and may play role in the tuning the basilar membrane.
- Noise reduction values for hearing protectors determined in laboratories over predict the protection wearers receive.
- Noise may or may not have an effect on blood pressure, but hypertension does increase susceptibility for hearing loss.
- Noise is more hazardous to hearing when combined with other physical agents such as vibration and heat.
- The equal-energy rule applies to continuous noise and impulsive noise below certain levels.

- The equal-energy rule under predicts hearing loss for high-level impulsive noise and for intermittent high-level continuous noise.

TECHNOLOGY:

The principles of noise control have been pretty well understood for last ten years. Absorbers still absorb, isolators still isolate, and the inverse square rule still applies. Improvements in technology have been slowly accepted because there are no markets for them due to the lack of regulatory pressure.

There have been changes in instrumentation for measuring noise. Integrating sound level meters with real-time spectrum analysis and multifunction dosimeters have all appeared in the last decade. Digital audio tape recorders are affordable and rugged enough to record excellent samples of noise for further analysis in the laboratory.

Analyzers that display signals in the time and frequency domains, perform spectrum analysis and Fourier analysis have replaced oscilloscopes. Commercial computer programs are available for designing spaces for sound, in large part due to the commercial sound industry. Mathematical modeling tools are also available for development and testing of noise-control parameters.

Computer programs have been developed for collecting hearing loss prevention program data such as noise exposure, hearing protector use, and audiograms. To date these programs replace the older paper file systems. Integrating the data for use in developing control and prevention strategies still awaits the information systems development.

The last ten years have seen improvements in hearing protectors. While the yellow or green slow-recovery foam earplug still has the widest world-wide use, new earplugs and earmuffs have been developed that are easier to use, more comfortable, or that improve speech communication in noise. The passive tuned resonator earplug or earmuff with flat attenuation can be used with great success in most industrial noise environments as well as by musicians. The passive earplug with a cavity can be used against impulsive noise such as gunfire while allowing low-level sounds to be heard. Earmuffs with radios, active level-dependent earmuffs, and earmuffs with active noise cancellation have all been developed.

Instrumentation has been developed to fit-test hearing insert-type hearing protectors. Employing large circumaural earphones, the worker is tested with ears open and protected to determine the amount of attenuation received from the protectors as they are worn. This removes the need to rely upon the labeled NRR, SNR, or HML. This method could also be employed at the time of annual audiometry to confirm the fitting of the protectors.

As with improvements in control technologies, there has not been wide acceptance of the newer protection technologies due mostly to cost. Without some demonstration of an exceptional advantage of a $150.00 level-dependent earmuff that needs batteries and other maintenance over a disposable $0.04 foam earplug (less than $20.00 per year), adoption of the newer technology protectors will be slow. Employing a fit-test method for protectors more than doubles the time to assess each worker compared to testing only hearing sensitivity, an expense many employers may be unwilling to bear in the absence of a compelling reason.

PUBLIC AWARENESS:

In general, the public knows that exposure to high-level noise results in hearing loss. They also know that hearing loss is related to aging. What the public does not seem to know is that a host of everyday tasks, experiences, and recreational activities produce noise levels that are hazardous. While in the United States no one shoots at a gun range without using hearing protection, hunters disdain using protectors, including those with built in active compression circuits. The personal stereo has become a universally accepted devise, more common than sunglasses. Most of these systems are capable of producing hazardous levels of program. The NIOSH Hearing Protector Laboratory has noticed that there is sufficient prevalence of hearing impairment among young adult males to result in 1 of 2 or 3 failing to meet the requirements for normal hearing.

OUTCOMES:

An effective hearing loss prevention program that involves the use of hearing protection and other measures should have the same outcomes as a program that has reduced the noise levels to below the exposure limit. Restated, the incidence of significant threshold shift and the prevalence of hearing impairment for workers using protection against noise should be no greater than it is for workers not exposed to hazardous noise.

Results from available audiometric databases from industry and the military show:

- Programs that monitor workers' hearing more often than not document hearing loss.
- Requiring the use of hearing protectors above a set exposure limit is not as protective of hearing as reducing the noise to the exposure limit.
- Protected noise-exposed workers have a greater prevalence of hearing impairment than workers not exposed to hazardous noise.
- Unprotected workers exposed to "low-noise" (85 to 90 dB as U.S. OSHA presently allows) have greater incidence of threshold shift than protected workers exposed to noise levels of 90 dB or above.
- Whereas by age 50 in the non-exposed general population, 1 in 9 males should have a hearing impairment, in some industries between 1 of 3 have impaired hearing (automobile manufacturing) while in others 9 of 10 are impaired (coal mining).

Now, let's look ahead 5 years in each of the four aspects.

REGULATION:

The only thing that moves slower than regulatory reform is a glacier. Five years from now we should expect to find:

- In the U.S., the EPA may revise its hearing protector labeling rule so that the Noise Reduction Rating actually predicts protection workers can expect.
- In the U.S., OSHA and MSHA will probably not have adopted NIOSH's recommendations of an exposure limit of 85 dBLeq8 (3-dB exchange rate) or NIOSH's 15-dB twice, same ear, same frequency definition of significant threshold shift.
- Countries with regulatory processes that are more fluid than in the United States or developing countries may adopt NIOSH's recommendations along with the TLVs of the ACGIH, including provisions for combined exposures to noise and other chemical or physical agents.

- There will be no increase in regulatory pressure to control noise and workers will still rely predominantly on hearing protection to prevent noise-induced hearing loss.

SCIENCE:

Within the next 5 years, the role of free radicals in noise-induced hearing loss and the preventive properties of free-radical scavengers–antioxidants–should be known. Although a system was patented and released in the U.S. for delivering antioxidants directly to the round window of the cochlea, it will not have widespread acceptance because of its invasive nature. But, combinations of vitamins and food supplements may prove to be as effective.

Work will continue to discover sentinels of susceptibility–what non-hearing indicators may there be to identify persons most susceptible to noise-induced hearing loss. It may be that a profile can be developed of those persons most at risk of losing hearing to noise so that those persons can be identified and managed more aggressively. For example, a person who has hypertension, a history of head trauma, adult-onset diabetes, high blood cholesterol, a family history of early-onset hearing loss, and who smokes might be provided double hearing protection and receive monitoring audiometry every six months to assure that no noise-induced hearing loss is appearing. Similarly, this person may receive a few sessions of pre- and post-exposure testing to assure that no temporary threshold shift is occurring and that hearing protection is adequate.

Audiometric methods may develop that more accurately assess hearing sensitivity and ability. The air-conduction pure-tone audiogram, while providing a view of gross hearing sensitivity, does nothing to identify conductive hearing losses. Without masking it is impossible to resolve the unilateral hearing loss. Without speech testing it is impossible to evaluate the effect of hearing loss on the communication abilities of those workers in hearing-critical jobs. A mix of pure-tone audiometry, tympanometry, reflexometry, and discrimination may develop as useful tool, especially for evaluating those exposed to combined agents. Auditory performance standards may be developed for workers in hearing-critical jobs.

Dose-response relations may be established for intermittent high-level noise and for impulsive noise in or out of a continuous noise background.

Investigations will continue on cochlear mechanics and signal processing of the cochlea and auditory nervous system. The differential roles of inner and outer hair cells will be better understood. A new unified theory of hearing may be developed.

Hair cell deterioration due to aging and trauma from noise and other agents may be better understood. The gene that tells hair cells not to replicate may be identified and a way to "turn off" the gene may be discovered so that hair cell regeneration instead of high-frequency permanent hearing loss may be the body's response to exposures to high noise levels.

TECHNOLOGY:

As digital signal processing chips become inexpensive and widely used, sound measuring and analysis equipment will become more affordable and the types of measures obtained to define exposure will have increased. Instead of relying on the full-shift dose from one worker who is representative of a group of workers, identification of noisy tasks along with the creation of hazardous task inventories may be used to build exposure profiles for each worker.

Development of a distributed digital noise library and a compendium of noise-control solutions should be underway.

Passive hearing protectors that are easy to insert or don and that are comfortable to wear while being effective may be developed. The cost of electronics and packaging will decrease for active level-dependent protectors, radio earmuffs, communication headsets, and active noise reduction systems, increasing their acceptance by companies. Hydra systems, such as a level-dependent system with a built-in communication function and active noise reduction, will be more acceptable since they provide many functions economically.

In the absence of regulatory pressure, there will be few advancements in noise control. Companies with buy-quiet program specifications will insist on quieter equipment and facilities and other companies may benefit from the technology development. Care will have to be taken to not have both a quiet and noisy version of the same equipment with the quiet version only offered to those who request it.

PUBLIC AWARENESS:

In the U.S. a Hearing Loss Prevention Campaign will have been functioning for four years. The campaign will have evaluated the national attitude toward noise-induced hearing loss. Research initiatives in communicating hearing loss prevention will have been created and awarded by Congress. Information about other health factors associated with hearing impairment will have been prepared and distributed. The myth that everyone loses their hearing as they age and the belief that hearing loss is just part of the "trade" will have been dismissed. The general public will recognize that loud is not safe and that old does not have to mean deaf.

OUTCOMES:

Hearing loss prevention programs that are proactive, driven to prevent noise-induced hearing loss by focusing on preventing temporary threshold shift, will be effective to the point of having prevalence of hearing impairment and significant threshold shift that approach those of the non-exposed population.

Regulatory compliance driven hearing loss prevention programs that rely on hearing protectors over noise control will continue to less effective than proactive programs.

In the absence of regulatory pressure for noise control, the numbers of worker exposed to hazardous noise and other ototoxic agents will remain too high.

SUMMARY:

When embroiled in the middle of a situation, it is difficult to determine when progress is made or ground is lost. Among other things, these international conferences provide the opportunity to be introspective, to discover successes and failures, to identify new avenues for development, and to adjust plans for the future. They also provide a forum to review predictions from the previous Congress and to make predictions for the next.

Effect of Noise and Solvents on Hearing: A Review of Field Studies and Their Relationship to Animal Models

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INTRODUCTION

Noise exposure has long been recognized as the major contributor to occupational hearing loss, but an important recent finding in the area is that the effects of noise in the workplace can be exacerbated by other non-acoustic agents, e.g., extreme temperatures, vibration, and ototoxic drugs27, 30, 41, 48, 49, 63. Unfortunately, audiograms of noise-exposed persons often exhibit hearing losses which are similar to patterns resulting from of other types of exposure.

Exposure to heavy metals produce a variety of effects in the central and peripheral nervous system60. Environmental exposure to arsenic produced hearing losses in the air conduction thresholds of children at 125, 250 and 8000 Hz 2. Changes in the organ of Corti and stria vascularis due to arsenic exposure have also been demonstrated37. In a study and review of workers exposed to mercury and lead in an occupational environment, the brainstem auditory evoked potentials (BAEP) exhibited significant increases in the wave I-V interpeak latencies10. The discussion in Discalzi et al.10 showed that the majority of studies demonstrated effects on the BAEPs of workers exposed to lead. Several other metals have demonstrated ototoxicity such as tin, cadmium and manganese13, 14, 37, 60. A variety of pharmaceuticals have demonstrated ototoxicity (e.g. carboplatinum, cisplatinum, aminoglycosides, salicylates and loop diuretics)61. Exposure to carbon monoxide, an asphyxiant, has been shown to exacerbate hearing loss in guinea pigs due to noise exposure11, 12. Similarly, chronic exposure to organic solvents has been shown to produce amounts of hearing loss comparable to noise exposure62. Combined exposures to organic solvents and noise have demonstrated the synergistic interaction of these ototoxic exposures in both humans and animals 1, 4, 17, 21, 22, 25, 40, 42, 43, 44, 45.

The interaction of noise and other agents contributes to the large variability observed in a population's response to noise exposure, and, if overlooked, may undermine the success of traditional hearing conservation programs18. Among the factors that may interact with noise, occupational exposure to chemicals is one of critical relevance because of the magnitude of workers exposed40 and the evidence that chemicals may affect the auditory system despite the absence of intense noise exposure25.

With the advent of more powerful epidemiological analysis and the ability to field audiometric testing procedures beyond the traditional air conduction test, hearing loss prevention is expanding beyond the traditional boundaries of noise reduction and hearing protection. Researchers and practitioners have come to realize that other risk factors for hearing loss exist in the occupational setting. The available evidence indicates that the ototoxic action of solvents constitutes a serious occupational health problem, and also delineates the need for further research25.

THREE FIELD STUDIES OF NOISE AND SOLVENT EXPOSURE IN HUMANS

The first study of 190 workers was conducted in a Brazilian rotogravure printing plant39. The hearing function of a group of printers exposed simultaneously to noise (88-98 dBA) and toluene (100-365 ppm) were compared with a group of printers exposed to noise alone (88-97 dBA), a group exposed to a solvent mixture in which toluene was the major component, and an unexposed group with neither noise nor toluene exposure. The audiometric thresholds of the four study groups were averaged and compared as the first step in the data analyses38. Initially, the thresholds from the non-exposed subjects were compared with ISO Median Hearing Levels19 for males from the general population exposed to noise levels up to 80 dBA. These were not found to be significantly different.

The audiogram of each worker was then classified as either normal or altered by a conductive or sensorineural hearing loss. The losses were scaled according to different levels (mild to profound), and further classified as either bilateral or unilateral. The use of clinical audiometric classification indicated that most of the hearing losses for the groups exposed to solvents were mild (up to 45 dB HL)39. The prevalence of sensorineural hearing loss found in the group exposed to noise and toluene simultaneously (53%) was larger than in other groups: 8% in the non-exposed group, 26% in the noise exposed group and 18% in the group exposed to a mixture of solvents. It should be noted that the prevalence of high-frequency hearing losses observed among those exposed to solvents only (18%) was higher than for those unexposed (8%), although they had equivalent mean thresholds.

For the next analysis, conductive and unilateral hearing losses were entered as normal hearing, as these could not be clearly related to the occupational exposures. Whenever the period of observation is equal for all study subjects and the outcome of interest is a binary factor, logistic regression is a powerful statistical tool for the estimation of risk ratio adjusted for other risk factors26, 36. The exposure groups were coded using dummy variables. Other variables considered for inclusion in the model were: age, length of employment, previous occupational exposure to noise or to chemicals, and exposure to non-occupational noise. The only variables that met the significance level criterion for entry in the model, besides group, were age and length of employment. Since the study population was relatively young, the median age was 33, and the groups were similar in age, the exposure variable, length of employment, was included in the model rather than age. Estimates of adjusted relative risk for developing hearing loss are displayed in Table 1.

Table 1: Adjusted Relative Risk for Occupational hearing Loss, by Group39

Variable/Group	p Value	Relative Risk	95% Confidence Interval
Noise	0.012	4.1	(1.4, 12.2)
Noise and Toluene	<0.001	10.9	(4.1, 28.9)
Solvent Mixture	0.011	5.0	(1.5, 17.5)
Employment Time	0.004	1.1	(1.0, 1.1)

The second field study conducted in 1997 evaluated, using pure tone audiometry and acoustic immittance measurements, the occurrence of hearing disorders in groups of Colombian refinery workers exposed to neither noise nor solvents, and groups of refinery workers exposed to various levels of noise and solvents43. Workers from a refinery (n=438) were interviewed, had their hearing tested and had their exposures to noise and solvents assessed. Measurements suggested that most exposures to noise and solvents were within exposure limits recommended by international agencies; however, the prevalence for hearing loss within the exposed groups ranged from 42-50%, significantly exceeding the 15-30% prevalence observed for unexposed groups. The adjusted odds ratio estimates for hearing loss were 2.4 times greater for groups from aromatics and paraffins (95% CI: 1.0-5.7), 3 times greater for the maintenance group (95% CI:1.3-6.9) and 1.8 times greater for the group from shipping (95% CI: 0.6-4.9), when compared to unexposed workers from the warehouse and health clinic. The results of acoustic reflex decay tests suggest a retrocochlear or central auditory pathway involvement in the losses observed in certain job categories.

The third study conducted with a different group of Brazilian rotogravure printing workers investigated the hearing of 124 individuals exposed to various levels of noise and an organic solvent mixture of toluene, ethyl acetate and ethanol44. Data on work history, psychosocial aspects of their job, medical history, present health, stress, occupational and non-occupational exposures to noise or chemicals and lifestyle factors were collected through an interview. The participants underwent pure-tone audiometry and immittance audiometry testing. Their exposures to noise and solvents were meticulously assessed. Forty-nine percent of the workers had a hearing loss. From the numerous variables that were analyzed for their contribution to the development of hearing loss (age, tenure, noise doses, solvents concentration in air, biological marker for toluene, job category, work and medical history items, smoking, alcohol consumption, work perception scores, non-occupational exposures), age and hippuric acid (the biologic marker for toluene in urine29), were the only variables that met the significance level criterion in the final multiple logistic regression model. The odds ratio estimates for hearing loss were 1.07 times greater for each increment of 1 year of age (95% CI: 1.03-1.11), and 1.76 times greater for each gram of hippuric acid per gram of creatinine (95% CI: 1.00-2.98). The findings suggested that exposure to toluene to concentrations below current recommended exposure limits had a toxic effect on the auditory system. Further research is needed on the mechanisms underlying the effects of toluene and on the adequacy of recommended exposure limits.

EFFECTS OF SOLVENT EXPOSURE ON HEARING IN ANIMALS

Several studies initially identified the ototoxicity of organic solvents in rats by examining changes in Conditioned Avoidance Response (CAR) thresholds and Auditory Brainstem Response (ABR) thresholds following exposure to aromatic solvents (e.g. toluene, xylene and styrene)50, 51, 52, 55, 56, 57. Changes in CAR or ABR could indicate either cochlear or retrocochlear effects. CAR and ABR thresholds were increased due to the exposure to aromatic solvents while exposure to aliphatic solvents and alcohols did not produce ototoxic effects46, 47, 55. Changes in the ABR consisted of increased latencies and decreased amplitudes of wave I suggesting that the ototoxicity was occurring in the cochlea.

Subsequent studies with rats further investigated the effects of toluene exposure on the cochlea. The majority of the studies which used ABR, CAR, or Reflex Modification Audiometry (RMA) found positive effects when animals were exposed to solvents. In rats, a mid-frequency hearing loss develops as a result of exposure to solvents7. Toluene exposure has been demonstrated to affect the amplitude and input/output growth function of distortion product otoacoustic emissions (DPOAE)9, 23, 24. In rats and mice, there is strong evidence for a cochlear site of the damage caused by toluene4, 21, 23, 24, 52. Histologic examination of the organ of Corti revealed progressive damage of the outer hair cells with the most damage being to the third row of OHCs and the least damage to the inner hair cells24. Changes in CAP were positive for styrene and trichloroethylene (TCE) exposures of rats16, but negative when guinea pigs were exposed to styrene15. No permanent shifts in the whole nerve action potential were found in toluene-exposed guinea pigs3 and no permanent threshold shifts in the ABR were found in the chinchillas9 exposed to toluene. Changes in cochlear microphonic (CM) were not observed in guinea pigs exposed to styrene15. Other experiments demonstrating a variety of interactions between solvent exposure and other factors, including age, genotype, intake of alcohol or acetyl salicylic acid, exposure to other solvents are summarized in Johnson and Nylen25. The effects of solvents on different measurements of the auditory system demonstrated in animal studies are summarized in Table 2 below.

Table 2: Effects of organic solvents on audiometric measurements in animal studies. The numbers in the table correspond with the bibliographic numbers.

Measurement	ABR	CAP	CAR	CM	DPOAE	RMA
n-Hexane +	46, 47, 54, 57					
n-Hexane -	55					
Styrene +	34, 59, 64	53	53			7
Styrene -	59	15		15		
TCE +	20, 58, 59	16				6, 7, 8, 16
TCE -				16		
Toluene +	4, 28, 50, 51, 52, 56		50, 52		23	7, 35
Toluene -	9	3			9	
Xylene +			53			7
Xylene -	46					

ABR: Auditory Brainstem Response; CAP: Compound Action Potential; CAR: Conditioned Avoidance Response; CM: Cochlear Microphonic; DPOAE: Distortion Product Otoacoustic Emission; RMA: Reflex Modification Audiometry; TCE: Trichloroethylene; +: Positive Observed Effect; -: Negative Observed Effect.

While numerous animal studies have identified the potential for solvents to produce hearing loss, only a few studies have demonstrated the potential risk for combined exposure to noise and solvents. Johnson *et al.* 21, 22 demonstrated that the sequence of exposure to nonsimultaneous noise and toluene affected the severity of hearing loss. They reported that the toluene exposure followed by noise produced more loss of auditory threshold than noise exposure followed by toluene exposure. One should note that the proximity of the completion of the noise exposure to the post-exposure ABR assessment was 2 days for toluene followed by noise and was 3-5 weeks for the noise followed by toluene. The difference in the threshold shifts could likely be the temporary threshold shift versus the permanent threshold shift.

Campo *et al.*3 conducted a sequential exposure of guinea pigs to toluene, noise and toluene followed by noise. No significant difference in the shift of the CAP was observed between the noise-exposed and toluene/noise exposed animals. Cochleograms of the hair cell counts of the different exposure groups exhibited no significant differences between the exposed animals and the control animals. Similarly, Fechter15 also found no effects in guinea pigs exposed to styrene, noise and simultaneous noise/styrene. In that case, styrene and noise exposures did not affect the CAP or the CM differently than just noise exposure alone.

Davis *et al.*9 reported on chinchillas exposed to 95 dBA octave-band noise centered at 500 Hz for 8 hrs/day for ten days and varying amounts of toluene exposure. The toluene exposures were either 2000 ppm for 8 hours/day and ten days or 2000 ppm for 12 hours/day and ten days. No statistically significant permanent threshold shift was observed at any of the octave test frequencies 500 to 16 kHz. No interaction was observed between the noise/solvent exposure groups. Follow-up exposures proved that the chinchilla was intolerant of higher concentrations of toluene, specifically 2250 ppm for 9 days. The chinchillas exhibited temporary changes in their distortion product otoacoustic emissions, but quickly recovered normal DPOAE function. As well, the outer hair cells were minimally affected due to the toluene exposures. Davis et al. also exposed Long-Evans rats to 2000 ppm toluene for 8 hrs/day for five days and observed an average 15 dB permanent threshold shift of the click-evoked ABR and 500 Hz toneburst stimuli. The results from chinchillas and guinea pigs are not representative of the findings when similar exposures are performed using rats.

Lataye and Campo28 conducted a simultaneous exposure of rats to noise and toluene. In this case, rats were exposed to toluene at 2000 ppm for 6 hrs/day, 5 days/week for four weeks. Noise exposure was 92 dB octave band noise centered at 8 kHz. The toluene-exposed animals experienced a permanent threshold shift of 5-25 dB which peaked at 16 kHz while the noise-exposed animals experienced a narrower frequency region of threshold shift, 10 dB shift at 10, 12 and 16 kHz. The toluene/noise-exposed animals exhibited a loss of 10-35 dB permanent threshold shift which peaked at 16 kHz and spread across almost the entire test spectrum 2-32 kHz. The toluene/noise-exposed animals exhibited almost 100% loss of the third row of OHCs and greater than 50% loss of the second row of OHCs. The toluene-only exposed animals exhibited considerably less loss of OHCs but had damage over the entire range except the more basal end of the cochlea.

Campo *et al.*5 exposed rats to a mixture of toluene and ethanol. The ethanol was administered via gavage and the toluene via inhalation. Hearing thresholds were assessed with ABR. Ethanol exposure produced no ototoxic effect while toluene produced a significant deficit in the mid-frequency region. However, when rats were exposed to a combination of the two chemicals, significantly more hearing deficit was observed. The ethanol and toluene were believed to be competing for the metabolic processes in the liver which increased the concentration of the toluene levels in the blood. This increase would conceivably result in a greater ototoxic effect upon the cochlea.

Makitie34 has demonstrated a similar level dependence in rats exposed to styrene. Groups of rats were exposed to 0, 100, 300 and 600 ppm styrene and/or noise levels of 100-105 dB. The animals exposed to 600 ppm styrene alone exhibited about 3 dB of hearing loss and considerable loss of the third row of the OHCs. Those animals exposed to 100 or 300 ppm alone exhibited no hearing loss or hair cell damage. However, animals exposed to both styrene and noise at concentrations of 100 and 300 ppm exhibited hearing loss and OHC damage which was similar to noise-exposed animals. The group of animals exposed to the highest concentration of styrene and noise exhibited the greatest amount of hair cell damage and hearing loss (23-27 dB). The ABR measurements did not exhibit changes in latencies which again points to a cochlear site for ototoxic action.

Makitie34 found increased vesiculation and vacuolization of OHC cytoplasm and occasional pathological changes to the mitochondria of the OHC. Makitie hypothesized that the styrene alters the stability of hair cell and other cochlear membranes and energy metabolism which induces changes in the intracochlear homeostasis. Changes in the strial function and mitochodrial dysfunction could induce changes in the ion concentration thus altering the endocochlear potential. Such changes would be reflected in the balance of K+, Na+ and Ca2+ in the cochlear fluids. Liu and Fechter31 demonstrated that {\em in vitro} exposure of outer hair cells and spiral ganglion cells to toluene caused a significant shortening of the OHC length, when concentrations were greater than 100 µM and that the calcium homeostasis was disrupted due to toluene exposure. Interestingly, they noted that the concentrations at which the effects were observable were below the predicted concentrations in the brain for humans exposed at the OHSA permissible exposure levels.

Recent work of Fechter *et al.*16 and Loquet *et al.*32, 33 seem to suggest that the action of the solvents are two-fold: destruction of the central auditory pathway and poisoning of the sensitive organ of Corti. Fechter *et al.*16 exposed rats to TCE and examined changes in the RMA, CM, CAP and histology of the OHCs and spiral ganglion cells. Increases in the RMA occurred in the mid-frequency region as previously reported 6, 7. No changes in the CM were detected which correlated well with the lack of OHC damage. However the density of the SGCs was reduced and increases in the CAP input/output function were observed. Such effects suggest that TCE affects the innervation of the cochlea more than it damages the outer hair cells. Loquet *et al.*32, 33 found that the route to ototoxicity of toluene and styrene involves the stria vascularis and the supporting cells of the basilar membrane more than previously believed. Samples of blood and cerebral spinal fluid were collected from rats shortly after completion of an inhalation exposure. Also, samples of the cochlea were processed to separate out various parts of the organ of Corti to determine the level of toluene and styrene via gas chromatography. They found that although the levels in the blood and CSF were low, the solvent concentrations in the outer sulcus, Henson and Dieter cells were considerably higher than the blood concentration. This finding suggests that the solvent is diffusing through the lipid rich tissues which are capable of supporting higher concentrations of the solvent. As well, the tissues exhibited a gradient of concentration with the highest concentrations being closest to the stria vascularis and lower concentrations being further away. The differential solvent concentration correlates well with the observed damage of the OHCs in solvent-exposed rats4, 5, 24, 32, 33.

CONCLUSIONS

The human epidemiology data suggest that when solvent exposure is combined with noise, the potential for non-additive hearing loss is increased. The research performed with animal models indicates that solvent exposure produces hearing loss and increase the amount of hearing loss when in combination with noise exposure. The synergistic interaction has been clearly demonstrated in studies of solvent noise exposure with rats. However, such interactions have not been replicated in other species. The lack of results in other animal models may be due to differences in metabolic processing of chemicals.

Mechanistic studies of solvent ototoxicity will prove to be invaluable to our understanding of the risk posed by the exposures in the workplace. Phenomenologic studies are needed to improve the ability of audiometric tests to verify the site-of-lesion in epidemiologic studies. Lastly, one should not lose sight of the purpose of the research in occupational safety and health, the worker. Industries which have workers exposed to solvents and noise have only the permissible exposure levels (PEL) to use for guidance, and the Hearing Conservation Amendment that only considers noise as a risk factor for hearing loss. Without a more holistic approach to hearing loss in the workplace, workers may unknowingly be exposed to a greater risk of prematurely losing their hearing.

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Longitudinal Study of Hearing Thresholds

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1 Introduction

The MRC National Study of Hearing [1,2] showed that about 20% of the overall adult population had an average hearing threshold level of 25 dB or greater in the better ear. The major factor that determined both prevalence and the distribution of hearing thresholds was age. At the higher percentiles the effect of age appeared to be greater than at the lower percentiles [2,3], but in general the effect was monotonic and the rate of decrease of hearing impairment appeared to be greater for those over 50-55 years than for those younger than 50 years. A longitudinal study [4] was designed to see whether the patterns observed in the cross sectional studies would be confirmed or not.

In the analysis of the NSH despite extensive efforts to account for hearing losses in the elderly by specific environmental factors, age remained the most important factor. However, the natural history of hearing impairment with ageing had received little study with tightly controlled audiological investigation. We therefore addressed three basic questions about the progression of hearing impairment with time:

(1) Does the apparently continuous degradation of hearing function over time in cross-sectional studies happen via abrupt moderately large changes in a small number of individuals or in a truly continuously progressive fashion?
(2) Is the high apparent rate of deterioration of hearing in our cross-sectional samples aged 55-60 part of a birth cohort effect, and more generally do 'incidence rates' for particular levels of impairment calculated from cross-sectional prevalence data provide adequate estimators of incidence?
(3) Is the rate of progression of impairment influenced by birth cohort, sex, noise exposure, otological history or degree of hearing impairment on entry to the study (the "starting-value" effect)?

2 Methods

From a random sample of the population, 400 people were selected and stratified by age (initial age range 40-65 years), sex, reported noise exposure and site (Cardiff, Glasgow, Nottingham and Southampton) to take part in the study along with a smaller number (about 180) of twins. The design of the study was such that there were four major design factors, three of which were crossed. The three crossed factors were age-group in five five-year age bands between 40 and 65, sex and reported noise exposure. The uncrossed factor was whether the proband was a twin. Twins were asked to take part in the study and to encourage their other twin to take part in the study as well. It was planned to see each of the 400 people in the main design every three years over five visits. However, due to operational and funding problems this was not possible for all people. We planned to ask the subjects to visit the clinical outstations for testing every three years. The 12-year follow-up data are currently being scrutinised for calibration changes. Follow-up rate has been reasonably high at 70, 48, 81, 80% in Cardiff, Glasgow, Nottingham and Southampton respectively (not adjusted for mortality). Details of the audiological and clinical investigations have been previously described [2,4]. Noise immission ratings for occupations (NIRO) were retrospectively estimated and coded as 0, 1, 2 and 3+ for NILs of <97, 97-106, 107-116 and 117+ dBA, respectively. A similar rating scale was used for gunfire (NIRG).

The main statistical analyses were carried out in GLIM using a general linear model with normal errors. NIRO was used as a factor with 4 levels, gender with 2 levels, Occupational group as 2 levels (manual and non-manual) and age was used as a continuous variable. The major dependent variable was the rate of change of hearing threshold which was derived from the data in the following way: first the initial threshold was subtracted from the final threshold and then divided by the number of years between each observation. Individuals with substantial air-bone gaps (>15 dB) at either visit were discounted from the GLIM analyses.

3 Results and discussion

Initial analyses, taking the first and last available audiogram (n=380), have indicated (i) that only 10-12% of people have an average rate of change exceeding 15 dB per decade, with 4% exceeding 30 dB per decade (ii) that the incidence of hearing impairment ≥ 25 dB HL was about 15% per decade around the average initial age of 53 years. (iii) that the rate of change of hearing thresholds over time is a complex function of the frequency tested, age at the outset of the study and the degree of hearing impairment at 4 kHz at the outset. There is little effect of gender, social class or reported noise exposure. This is contrary to recently published data [5,6] which showed substantial gender effects. The difference may be accounted

for by the homogeneous age distribution in our sample, together with the appropriate stratification for reported noise exposure.
At mid and high frequencies we found that the rate of change of hearing thresholds is dependent solely on age. There is an increased rate of change at 1, 2 and 3 kHz for those people whose hearing thresholds at 4 kHz started in the 30-45 dBHL region (n=88 in the sample and 15% in the population, but comprising 25% of those with significant occupational noise exposure). It is lower for those with good hearing (n=213). Those with already poor hearing (n=79) at 4 kHz have a lower rate of change than others at adjacent frequencies do (floor effect), but higher rate at lower frequencies. There is no effect of initial hearing threshold on the rate of change of the 4 kHz threshold itself. This pattern of results makes good sense, in that if hearing is not damaged at 4 kHz (e.g. by noise) then this frequency cannot act as a marker for influences on the rate of change elsewhere. On the other hand if it is badly damaged the hair cells most responsive to adjacent frequencies are probably affected already. There appears to be a supra-additivity of age with those factors that affect the hearing threshold at 4 kHz (of which occupational noise exposure is the most important), affecting at least 25% of the population.

We have looked extensively to see if there were patterns in the audiogram eg dips at 4kHz that may emerge over time associated with previous noise exposure. We defined a dip as being at least a 15 dB difference between the 4kHz threshold and the 2kHz threshold in combination with at least a 10 dB difference between the 4kHz threshold and the 8kHz threshold. At the initial visit there were 8.8% of people with such dips on the better ear that were associated with occupational noise exposure (4.8% NIRO 0 vs 16.7% NIRO 1-3 averaged; 7.2% NIRG 0 vs 13.0% NIRG 1-3 averaged). The prevalence was lower at the final recorded visit at 6.4%. A similar effect was found on the worse ear where the prevalence was 9.2% on first visit and 7% on the last recorded visit. The effect of occupational or gunfire noise was not as evident in the later data. We analysed the data for those without a dip at the first visit only to examine whether the onset of dips could be associated with previous noise immission, excluding those with initial 4kHz thresholds ≥ 45 dB HL. We did not find an effect on the better ear, but on the worse ear there were effects of the initial 4kHz threshold (≥ 25 dB HL or not) and of occupational noise (≥ NIRO 1 or not). The odds ratios were increased by 3.29 (ci 0.99 – 10.94) for the 4kHz threshold and by 4.24 (ci 1.09 – 16.51) for occupational noise exposure. This is some further evidence that those with mild hearing impairment initially, at 4kHz, who have significant noise immissions may be more likely to develop 4kHz dips in the audiogram.

The twin component of the longitudinal study has not yet been fully analysed, however, there are 188 twins who have been part of the study at one time or another. Some of these could not have their twin as part of the study; thus there were 63 pairs of twins at the outset, with 58 supplying some longitudinal data (20% were monozygotic). In earlier analyses, the rate of change of hearing thresholds over time was the same as for the main study when age was taken into account (3-6 dB per decade at mid-frequencies). The expected correlation between hearing thresholds at mid-frequency for non-related same age and sex adults was computed from a thousand samplings of the NSH data to be 0.35 (sd 0.11). The average correlation for hearing thresholds at the start and at the last measured threshold for twins was significantly higher at about 0.45 (with correlation between ears in the region of 0.80). However, monozygotic twins did not have greater correlations. There was zero correlation between twins in terms of rate of change of thresholds. The twin study will be useful in giving a wider range of ages over which we have studied rate of change, but the results have low power for heritability in average hearing thresholds *per se* or in the rate of change of hearing for the age group. We speculate that other external influences e.g. noise and susceptibility to noise may swamp normal heritability components in the very gradual changes that we have observed. Dominant genetic impairments of early adult onset may be more due to environmental susceptibility factors rather than linked to year-on-year / decade-on-decade rate of change of hearing function.

The analysis of both components of the study continues. The major direction of further analysis, both of the hearing thresholds and the otoacoustic emissions will be to look at the influence of the initial starting threshold at 4kHz as this seems to be the one factor other than age and gender that determines the rate of change of hearing thresholds.

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EARLY DETECTION OF NOISE-INDUCED EAR DAMAGE USING OTOACOUSTIC EMISSIONS

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Abstract

There is a fundamental problem in trying to use any parameter as the measure of disability and also that same parameter as a predictor for that disability, yet essentially this is the basis by which most hearing conservation programs are currently conducted -- attempting to use hearing levels to anticipate increased risk of hearing loss. We have been investigating whether transient-evoked otoacoustic emissions (TEOAE) obtained with the ILO88 Otodynamics Analyser may provide an earlier measure of ear damage than does pure tone audiometry for hearing conservation purposes. We have previously shown that average TEOAE levels steadily decrease for a long period prior to change in hearing levels. More recently in a group of 874 personal stereo (PS) users claiming no known hearing problems, we have shown a significant decline in emission levels ($p<.001$) in proportion to exposure levels (classified as moderate or heavy) relative to non-users, while the decline for the PS group as a whole is comparable with another group of industrially noise-exposed workers. Taken together with results from a cohort whose emissions have been monitored over 8 years, this gives rise to a "fuel-tank" model of ear aging in which an empty tank equates to the *onset* of disability, or a "mild" hearing loss. Presbycusis may thus be redefined as the process of reaching that end stage at a minimal rate of accumulated outer hair cell loss, and noise-induced hearing loss is defined as the premature arrival at that end stage due to accelerating factors, particularly prolonged exposure to loud sound.

Introduction

Preventive medicine programs in existence fall into two categories: those that rely upon detection of the first manifestation of the full-blown condition requiring immediate and often drastic action, and those for which a preclinical risk indicator has been identified. The core feature of successful prevention programs is early warning, or determination of preclinical signs of disability. The longer the lead time provided by positive determination of risk factors, the more time exists to avert the development of the full-blown condition either by self-modification of behaviour or by regulation. Once a viable risk indicator has been determined, acquiring a disability is no longer "bad luck"; doing nothing to delay onset constitutes bad management. In the case of hearing disability, noise-induced hearing loss (NIHL) results in a major reduction in lifestyle costing our community very heavily both in human and financial terms (last year over $100 million in New South Wales for compensation alone (WorkCover NSW[1]), so being able to reliably identify those at increased risk constitutes a major new plank in any hearing conservation program. Since sound overexposure first affects cochlear biomechanics, the technique of otoacoustic emissions has potential to provide early warning. This paper sets down the extent to which it exists already and the areas in which further refinement of the technique is required.

Methods

The otoacoustic emission technique exists in various forms but the two methods used most in clinical practice are distortion products (DPOAE) and click- or transient-evoked otoacoustic emissions (TEOAE). Both methods extract from the total sound in the ear canal that tiny component of the signal which specifically results from activity of the outer hair cells (OHC) - a nonlinear function of the stimulus sound level and frequency. Both methods have been used extensively for screening applications in respect of testing normal cochlear function in neonates. This is because neonates are expected to have high level emissions, so with relatively unsophisticated processing one can obtain high values of test sensitivity and specificity ie. confidence as to whether the emission is high level constituting a pass, or lower level constituting a failure and therefore reason to refer for further evaluation. In the case of children and adults, however, the task is not so clear cut because emission levels in general are lower for reasons which are multiple. All of our data here is for the transient method obtained using the Otodynamics ILO88 analyser. Our definition for the level of the emission signal, after time windowing to remove the stimulus artifact, is "Coherent Emission Strength" (CES dB SPL), the averaged rms sound pressure of the emission weighted by the square of the reproducibility of alternate click responses. In a series of studies measuring emissions from 2500 Australians of all ages and occupations, Murray and LePage[2], LePage and Murray[3] have shown how the strength of emission varies as a function of age, occupation and various related factors given in the questionnaires. One feature which has become prominent in comparing TEOAE results with pure tone thresholds in the same individuals is that for any ear there appears to be a critically low value of emission strength (which some authors denote as emission "absence") at which the probability of a sensitivity loss rises markedly (LePage and Murray[3]). Two important studies on the prevalence of hearing loss as a function of age are relevant for comparison with the emissions picture. Key results from the recent South Australian demographic study[4] are comparable with those of the British study[5] and are shown in Figure 1.

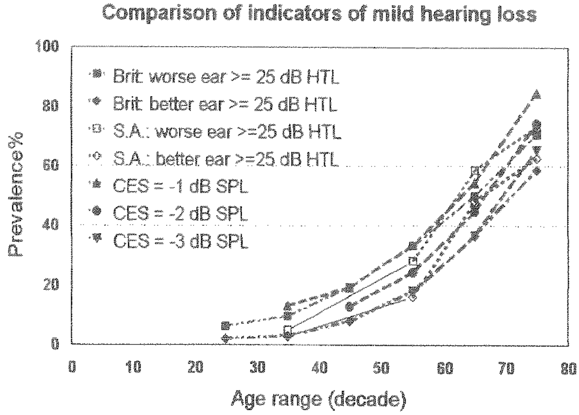

Figure 1 Comparison of audiometric measures of prevalence of ≥25 dB HTL (at least a mild hearing loss) (British and South Australian studies, with estimates of distribution of population values of CES (dashed lines); CES= -1 dB comparable to the Worse ear, CES= -3 dB comparable to the Better ear.

Results

It is seen that when the comparable prevalence percentages for TEOAE are superimposed in Fig. 1 there is fair agreement. On a population basis, the incidence of at least a mild hearing loss is approximately the same for both audiometric studies. Secondly, values of CES can be used to estimate general risk of the imminence of at least a mild hearing loss; the closer the emission strength is to a condition representing net absence of outer hair cell activity, the higher the risk. The important distinction being made here is that while the prevalence curves for the audiometric data constitutes a diagnostic criterion for the ***onset*** of hearing loss, (the first secure manifestation of disability), a ***"critical" CES value*** of -2 dB SPL is below the 20th percentile of the range of CES dB SPL values (-12, +38)[3]). Emission strength therefore may be used, subject to the caveat below, to describe net ***preclinical*** changes in emission since birth. By inference, it may be useful to monitor the degradation of cochlear mechanical processes, not just leading to noise-induced hearing loss, but degradation due to all causes. Whereas the bulk of the population has normal hearing, the same cannot be said of ear emissions - the range of encountered values for an individual of any age is relatively wide[5].

To illustrate the power of ear emissions applied to early identification of high risk activities, each person in our population sample provided, by way of answers to a questionnaire, an indication of various types of noise-exposure they had experienced throughout their lives. In particular, responses indicating any form of industrial exposure was designated "Ind=1", no such exposure "Ind=0". Of the leisure types of sound exposure recorded, subjects' answers included whether they owned/used a personal stereo (PS) unit and were designated "PS=0" for no exposure or just occasional use, but "PS=1" for regular use more than 1 hour per week. Obviously no sound levels could be associated with either kind of exposure in our subjects. Suffice to say that all noisy industries were represented and the sample included 24 deep black coal miners from New South Wales. Recording personal stereo use as part of the questionnaire stemmed from concerns expressed since an audiometric study by Carter et al.[7] which failed to observe any effect due to their use, while another study showed that the average listening levels to be around 95dB SPL[8]. Our data were analysed using an ANOVA with highly significant results comparing just two the two types of noise exposure, for 1724 subjects including 874 personal stereo users, partitioned in decade age ranges[9].

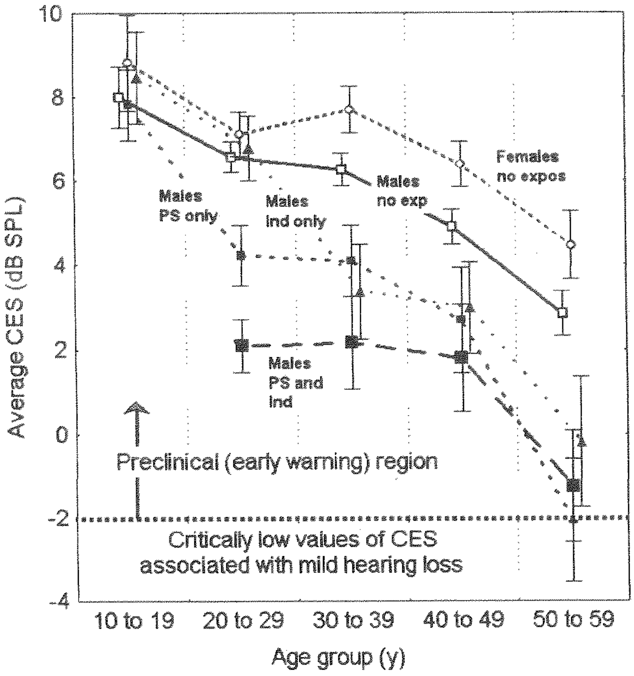

Figure 2 Comparison of CES values for subject data partitioned according to decade age ranges as shown, and grouped according to the type of exposure (see text).

Figure 2 shows the mean CES values of five age groups (10-19y, 20-29y, .. 50-59y) partitioned according to subjects' answers. The two curves with open symbols at the top of the figure represent CES values for females and males with no significant high sound exposure. The filled symbols below are for males only (our sample for females in industry was small). The bottom four curves therefore are for males with mutually exclusive partitions (Ind=0, PS=0; Ind=0, PS=1; Ind=1, PS=0; and Ind=1, PS=1). The error bars represent 1 standard error and from the analysis the differences are significant in nearly all instances where the error bars do not overlap. In particular, all noise-exposed groups were significantly lower ($p<0.01$) than non-noise exposed groups for all five age ranges. Secondly there is a significant difference ($p<0.001$) in CES values between the teenagers and young adults indicating that the PS exposure has had a relatively rapid effect upon the state of ear damage in young people. The difference between the PS users and non users is significant for all the higher age groups. Subjects with industrial exposure display a decline of CES of similar magnitude, but a decade later. For young adults with both industrial and personal stereo exposure there is a marked additive effect, significant ($p<0.001$) for 20-29y range.

Discussion

It is clear that at least when considering population statistics and large sample sizes, otoacoustic emissions do offer advance indication that emission strength is declining considerably faster in people with prolonged exposure in industrial work places and indeed with protracted use of personal stereo units and that the apparent rates of accumulation of this ear damage are comparable. It is possible therefore to consider a new definition of susceptibility to hearing loss in terms of actual values of net emission strength, or of apparent rates of decline in emission strength, or both factors combined. Since all these significant gradations of emission level have been observed in 1724 people only 39 of whom self-reported any hearing problems, we may confidently talk of otoacoustic emissions providing the basis of relative risk determination between groups with differing noise-exposure profiles. A predictive model was developed based upon CES values as a function of age being normally distributed and also upon calculated rates of aging of the ear, also a function of age. It was thus possible to anticipate a steep rise in the number of young males with hearing problems within the next decade (Fig 3)[10].

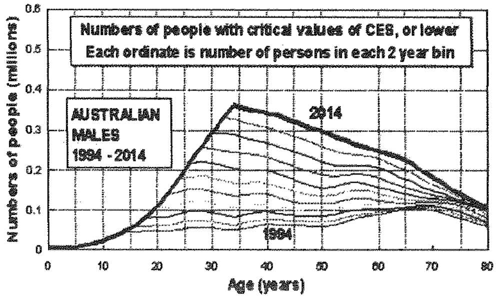

Figure 3 Mathematical model (LePage[10]) showing the projected rise in number of Australian males (ABS projections) with at least a mild hearing loss, for 20 years. The model was based on the number of males whose CES values (near normally distributed) reached critical values of CES The preliminary stage was a determination on the basis of the data pool the rate of aging as a function of age - evidently double in young people (8 dB/decade) the average adult value (4 dB/decade). The result is a shift in the shape of the age distribution from old to young.

The objective of this research is ideally to provide a measure of risk determination for individuals, not just sizeable groups. We have noted elsewhere that individual day-to-day variability for the same ear in terms of the CES value is about ±3.5 dB[11]), so it may be appreciated that the predictions of who is susceptible depends very much upon the overall level of CES for either ear. For example, if an individual has an emission level of 20 dB it is going to take many years to use up this level of **"redundancy"**, i.e. the distance between their individual score and the critical CES value of -2 dB. If the individual has a CES value of 10 dB, we can say that the level of risk of imminent hearing problems is slightly higher than the person at 20 dB but still quite low. Someone with an ear score of 0 dB is much more likely to be at risk. This therefore is the basis of our "fuel-tank" model of presbycusis. While there is still some fuel in the tank, the engine works normally without sign of lowering reserves. Lower levels therefore mean reduced redundancy and higher risk, but much lower certainty because range of test-retest variability (dB) is comparable to the critical value. The non-noise factors leading to loss of OHCs appear so significant as to complicate the whole issue of characterising and preventing NIHL[6]. The caveat mentioned above is that when trying to assess *individual risk* therefore we are dealing with a much more complex problem which cannot be answered without longitudinal studies such as the one presented by my co-author[12,13] detailing long-term variation of emission characteristics.

Summary

These Australian population data show that purely on the basis of their ear emission data groups with different noise-exposure profiles reveal different aging characteristics and when compared with the non-exposed groups, exposure to personal stereo use is predicted to result in premature hearing loss comparable to industrial noise exposure. Hearing loss prevention strategies may proceed on the basis that it is now beyond doubt that some noisy leisure pursuits are having a measurable effect as a premature decline in the levels of activity of the OHC - the source of the nonlinear behaviour. In terms of the "fuel-tank" model, ear emissions now are useful not just for screening neonates, but may serve as a "fuel gauge" or indicator of total accumulated dose for adult exposure.

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TREATMENT OF NOISE-INDUCED-HEARING LOSS

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1. INTRODUCTION

Intense sound stimulation results in structural changes leading to functional auditory impairment. Intense sound stimulation induces two major types of damage: 1) injuries occurring first in the first row of the outer hair cells (OHCs), then in the inner hair cells (IHCs) and in the second and the third rows of OHCs [1], and 2) a massive destruction of dendrites of the primary auditory neurons below the IHCs [2,3]. After an acoustic trauma (intense continuous noise), the acute hearing losses are due both to hair cell injuries and to dendrite damage [4]. Synaptic repair can occur in 5 days [5] but most hair cell damage remains, which is probably responsible for the long-term threshold shifts. Therefore, it is essential to treat patients who undergo acoustic trauma by addressing both the hair cell injuries and the dendrite damage.

Due to the variability of the functional losses and of the treatments presently used, due to the ignorance of the pre-exposure hearing condition and of the parameters of the noise exposure, the efficiency of the present medical treatments of the acoustic trauma is very difficult to assess in man. It is also difficult to estimate which part of the functional recovery is due to the treatment, and it is impossible to assess the morphological changes at the level of the organ of Corti.

The aim of this study is to assess the actual efficiency of the main medical treatments of the acoustic trauma by using a well-standardised animal study. The effects of the acoustic trauma are evaluated by electrocochleography, and by the direct observation of the hair cells (scanning electron microscopy).

2. MATERIAL AND METHODS

Pigmented guinea pigs (300-350 g) free of middle-ear infection are anaesthetised. The bulla is opened to expose the cochlea. A recording electrode is put on the round window. The bulla is reclosed and the recording electrode and the reference electrode are soldered to a plug fixed on the skull. Finally, the surgical wound is sutured and animals are left to recover from the surgical operation for 3 days.

Functional evaluation: tone bursts with a 1 ms rise/fall time (12.5 ms duration) are generated by a Tucker Davis system and presented (8/s) in free field. The frequencies are 2, 2.8, 4, 5.6, 8, 9.5, 11.3, 13.4, 16, 19, 22.6 and 32 kHz. CAP thresholds can be recorded either in awake or in anaesthetised animals.

Acoustic trauma: three days after the surgical preparation, the animals are anaesthetised and a pre-exposure audiogram is performed. Immediately after, the animals are exposed to 1/3 octave band noise centred on 8 kHz at 129 dB SPL during 20 minutes. Twenty minutes after the end of stimulation another audiogram is performed to obtain the short-term threshold shift. Long-term threshold shift is measured at days 1, 2, 3, 7 and 14 in awake guinea pigs.

Morphological observations: after the last audiogram (14 days) the animals are deeply anaesthetised. The cochlea is taken, fixed and sent to the Hadassah University Hospital for SEM observation. The organ of Corti is thoroughly analysed with respect to damage to the stereocilia of the inner and outer hair cells. Stereocilia damage is defined according to Borg [6]: (i) destroyed: a total loss of the stereocilia bundle, (ii) damaged: more than 10% disarray, fall or loss of the stereocilia (corresponding to "altered stereocilia" in Borg classification and to a grade 1, 2 in Fredelius scale [7]). Cochleograms represent the percentage of intact, damaged and destroyed hair cells every 200-micrometer (corresponding approximately to 20 IHCs) from 2 to 10 mm from the base (first and a half turn).

3. MEDICAL TREATMENTS

For each group of animals (n=10), the treatment begins 1 hour after the end of the sound exposure and lasts for 5 days.

Carbogen therapy: a carbogen mixture (7% carbon dioxide and 93% oxygen) is delivered at ambient pressure and at a constant flow rate for 30 minutes., twice a day.

Oxygen therapy (ambient pressure): pure oxygen is delivered at ambient pressure and at a constant flow rate for one hour, twice a day.

Hyperbaric oxygen therapy: animals are placed in a pressure chamber. The chamber is pressurised at 2.5 ATA or 1.5 ATA with 100% oxygen. The pressure is held for 1 hour, twice a day.

Corticoid therapy: methylprednisolone hemisuccinate (Solu-Medrol®, Upjohn) 2, 20, 40, 100 or 200 mg/kg is given once a day by intramuscular injection.

Combined hyperbaric oxygen-corticoid therapy: animals receive corticoids (20 mg/kg) and breathe hyperbaric oxygen (2.5 ATA).

4. RESULTS

Functional and Morphological Correlation

To compare the threshold shifts and the cochlear damage, the audiograms and the cochleograms are scaled to adjust the distance from the base of the cochlea to the frequency. In some animals, threshold shifts and cochlear damage correlate well. However in some other animals, despite the complete recovery of the threshold shifts, important morphological damage to the stereocilia can be observed.

Medical Treatments of the Acoustic Trauma

Carbogen therapy: no significant difference for audiograms can be observed between controls and carbogen treated animals (Figure 1 and 2).

SEM observations indicate that hair cell damage is maximal between 3.5 and 6.5 mm from the base of the cochlea (CF from 13,4 kHz to 8 kHz) (Figure 2).

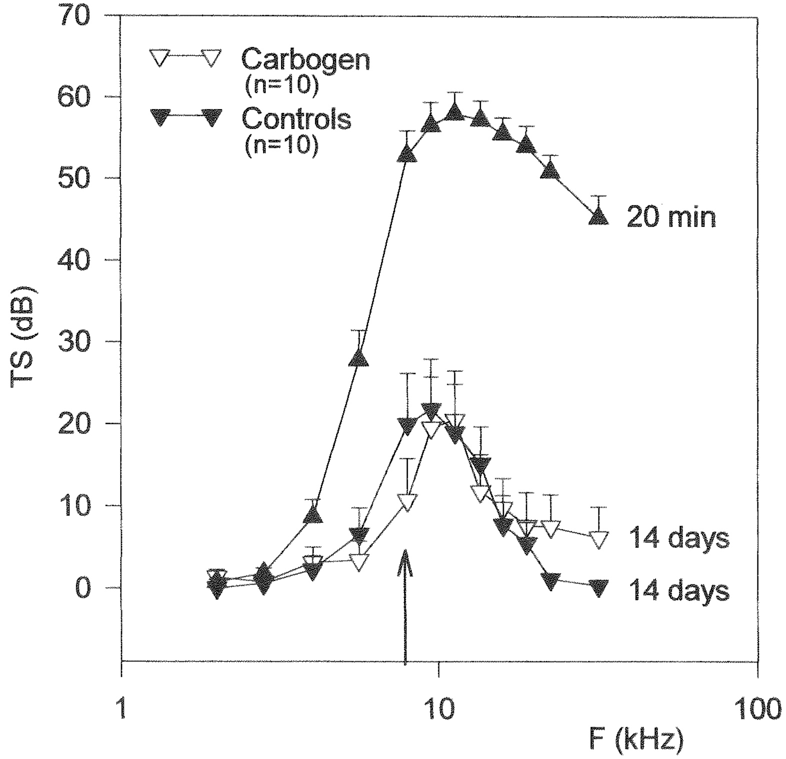

Figure (1): CAP threshold shifts in dB (mean values and SD) recorded immediately after and 14 days after the acoustic trauma in controls and in carbogen treated animals

Oxygen therapy: when oxygen is delivered at ambient pressure, no significant difference can be observed between controls and treated animals either for audiograms or for cochleograms.

Hyperbaric oxygen therapy (2.5 ATA): at day 14, threshold shiftts are higher than in the control group (40 dB instead of 20 dB). These results are statistically significant $(0.001<p<0.01)$. Cochlear damage is larger than for the controls: inner and all three rows of outer hair cells are heavily damaged (Figure 2). The same kind of results is observed with hyperbaric oxygen therapy using 1.5 ATA.

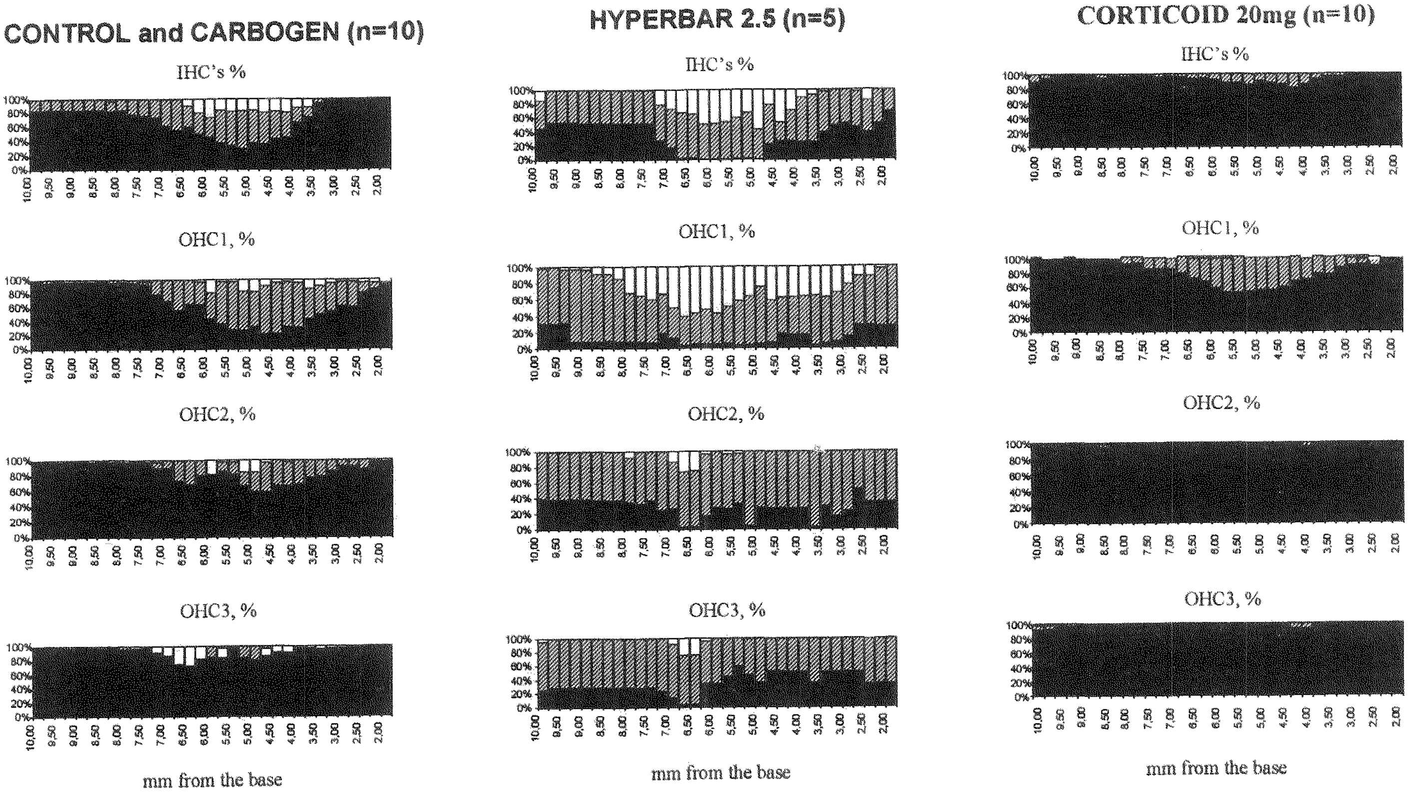

Figure (2): Cochlear damage 14 days after the acoustic trauma: (i) Carbogen treated animals, (ii) Hyperbaric Oxygen treated animals (2.5 ATA), (iii) Corticoid treated animals (20mg/kg) (white: destroyed cells, hatching: damaged cells, black: intact cells)

Corticoid therapy: when the animals are treated at once (and during five days) with doses of 20 mg/kg, the recovery of the threshold shift is significantly improved as well 1 day as 14 days after the exposure (maximal TS: 25 dB instead of 38 dB on the 1st day, and 10 dB instead of 20 dB on the 14th day). Cochlear damage observed at day 14 in the treated animals is smaller than in the controls and is restricted at the first row of the outer hair cells and at the inner hair cells (Figure 2). Corticoid therapy (20 mg/kg) improves significantly the functional and morphological recovery. Moreover, combined hyperbaric oxygen-corticoid therapy improves significantly the functional and morphological recovery (data not shown).

4. DISCUSSION

In some animals the functional recovery (assessed by CAP audiograms) is complete but morphological damage remains. Therefore in man, apparent complete functional recovery (assessed by behavioural audiometry) does not exclude the possibility of stereocilia damage. In case of further exposures, this damage could account for a higher sensibility to acoustic trauma and more rapid tendency to presbyacousis.

These preliminary results indicate that among the medical treatments presently prescribed in man, only corticoid therapy improves functional and morphological recovery after acute acoustic trauma. When used alone, the other treatments: namely carbogen, oxygen at ambient pressure level or hyperbaric oxygen, are either ineffective or ill effective. Unexpectedly, hyperbaric oxygen combined with corticoid therapy improves recovery when compared to corticoid therapy used alone.

Carbogen is considered one of the most powerful vasodilators of cerebral capillary beds. Many studies indicate that carbogen inhalation during noise exposure results in a reduction of NIHL [8]. Brown [9] found significantly less outer hair cell loss in guinea pigs which were given carbogen during a 120 dB broad band noise exposure. However, and as reported by Hatch et al, [10], we observe no significant difference between the carbogen treated animals and the control group. Therefore, carbogen could have a protective effect but almost no curative efficiency.

The idea that inhalation of pure oxygen could be used as medical treatment of acoustic trauma is based on experimental studies performed by Lamm and Arnold who have shown that high-intensity noise causes cochlear hypoxia which correlates with post exposure hearing loss [11]. However, the same authors showed that noise-induced cochlear hypoxia is not compensated by oxygen delivered at ambient pressure level [12]. Moreover, improvement in threshold shifts is only reported when pure oxygen is given during noise exposure [10]. Accordingly, the effectiveness of oxygen delivered at ambient pressure level after intense noise exposure is not apparent in our study.

The aim of hyperbaric oxygen administration is to significantly improve partial oxygen pressure in inhaled air. At 2 ATA, the available amount of oxygen and the blood dissolved oxygen fraction are multiplied by 10 [13]. However, in our study hyperbaric oxygen treatment induces higher threshold shifts and additional hair cells damage. Together with the fact that this treatment induces barotrauma in up to 50% of the human patients (Probst, 1998), that suggests that hyperbaric oxygen should not be used alone as an acute treatment of the acoustic trauma.

When corticoid is administrated one hour after the noise exposure, less threshold shift and less hair cell damage are observed [12]. One hypothesis put forward by Lamm and Arnold is that the activation of the enzyme Na,K-ATPase by corticoid may contribute to restoration of disturbed cellular osmolarity, electrochemical gradients, and neuronal conduction. Actually, it seems that corticoids act both at the dendritic and the cellular level [4,5]. However, corticoids induce oxygen consumption to mobilise amino acid for glucogenesis and alter glucose utilisation by oxygen consuming mechanisms. Therefore, improving partial oxygen pressure in inhaled air could compensate the decline of partial oxygen pressure and potentiate the corticoid effect. Our first results indicate that combined corticoid and hyperbaric therapies significantly improve functional and morphological recovery.

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MAGNESIUM REDUCES NOISE INDUCED HEARING LOSS: ANIMAL STUDIES

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1. INTRODUCTION

Early experimental research on guinea pigs [1] and rats [2] had indicated that auditory susceptibility to noise exposure depends on the animal's magnesium (Mg) status. In these experiments, the animals, which were exposed to chronic noise, differed widely in their Mg status. The purpose of our initial studies was, therefore, to investigate whether small preventive increases in Mg, while still being in the physiological limits, may offer protection from acute impulse noise-induced hearing loss, which may occur in military and industrial environments. Furthermore, we tested whether Mg also has a therapeutic effect on acoustic trauma.

2. PROPHYLAXIS STUDIES

The experiments were performed on anesthetized (ketamine-xylazine) pigmented guinea pigs with either a pysiologically high or low Mg status produced by oral intake of different diets. The animals were fed an experimental low-Mg (0.01%) diet and received tap water either with an additive of 39 mmol $MgCl2/l$ (high-Mg group) or without Mg admixture (low-Mg group). The Mg status was determined by analyzing the total Mg concentrations in perilymph (PL), cerebrospinal fluid (CSF) and blood plasma by means of atomic absorption spectrometry.

The Mg status of the animals in the high-Mg and low-Mg groups are shown in Table 1. The Mg levels of the individual fluids differed significantly in both groups ($P<0.05/0.01$). All 3 fluids showed a significant increase in the high-Mg group as compared to the low-Mg group ($P<0.01$), but the increase in plasma and also in PL was much higher than that in CSF. This suggests that Mg reaches the inner ear directly via the blood-perilymph barrier rather than via the blood-brain barrier, as assumed in the past. The fluid Mg levels of these two groups were at the upper and lower limits of the *physiological* range.

Table (1)
Total Mg concentration (mmol/l) of perilymph, cerebrospinal fluid and plasma for the high-Mg and low-Mg groups (mean ± SD, *n* number of animals tested)

Fluid	High-Mg group	Low-Mg group
Perilymph	0.80 ± 0.14 (38)	0.58 ± 0.11 (50)
Cerebrospinal fluid	0.87 ± 0.11 (34)	0.79 ± 0.11 (46)
Blood plasma	1.24 ± 0.21 (44)	0.68 ± 0.16 (49)

To test the protective effect of Mg on noise-induced hearing loss, the animals were exposed unilaterally to a selected impulse noise at 167 dB peak SPL for 38 min (1/s). This intense exposure was used to produce a severe permanent hearing loss. Hearing function was determined by auditory brainstem response audiometry. Acoustic stimuli were Gaussian-shaped tone pulses with carrier frequencies of 0.5-32 kHz. Permanent hearing threshold shifts (PTS) were measured one week after exposure.

Figure (1)
Dependence of PTS (mean ± SEM) on animal's Mg status.

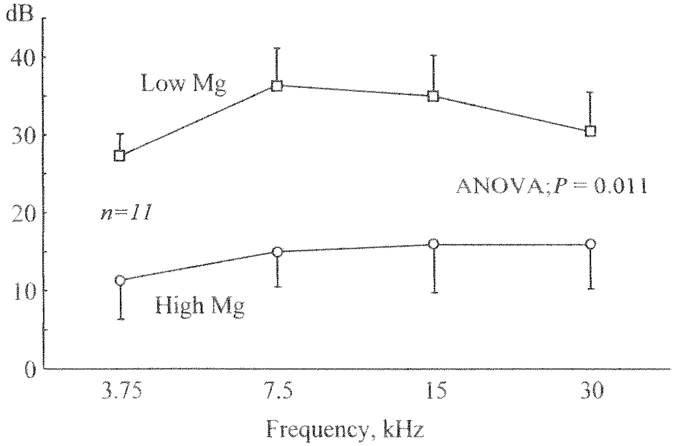


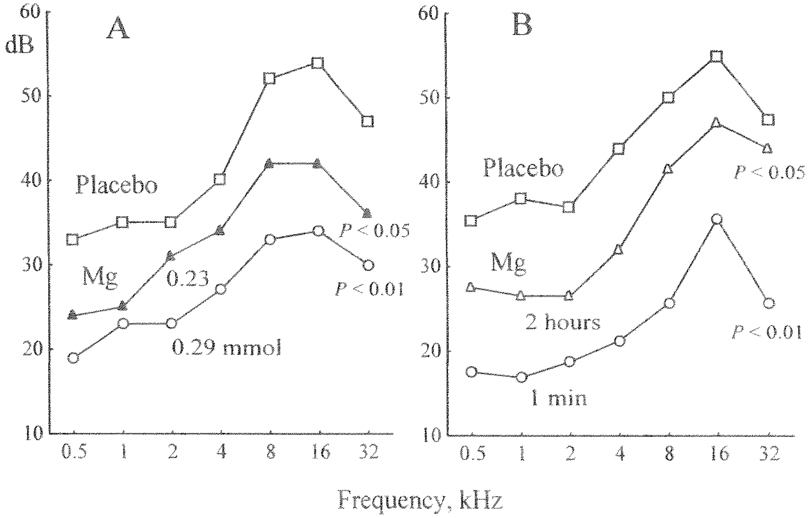
Figure 1 shows the mean PTS for the two experimental groups. In the low-Mg group, the impulse noise exposure caused a considerable mean PTS of as high as 27 to 36 dB depending on the test frequency (3.75-30 kHz). In contrast, in the high-Mg group, the mean PTS was significantly lower by 14 to 21 dB.

In order to verify the functional findings morphologically, the noise-induced damage to the hair cell stereocilia was also tested, using scanning electron microscopy. The stereocilia were found to be damaged in a different degree. We observed a gradual difference in the susceptibility of the stereocilia to the impulse noise exposure, with the 3rd row of the outer hair cells being the most vulnerable structures and the inner hair cells being less vulnerable. Furthermore, there was a Mg-related difference which was particularly evident in the inner hair cell stereocilia. In the high-Mg animals, the extent of the damage to the stereocilia along the basilar membrane was only approximately half of that observed in the low-Mg animals. These morphological findings support our functional results.

3. THERAPY STUDIES

The therapy experiments were performed under the same experimental conditions as were used in the prophylaxis tests. In a first series, guinea pigs with the low Mg status received subcutaneous injections of either a selected Mg dose (0.23/0.29 mmol $MgSO4$ per 100 g body weight) for three days combined with 39 mmol $MgCl2/l$ drinking water for one week (Mg group) or saline and water without Mg admixture (placebo group). The first injection was given immediately after exposure (167 dB peak SPL, 1/s, 38 min).

Figure (2)
Dependence of PTS on (A) Mg dose (n = 8-14/group) and (B) post-exposure time of onset of Mg treatment (n = 8-10/group)



The audiometric results of the therapy experiments are shown in Figure 2. Compared to that of the placebo group, the mean PTS was significantly lower in the two Mg-treated groups, with the difference depending on the given dose. With the lower dose (0.23 mmol Mg/100 g) the difference ranged between 5 and 12 dB ($P<0.05$), whereas with the higher dose (0.29 mmol Mg) a highly significant ($P<0.01$) reduction by 13 to 20 dB was observed. A further increase in the Mg dose did not improve the therapeutic effect. The present observations are the first to demonstrate that Mg also has a therapeutic effect on acoustic trauma. We found a significant negative correlation ($P<0.01$) between the perilymphatic Mg level and the PTS, which suggests that the intracochlear Mg level may play an important role in the auditory system during acoustic exposure.

In a second series, we tested the dependence of PTS on post-exposure time of onset of the Mg treatment. For these experiments, guinea pigs with a normal Mg status (total Mg in PL/CSF/plasma: 0.66/0.81/0.97 mmol/l) were used and treated with the optimal Mg dose (0.29 mmol/100 g). The treatment was started either immediately (1 min) or 2 hours after exposure (Figure 2B). In the 2-hour animals, the PTS was also significantly lower than that in the placebo group, but the difference was only 4 to 12 dB, while in the 1-min animals, a difference between 13 to 20 dB was measured. These findings demonstrate that the Mg treatment should be started as soon as possible after exposure.

4. CONCLUSIONS

Our animal studies have shown that the rate of acoustic trauma, caused by high-intensity impulse noise exposure (simulated small-weapon noise), can significantly be reduced either by an optimal physiological Mg status, induced by *preventive* supplements with oral Mg, or by a markedly higher Mg status produced *therapeutically* as soon as possible after exposure. The intracochlear Mg level seems to be an important factor in bringing about these protective effects. Mg prophylaxis has recently been found also to reduce noise-induced impairment of cochlear microcirculation [3] and oxygenation in the guinea pig. Moreover, preventive Mg supplements were also observed to reduce permanent hearing loss in humans [4].

ACKNOWLEDGEMENT

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NOISE-INDUCED HEARING LOSS AND TINNITUS IN KINDERGARTEN TEACHERS

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1. INTRODUCTION

Noise-induced Hearing Loss (NIHL) is often accompanied by tinnitus. The prevalence of tinnitus has been reported to about 50% from occupational noise exposure [1] whereas the prevalence of tinnitus is often 100% in cases of acute acoustic trauma after impulsive noise exposures [2].

In later years we have seen an increase in complaints of hearing loss and tinnitus in teachers working in kindergarten institutions. This increase has also come to the attention by the Danish Work Environment Agency.

2. MATERIAL AND METHODS

From the database at the Department of audiology we have selected the kindergarten teachers who have visited the audiology department during 1996-1998. The group consisted of 31 subjects, nineteen women and twelve men aged 22 to 54 years. Two other subjects were excluded because of hearing loss of different origin, which could explain the tinnitus. The main complaint was tinnitus rather than hearing loss.

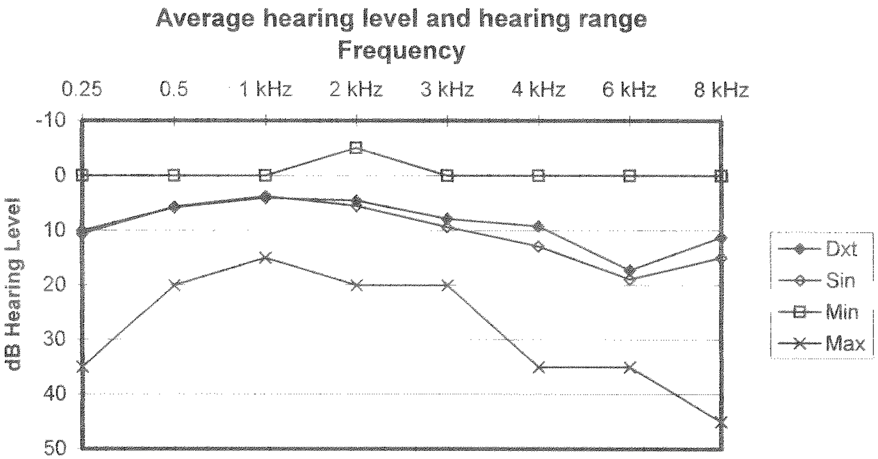
All subjects have been seen by a ENT-physician and were then investigated with pure tone and speech audiometry using Interacoustics AC40 clinical audiometers calibrated according to ISO R389,1975. The investigation also included measurements of the middle ear impedance and reflexes. Measurements of tinnitus pitch, loudness and residual inhibition were performed in nine of the subjects. After the investigation tinnitus treatment was implemented according to the procedure adopted at our department [3].

3. RESULTS

Of the subjects, two men and seven women had a slight high tone loss in the 4-8 kHz region, defined as exceeding the 20 dB hearing level. This could be attributed to other causes than work-related NIHL in both males, since one had worked as a disk-jockey and the other as a rock musician playing drums. Of the seven females, one had an earlier history of otitis media accompanied by a facial palsy, another had previous middle ear infections and elevated middle ear reflex thresholds. A third woman had a story of sudden deafness in the affected ear. A fourth woman had family members with hearing loss starting at early age. The fifth woman had a history of occupational noise exposure. Thus in two women a very discrete high frequency hearing loss was found that possibly could be attributed to noise exposure from the current work amounting to 35 dB HL in one side at 6 or 8 kHz.

The hearing was reported to be affected by 9 subjects, 7 had difficulties in background noise or at group conversations, one experienced sound distortion and one reported higher settings of the radio/TV amplifier. In most of these cases the hearing was normal. Figure 1 illustrates the average hearing for both ears and the total range of hearing in the group.

Figure1, Average hearing of the right and the left ear, max and min values are also illustrated.



Tinnitus and hyperacusis was the main complaint in all of the subjects. The tinnitus was often worsened by the noise exposure at work and hyperacusis (hypersensitivity to loud sounds) was a prominent symptom. In three of the nine subjects who underwent the matching procedure, the subjective level exceeded 30 dB HL. Ten subjects reported tinnitus annoyance of such degree that they were referred to further tinnitus treatment in the department.

Noise dose measurements have revealed noise levels of 80-85 dBALeq during work time with a maximum of 90 dB. The average reverberation time was 1.12, which is twice the recommended value for this kind of institutions.

No measurements of dB Fast or peak levels are available. This professional group have started a major investigation of the sound milieu of their work places in order to prove that they are exposed to hazardous noise. The results of these systematic measurements are not yet known or published.

4. DISCUSSION

Tinnitus as the first symptom of hazardous noise exposure has not been described earlier. Recently there has been focus on this possibility from high level sound exposures at rock concerts [4]. Here, however, it is well known that the sound levels are definitely dangerous. Equivalent sounds levels of 97-110 dB and peak levels have been measured up to 140 dB [5]. This is however far above the levels of 80-85 dBLAeq, which have been measured in the kindergarten localities.

The hearing in the patent group was normal except for two subjects. Since no systematic hearing controls have been performed it is unknown whether these discreet hearing deficiencies have developed from occupational exposure or had other earlier origins. In comparison with subjects suffering from tinnitus after rock concerts, the hearing in these instances are usually affected, sometimes severely.

Previous reports of the problems for kindergarten teachers do not exist. Complaints erupted rather suddenly all over the country. One reason for this could be that tinnitus problems have got much attention by news papers and radio programs in the last couple of years. It should however be noted that sound levels in kindergarten localities have increased, partly because of bigger groups of children and maybe because of a change in behaviour. Thus more children have been reported to develop hoarseness in this early age.

5. CONCLUSION

A group of kindergarten teacher is reported, Where the main complaint resulting from occupational noise exposure is tinnitus rather than hearing deficiency. No consistent NIHL was detected. The question still remains open whether there is a risk for noise-induced hearing effects and also whether tinnitus could be the first symptom of noise damage for this occupation.

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ON THE EFFECTS OF DYNAMIC MUSCLE WORK ON NOISE-INDUCED HEARING THRESHOLD SHIFTS

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1. Introduction and Objective

Exposures to noise at a level of 85 dB(A) for 8 h or energy-equivalent exposures of 3 dB more for half the time, e. g., 88 dB for 4 h, 91 dB for 2 h or 94 dB for 1 h – all of which are permissible in the production sector without wearing hearing protection devices in several countries (cp. [1]) – lead to substantial temporary threshold shifts in the range of 20 to 25 dB. Depending on the time structure of the preceding exposure, the threshold shifts take varying amounts of time to abate, e. g., in the case of continuous noise [2, 3] it usually takes no less than 2 h.

Until now, audiometric measurements in the laboratory with the above-mentioned exposures – which are still within the ethically acceptable bounds – were usually carried out when the subjects (Ss) were in resting position. During a normal work day, however, employees in the production sector are usually not in a resting position when they are exposed to noise. Often they have to perform physical work. On the other hand, it can be expected hypothetically that the hearing's fatigue represented in threshold shifts and their restitution may be modulated by the stimulated cardiovascular system due to physical activity [4]. Therefore, an experimental study was carried out in order to determine to what extent dynamic muscle work of 50 W – an exposure below the endurance level – influences the temporary hearing threshold shift TTS_2 and its restitution over time.

2. Methods and Materials

Ten male Ss from 24 to 43 years of age (28.6 ± 5.9 years) participated in the test series which were carried out in a 'cross-over' design. In a first test series TS I (cp. Figure 1), the Ss were exposed to continuous noise of 94 dB(A) for 1 h, as a reference measurement. Since similar threshold shifts can be expected from this exposure and an energy-equivalent exposure of 85 dB(A) for 8 h, an experimentally feasible exposure was defined with this noise level-time constellation in order to standardize the results of the other tests. In a second test series TS II, the Ss had to perform a physical output of 50 W on a bicycle ergometer after the noise exposure of 94 dB(A) for 1 h. In a third test series TS III, the ergometer work was carried out during the phase of acoustic stress, i. e., simultaneous to the noise exposure.

Hypothetically it could be expected – as shown in the upper part of Figure 1 – that the different exposures would cause different threshold shifts TTS_2 which would abate after varying restitution times.

By using an audiometer already during the selection process, it was ensured that – according to ISO 4869 [5] – only Ss with normal hearing were chosen for the study. Each subject's individual hearing threshold was again determined before each test series, since it served as the basis for further measurements and evaluations.

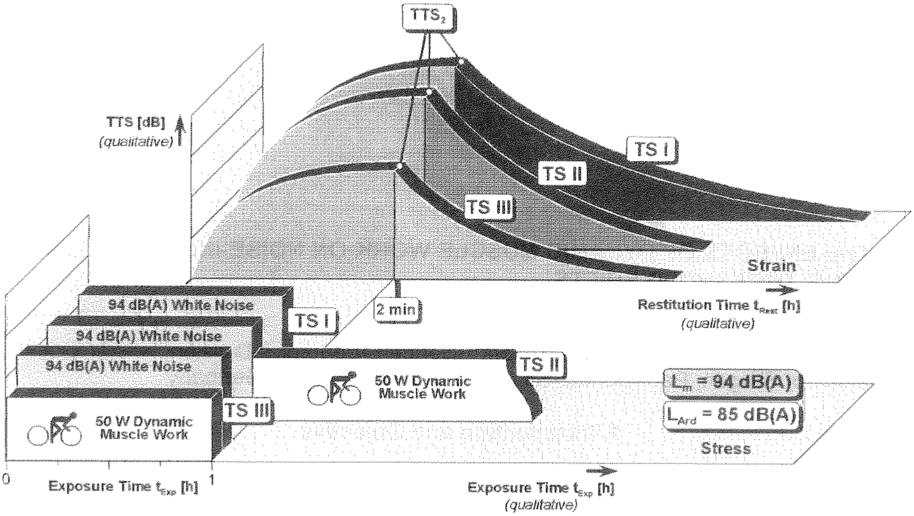

Figure 1: Schematic representation of the 3 exposures (lower part) and hypothetical responses, i. e., growth and restitution of the expected temporary threshold shifts (upper part)

During the test series, the Ss were exposed to 'White Noise' via headphones. The physical stress in TS II and III was generated by a computer-controlled ergometer. A nominal value setting via an artificial head measuring system ensured identical noise exposures for all Ss. In a sound proof cabin, the measurement of the physiological responses to the noise exposure was carried out via pure tone audiometry.

While taking into account the individual resting hearing threshold, the frequency of a S's maximum threshold shift was determined within the first 2 min after completion of the noise exposures. The value of this threshold shift 2 minutes after the noise exposure is called TTS$_2$. Thereafter, the hearing threshold shift at the frequency of the maximum threshold shift, which was usually 4 or 6 kHz, was measured at exactly defined times until the resting threshold was reached again. This point of time is the so-called restitution time t(0 dB).

3. Results

Figure 2 shows exemplarily the results of TS I in which the Ss were exposed to 94 dB(A) for 1 h. The individually measured values and the mean restitution time course for all 10 Ss are plotted against the time axis. The measured values (TTS$_{2\,\mathrm{real}}$ and t(0 dB)$_{\mathrm{real}}$) and the results of the regression-analytical data analysis (TTS$_{2\,\mathrm{reg.}}$ and t(0 dB)$_{\mathrm{reg.}}$) are summarized in the upper right box. On average, the threshold shifts TTS$_2$ were just over 20 dB and took approximately 2 h to totally abate.

When the results of all test series shown in Figure 3 in summarized form, – averaged over the same test Ss in each case – are taken into consideration the TTS$_2$-values of 21.5 dB in TS I, 23.0 dB in TS II, and 23.7 dB in TS III exhibit only minor and insignificant differences in the maximum hearing threshold shifts within 2 min after the noise exposure. Consequently, moderate physical stress (in TS III) had no systematic influence on the level of the maximum threshold shifts. Yet, the results of the restitution times, i. e., the individual durations until the resting threshold shifts are reached again, show the expected differences of the hypothesis.

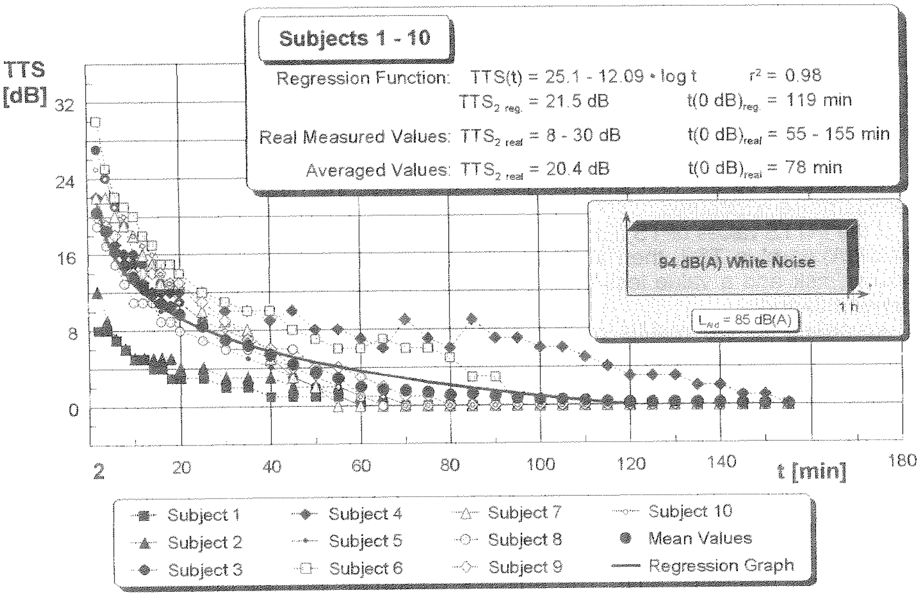

Figure 2: Individual and mean restitution time course TTS(t) for all 10 Subjects after the exposure of TS I (94 dB(A) / 1 h exclusively)

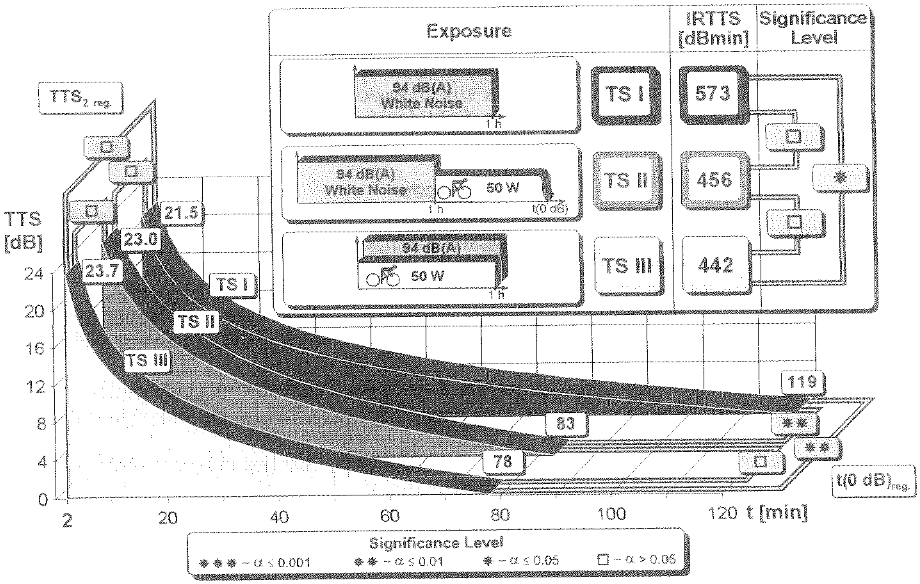

Figure 3: Restitution time course TTS(t) with characteristics $TTS_{2\ reg.}$, $t(0\ dB)_{reg.}$, and physiological cost IRTTS as well as symbolic labeling of significance levels for the differences between the responses to the exposures (according to the one-tailed WILCOXON-test)

While it takes approximately 2 h for the hearing thresholds to return to their resting level after exposure to noise exclusively (in TS I), the restitution time for the noise exposure which was followed by physical stress (TS II) is significantly shorter (83 min). Simultaneous physical stress and noise exposure in TS III lead to an even shorter, statistically significant restitution time (78 min). Finally, the calculation of the Integrated Restitution Temporary Threshold Shift [6, 7] yielded (IRTTS) values of 573 dBmin for TS I, 456 dBmin for TS II, and 442 dBmin for TS III. These figures can be interpreted as the total physiological costs which the hearing has to 'pay' for the various noise exposures.

If the IRTTS values of TS II and III are related to the value of the reference exposure '94 dB(A) / 1 h' in TS I, then a value greater than 1 corresponds with a higher, i. e., greater, risk and a value less than 1 corresponds with a lower or smaller risk for the human hearing.

According to the results of this standardization (456 dBmin / 573 dBmin = 0.80; 442 dBmin / 573 dBmin = 0.77), physiological costs to the hearing both after and simultaneous to physical work could be reduced by approximately 20 %. The lower hearing risk of 80 % due to combined acoustic and physical load can mainly be attributed to reduced restitution times.

4. Conclusions and Outlook

In conclusion, overall dynamic muscle work does not lead to a smaller amount of the maximum threshold shift; however, there is a positive and significant effect of muscle work on the restitution time. The effect is consistent with the paradigm of overall metabolism and the restitution processes in the sensory organs of the inner ear [8]. The results of the study show that moderate physical stress in combination with noise exposure should be evaluated positively rather than as an additional strain in terms of the physiological costs for the organism due to stress from noise. Additional physical stress does not inevitably lead to an increase (in strain) but it can even result in reduced physiological costs for which the organism must pay. But it has to be added that cardiovascular activation which becomes evident in increased heart rates must also be interpreted in terms of physiological costs which have to be paid for dynamic muscle work. The combination of various stress exposures which influence the human being on a daily basis presents a wide field for future work-physiological research projects.

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ON THE EFFECTS OF DYNAMIC MUSCLE WORK ON NOISE-INDUCED HEARING THRESHOLD SHIFTS

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Until now, audiometric measurements in the laboratory with the above-mentioned exposures – which are still within the ethically acceptable bounds – were usually carried out when the subjects (Ss) were in resting position. During a normal work day, however, employees in the production sector are usually not in a resting position when they are exposed to noise. Often they have to perform physical work. On the other hand, it can be expected hypothetically that the hearing's fatigue represented in threshold shifts and their restitution may be modulated by the stimulated cardiovascular system due to physical activity [4]. Therefore, an experimental study was carried out in order to determine to what extent dynamic muscle work of 50 W – an exposure below the endurance level – influences the temporary hearing threshold shift TTS_2 and its restitution over time.

2. Methods and Materials

Ten male Ss from 24 to 43 years of age (28.6 ± 5.9 years) participated in the test series which were carried out in a 'cross-over' design. In a first test series TS I (cp. Figure 1), the Ss were exposed to continuous noise of 94 dB(A) for 1 h, as a reference measurement. Since similar threshold shifts can be expected from this exposure and an energy-equivalent exposure of 85 dB(A) for 8 h, an experimentally feasible exposure was defined with this noise level-time constellation in order to standardize the results of the other tests. In a second test series TS II, the Ss had to perform a physical output of 50 W on a bicycle ergometer after the noise exposure of 94 dB(A) for 1 h. In a third test series TS III, the ergometer work was carried out during the phase of acoustic stress, i. e., simultaneous to the noise exposure.

Hypothetically it could be expected – as shown in the upper part of Figure 1 – that the different exposures would cause different threshold shifts TTS_2 which would abate after varying restitution times.

By using an audiometer already during the selection process, it was ensured that – according to ISO 4869 [5] – only Ss with normal hearing were chosen for the study. Each subject's individual hearing threshold was again determined before each test series, since it served as the basis for further measurements and evaluations.

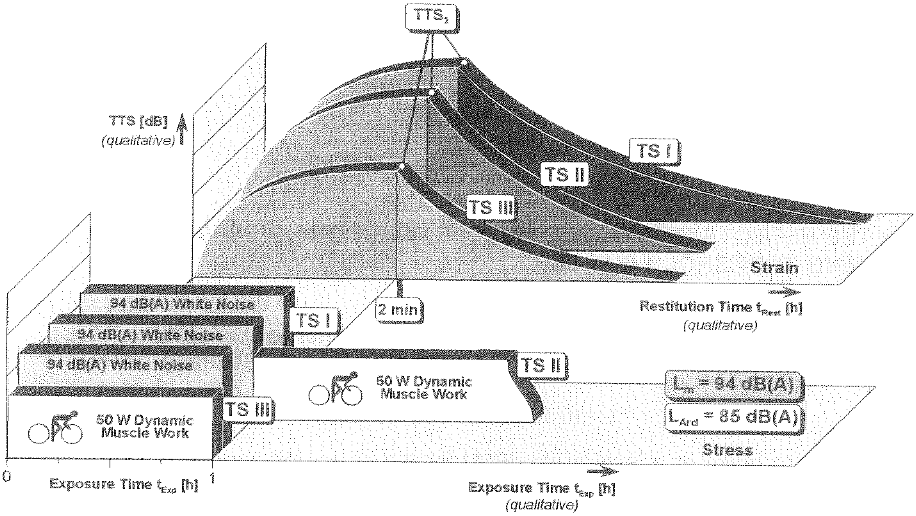

Figure 1: Schematic representation of the 3 exposures (lower part) and hypothetical responses, i. e., growth and restitution of the expected temporary threshold shifts (upper part)

During the test series, the Ss were exposed to 'White Noise' via headphones. The physical stress in TS II and III was generated by a computer-controlled ergometer. A nominal value setting via an artificial head measuring system ensured identical noise exposures for all Ss. In a sound proof cabin, the measurement of the physiological responses to the noise exposure was carried out via pure tone audiometry.

While taking into account the individual resting hearing threshold, the frequency of a S's maximum threshold shift was determined within the first 2 min after completion of the noise exposures. The value of this threshold shift 2 minutes after the noise exposure is called TTS_2. Thereafter, the hearing threshold shift at the frequency of the maximum threshold shift, which was usually 4 or 6 kHz, was measured at exactly defined times until the resting threshold was reached again. This point of time is the so-called restitution time t(0 dB).

3. Results

Figure 2 shows exemplarily the results of TS I in which the Ss were exposed to 94 dB(A) for 1 h. The individually measured values and the mean restitution time course for all 10 Ss are plotted against the time axis. The measured values ($TTS_{2\ real}$ and $t(0\ dB)_{real}$) and the results of the regression-analytical data analysis ($TTS_{2\ reg.}$ and $t(0\ dB)_{reg.}$) are summarized in the upper right box. On average, the threshold shifts TTS_2 were just over 20 dB and took approximately 2 h to totally abate.

When the results of all test series shown in Figure 3 in summarized form, – averaged over the same test Ss in each case – are taken into consideration the TTS_2-values of 21.5 dB in TS I, 23.0 dB in TS II, and 23.7 dB in TS III exhibit only minor and insignificant differences in the maximum hearing threshold shifts within 2 min after the noise exposure. Consequently, moderate physical stress (in TS III) had no systematic influence on the level of the maximum threshold shifts. Yet, the results of the restitution times, i. e., the individual durations until the resting threshold shifts are reached again, show the expected differences of the hypothesis.

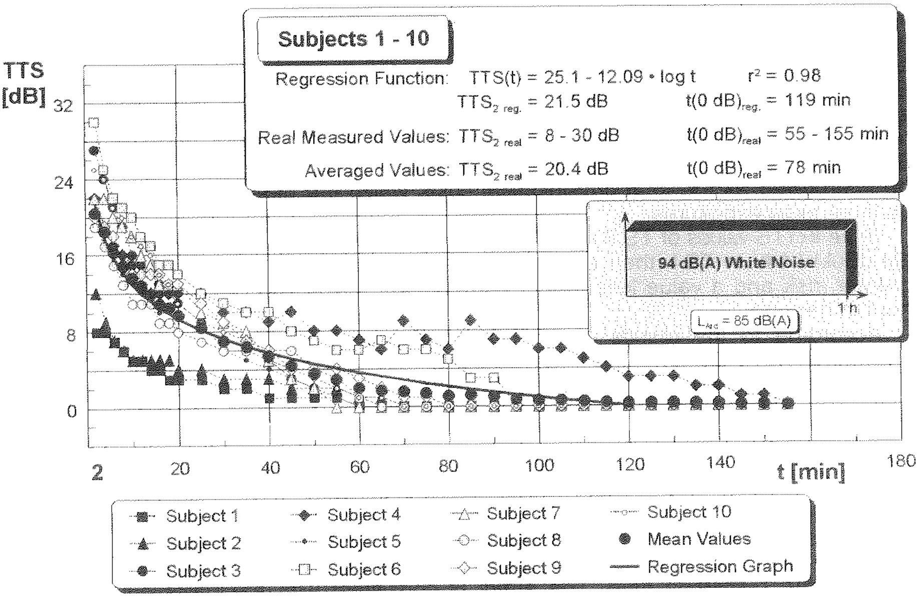

Figure 2: Individual and mean restitution time course TTS(t) for all 10 Subjects after the exposure of TS I (94 dB(A) / 1 h exclusively)

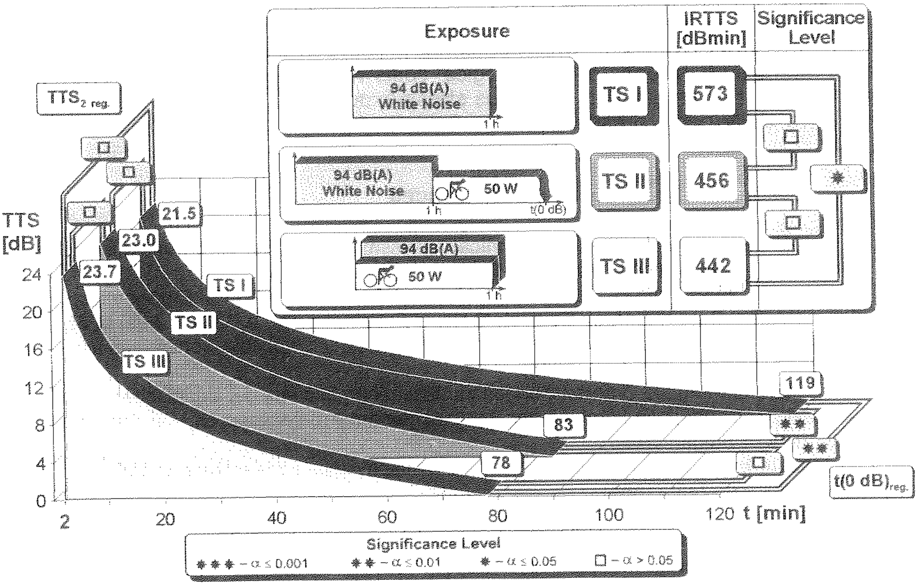

Figure 3: Restitution time course TTS(t) with characteristics $TTS_{2\,reg.}$, $t(0\ dB)_{reg.}$, and physiological cost IRTTS as well as symbolic labeling of significance levels for the differences between the responses to the exposures (according to the one-tailed WILCOXON-test)

While it takes approximately 2 h for the hearing thresholds to return to their resting level after exposure to noise exclusively (in TS I), the restitution time for the noise exposure which was followed by physical stress (TS II) is significantly shorter (83 min). Simultaneous physical stress and noise exposure in TS III lead to an even shorter, statistically significant restitution time (78 min). Finally, the calculation of the Integrated Restitution Temporary Threshold Shift [6, 7] yielded (IRTTS) values of 573 dBmin for TS I, 456 dBmin for TS II, and 442 dBmin for TS III. These figures can be interpreted as the total physiological costs which the hearing has to 'pay' for the various noise exposures.

If the IRTTS values of TS II and III are related to the value of the reference exposure '94 dB(A) / 1 h' in TS I, then a value greater than 1 corresponds with a higher, i. e., greater, risk and a value less than 1 corresponds with a lower or smaller risk for the human hearing.

According to the results of this standardization (456 dBmin / 573 dBmin = 0.80; 442 dBmin / 573 dBmin = 0.77), physiological costs to the hearing both after and simultaneous to physical work could be reduced by approximately 20 %. The lower hearing risk of 80 % due to combined acoustic and physical load can mainly be attributed to reduced restitution times.

4. Conclusions and Outlook

In conclusion, overall dynamic muscle work does not lead to a smaller amount of the maximum threshold shift; however, there is a positive and significant effect of muscle work on the restitution time. The effect is consistent with the paradigm of overall metabolism and the restitution processes in the sensory organs of the inner ear [8]. The results of the study show that moderate physical stress in combination with noise exposure should be evaluated positively rather than as an additional strain in terms of the physiological costs for the organism due to stress from noise. Additional physical stress does not inevitably lead to an increase (in strain) but it can even result in reduced physiological costs for which the organism must pay. But it has to be added that cardiovascular activation which becomes evident in increased heart rates must also be interpreted in terms of physiological costs which have to be paid for dynamic muscle work. The combination of various stress exposures which influence the human being on a daily basis presents a wide field for future work-physiological research projects.

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DECLINING PREVALENCE OF HIGH-FREQUENCY HEARING LOSS >20 dB IN NORWEGIAN 18 y OLD MALES AT MILITARY ENROLMENT IN THE 1990's

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1. ABSTRACT

The prevalence of high frequency hearing loss >20dB in 18 year old Norwegian male conscripts at enrolment, before start of military service, increased in the 1980's from around 15% in 1981/82 to around 35% in 1987/88/89, n=around 30.000 per year [2]. The hearing loss prevalences were constant for other frequency ranges. The locations, procedures and equipment were the same throughout. The figures were taken to reflect increased leisure noise exposure, most likely music noise, which may reach hazardious levels e.g. in rock concerts, in "walkman" audio-headset devices, and in discotheques [8].

During the 1990's the high-frequency hearing loss prevalence at enrolment declined gradually to around 15% level in 1995/96/97 - most likely reflecting the extensive public information on music noise hazard given through the media and in warnings on audio devices.

2. INTRODUCTION

Norway has 15 months' compulsory military service for all male citizens aged >18 years. Medical data collected at enrolment of conscripts - one year before military service - are thus representative for the entire Norwegian 18 year old male population. Since 1981, the medical data have been categorized and stored electronically in terms of digit codes to facilitate administration procedures. The "hearing digits" 9 through 3 denote whether the man has normal hearing, or low-, mid-, high- or mixed frequency hearing loss >20 dB on one or both ears (Table 1). Old-age presbyacusis and noise exposure are the only major causes of selective high-frequency hearing loss. The prevalence of selective high-frequency hearing loss - i.e. hearing digits 4 and 5 - recorded among Norwegian 18 year old men before military service will therefore reflect noise-induced hearing loss - largely caused by socioacusis or leisure noise, as most conscripts join the military directly from school [2].

3. METHOD

Pure-tone «screening 20 dB» audiometry - whether one can hear a tone of 20 dB (=normal hearing) on each ear for the standard test frequencies 250, 500, 1000, 2000, 3000, 4000, 6000, 8000 Hz - was performed annually in around 30,000 18-year-old Norwegian male conscripts at enrolment 1981-97, i.e. before start of military service. The locations, training of operators, and the procedures for sample selection, audiometry, coding and handling of data were the same throughout. Interacoustics AD12 or 25 audiometers and Tegner booths were used. In subjects with a hearing loss >20 dB for any test frequency, normal pure tone threshold audiometry was performed for all test frequencies. The data were categorized and stored electronically in terms of "hearing digits" according to the criteria given in Table 1 (for details, cf. Borchgrevink 1988b in [2]).

4. RESULTS

During the period 1981-89 the enrolment prevalence of selective high-frequency hearing loss (hearing digits 4 and 5) increased from around 15% in 1981/82 to around 35% in 1987/88/89. In the 1990's the high-frequency hearing loss prevalence declined: 31.1% in 1990, 30.8 in 1991, 24.6% in 1992, 19.2% in 1993, 17.5% in 1994, 15.7% in 1995, 12.9% in 1996 and 13.7% in 1997. Mixed hearing loss (digit 3, includes high-frequency loss) showed trends of a corresponding increase/decline pattern. Low frequency hearing loss (digit 8) and mid-frequency hearing loss (digits 6,7) showed no such variation (Table 2).

5. DISCUSSION

Most of the recorded high-frequency hearing losses must be small, as only 3% of the 1991 army conscripts showed hearing digit 2 at entry [2]. The hearing loss prevalence distribution at enrolment screening 1990 (n=34,409) was confirmed for the Army fraction (n=14.409) of the same group when entering military service 1991 [2]. The low- and mid frequency hearing loss prevalence show no systematic variation 1981-97. Mixed hearing loss (digit 3, includes high-frequency loss) shows trends corresponding to the high-frequency loss prevalence variation (Table 2). (For further discussion of validity, see [2]). The recorded prevalence and increase/decline of high-frequency hearing loss should thus be reasonably valid. For young men largely coming directly from school, the figures must reflect variations in socioacusis and/or leisure noise, e.g.music exposure.

Music noise affects many and may reach hazardious levels in rock concerts, in "walkman" audio-headset devices and in discotheques [8]. In Norway the "walkman" was introduced around 1979, 600.000 sets were sold by 1987, by 1993 >1 mill. - or one set per person aged 10-30 years [2]. «Walkman» listening levels in young adults exceeded 90 dBA Leq in 25%, and 100 dBALeq in 5% of British subjects (Rice & al 1987 in [2]) and averaged 104 dBA in a German

study [1]. Tinnitus after music listening was admitted by 20% in the British study (Rice & al 1987 in [2]) and by 37% in an Italian study [7].
Susceptibility varies across individuals. Temporary threshold shifts (TTS) of 5-25 dB was recorded in 6 volunteers after one hour "walkman" music at 95 dBA Leq (Turunen-Rise & al 1991 in [2]) and one of 10 subjects showed 35 dB TTS versus group mean 9 dB TTS after pop-music listening at "a level they enjoyed" (Hellström & Axelsson 1988 in [2]). TTS of 25 dB or more is considered likely to produce permanent hearing loss upon repeated exposure (NATO 1987 in [2]). Safe maximum exposure levels for music noise are estimated to 90 dBA for portable headset players and 95 dBA for discotheques [5].

High-frequency hearing loss in young adults is reported in an increasing number of studies, e.g. in conscripts at entry in Sweden (14% in 1970-77 and 1992 [11], Italy [7] and Canada [10]; in adolescents in Germany [1], France [8] and Japan [4]; in 15-45 year-olds in Australia [9] and in the NIPH n=51.000 audiometric survey in Norway (Borchgrevink & al 1998, this meeting). A 45% prevalence for hearing loss is reported for 20 year old British males (Davies 1993, quoted in [11]). US-NCHS indicated effects of music-induced hearing losses beginning in the late 1960s [6]. This implies noise-related socioacusis, but possibly combined with too restrictive ISO threshold norms at 6kHz. Restrictions on leisure noise exposure including music noise should be considered.
The decline recorded in high-frequency hearing loss prevalence in 18 year old Norwegian males in the 1990's most likely reflects extensive public information on music noise hazard given through the media, and warnings on audio devices.

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Table 1, The hearing digit code

		Hearing digit
Normal hearing, threshold ≤20 dB both ears, or		
Low-freq.loss >20 dB ≤500 Hz	one ear	**9**
" " " " "	both ears	**8**
Mid- " " " 1000, 2000 Hz	one ear	**7**
" " " " " "	both ears	**6**
High " " " ≥3000 Hz	one ear	**5**
" " " " "	both ears	**4**
Mixed hearing loss >20 dB with combined low+mid, low+high, mid+high or low+mid+high loss		**3**

Table 2, Prevalence of normal hearing and low/mid/high/mixed frequency loss >20dB on one or both ears in percent per year for Norwegian conscripts at enrolment 1981-1997

Hearing -digit -loss	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**
9 normal	73.7	77.4	70.6	68.2	61.3	63.9	53.9	51.3	51.3
8 low Hz	1.5	2.7	1.3	1.3	1.5	0.8	0.8	0.8	1.5
7 mid "	0.8	0.7	0.3	0.4	0.4	0.3	0.3	0.3	0.3
6 mid "	0.3	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1
5 high "	12.1	10.1	13.3	15.2	18.4	17.4	21.6	22.1	21.1
4 high "	5.9	4.2	6.4	7.3	10.9	9.0	14.1	14.5	13.9
4+5 high	**18.0**	**14.3**	**19.7**	**22.5**	**29.3**	**26.4**	**35.7**	**36.6**	**35.0**
3 mixed	5.6	4.0	5.0	4.7	4.8	5.6	5.6	7.1	7.7
tested n=	**34409**	**34856**	**35783**	**33419**	**27995**	**27612**	**33341**	**30792**	**29807**
% of total	100	100	97.6	97.6	98.0	97.6	96.9	97.2	

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
9 normal	55.3	56.3	65.0	69.0	71.1	67.4	69.9	72.4
8 low Hz	1.5	1.2	2.1	2.0	3.1	1.0	0.9	1.6
7 mid "	0.2	0.4	0.3	0.4	0.3	0.4	0.4	0.5
6 mid "	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
5 high "	20.0	20.8	16.2	12.9	12.7	10.8	9.5	10.1
4 high "	11.1	10.0	8.4	6.3	4.8	4.9	3.4	3.6
4+5 high	**31.1**	**30.8**	**24.6**	**19.2**	**17.5**	**15.7**	**12.9**	**13.7**
3 mixed"	6.9	6.7	6.8	5.7	3.3	4.0	3.4	3.5
tested n=	**32722**	**34776**	**35200**	**34793**	**29282**	**28538**	**27663**	**27302**

AURAL REFLEX ELICITING EARMUFFS FOR ARTILLERY GUN CREW

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1. INTRODUCTION

The Aural Reflex Eliciting (AR) Earmuff was designed and patented by the National Acoustic Laboratories (NAL) in the late 1980s. These earmuffs provide additional protection against impulse noise compared to ordinary earmuffs and are designed for artillery weapons operators. The principle underlying the design is that a stimulus, in the form of broad band noise, is presented to the ear to elicit the aural reflex 0.2 second before the weapon is fired.

NAL and DSTO (Defence Science and Technology Organisation) embarked on a collaborative study to evaluate the performance of the AR earmuff. This involved the exposure of subjects to high intensity impulse noise under controlled conditions. A previous study, in which subjects were exposed to only one impulse per day indicated that a good quality earmuff was adequate to protect hearing from single 'shots' of impulse noise and no benefit of adding the aural reflex was demonstrated [1]. In the present study the subjects were exposed to multiple 'shots' in a day, a condition that would be more realistic in a military operation.

The specific aims of this study were: (i) to determine whether acoustically-eliciting the stapedius reflex immediately before each shot provided additional protection of hearing in soldiers exposed to simulated artillery weapons noise at levels equivalent to those experienced by gun-layers; (ii) to determine whether evoked otoacoustic emissions (EOAEs) were a more sensitive indicator of the effects of gun noise on the inner ear than temporary threshold shift (TTS); and (iii) to develop a methodology for further investigations of the protective effect of hearing protectors and the acoustically-elicited stapedius reflex for soldiers under realistic (field) conditions.

2. EXPERIMENTAL METHOD

The impulse noise was generated by firing carefully prepared 0.50 calibre machine gun blank cartridges into a narrow end of a conical shock tube. This tube, made of stainless steel, was 6.7 m long, and clad in concrete housing. The half angle of the cone was 2^0. A truncated cone made of aluminium was attached to the large end of the tube to facilitate the passage of the shock-wave. The characteristics of the impulse noise generated by this method closely approximated those obtained from a 105 mm artillery weapon in terms of peak sound pressure level and frequency spectrum.

The AR earmuffs were Peltor H7A earmuffs modified to incorporate an electronic circuit, a power supply and a small speaker inside each cup. A small FM receiver was attached to the headband. An electronic white noise generator, interfaced to the firing device, was constructed to provide a burst of white noise at 97dB(A) and of 170 ms duration at the entrance to the ear canal. The white noise was transmitted by an FM transmitter to the earmuffs when the 'shot' was fired. The actual firing of the blanks was delayed and the impulse noise arrived at the subject about 0.2 s after the white noise to allow the stapedius reflex to become fully activated.

Approval was obtained from the Australian Defence Medical Ethics Committee to conduct the study. The subjects were Army personnel who were otologically normal and showed normal tympanograms and aural reflexes in both ears. Two persons were studied simultaneously. During the firing, each sat on a chair equipped with a small head-rest in front of the truncated cone on either side of the tube axis. They faced away from the tube, wore goggles for protection from dust and were asked to keep still.

Two studies were performed, the first in January 1996 with 21 subjects and the second in May 1997 with 24 subjects. In the first study the program consisted of exposing the subjects to 1, 1, 2, 2, 4, 4, 8, 8 shots during the eight day program. On days 1, 3, 5 and 7 the aural reflex eliciting stimulus was *on*, on days 2, 4, 6 and 8 it was *off*. The interval between shots was 10 seconds. In the second study the number of shots started with 2, not 1, thus reducing the exposure program by two days. There was no count-down, but the white noise provided a cue that the shot was coming when the aural reflex eliciting stimulus was *on*.

The effect of the impulse noise was measured by means of Bekesy audiometry and by evoked otoacoustic emissions (EOAE) using a portable Otodynamics ILO88 analyser. The tests were performed in audiometric booths just before and immediately after the exposure. The start-time for the post-exposure audiometry and EOAE measurements was recorded; the minimum time was one minute after the last shot had been fired. Since there was only one instrument to measure EOAE, one subject did the audiometry first after the exposure, whilst the other performed the EOAE test first. For all subjects the tests were first administered to the ear that received the highest level of impulse noise, namely the one closest to the axis of the shock tube.

During the firings, the impulse noise was monitored and recorded. Blast overpressure gauges, consisting of piezoelectric transducers were placed just outside the shell of the earmuffs worn by the subjects. In the main the impulse noise level was between 179 and 181 dB SPL, although there were occasions when it was outside this range.

3. RESULTS

The audiograms were analysed and TTS data (hearing level after, minus that before, exposure) obtained at 10 frequencies between 0.2 and 6 kHz. Mean TTSs of zero were found for all exposures *with* and *without* the stapedius reflex-eliciting stimulus. There was no evidence for TTS in any individual subject, ie no one showed the distinctive pattern of TTS normally associated with noise-induced effect and the subsequent systematic recovery.

The EOAE data were processed to give measures of Coherent Emission Strength (CES), and Correlation Coefficient Percent (CC%). CES is the RMS sound pressure of the emission, weighted by the wave reproducibility squared, and expressed as sound pressure level. CC% is the same as wave reproducibility and is the correlation between successive emission responses to the click. No effect of impulse noise on CES was found. Some preliminary analyses suggested that there may be an effect on CC% such that the above results may not hold for more critical exposure conditions.

4. DISCUSSION

The beneficial effect of aural-reflex in providing protection against impulse noise was shown in an early study [2] in which subjects were exposed to impulse noise generated by machine-guns both with and without a pre-exposure stimulus. The temporary threshold shifts (TTSs) obtained when the reflex-activating tone was used were significantly smaller than those obtained in its absence.

In another study involving over 40 students it was shown that the range of individuals' susceptibility to noise-induced temporary threshold shift was very large, and much greater than the range of susceptibility to steady-state noise [3].

The significance of these two studies is that the investigation of the effects of impulse noise must involve a sufficiently large sample size (at least 40); and that to show the benefit of the aural reflex, the subjects must sustain significant TTSs under non aural-reflex condition.

The present study did not result in TTSs in 45 subjects after exposure to 8 shots at impulse noise level of 179 - 181 dB SPL under the non aural-reflex condition. This did not allow for the effect of the aural reflex to be demonstrated. A conclusion from the study is that unmodified Peltor H7A earmuffs provided sufficient protection against up to 8 shots of artillery noise at levels of 179 - 181 dB SPL where the earmuffs were in good condition and were experimenter-fitted. Under these conditions there could be no advantage in eliciting the stapedius reflex.

The results of the present study are consistent with those obtained by Patterson and Johnson who exposed subjects to a much higher intensity impulse noise [4]. It was found that hearing protection was adequate for exposure to 50 impulses at 187 dB SPL, the A-duration of which was 3.0 ms. It was also adequate for 6 impulses up to 196 dB SPL, with 0.8 ms A-duration. The impulses were presented at one per minute.

Measurements have been conducted to investigate the attenuation of ear plugs and muffs for a range of weapons, from miniature rifles to howitzers [5]. The method used was to place miniature microphones inside and outside the aural protectors. One of the conclusions was that earmuffs appeared to be ineffective (less than 15 dB attenuation) against impulses from large-calibre weapons with energy content at low frequencies.

There appears to be a discrepancy between the results of studies involving the direct determination of hearing protectors attenuation and those involving the measurements of hearing thresholds of subjects exposed to impulse noise. The conclusion from the human studies appear to show that the reduction in the peak SPL by itself does not reflect adequately the ability of the hearing protectors to reduce auditory injury. An important factor that has to be taken into account is that the hearing protectors have the effect of changing the shock front so that it is more rounded, and thus reducing the harmful high frequency content [6].

The combined results of the previous study in which the subjects were exposed to one 'shot' per day [1] and the present study in which multiple 'shots' were used, support an earlier finding that if the most sensitive measure of effect has been used, and there was zero effect of a single shot, there would be no accumulation of effects from a series of shots [3].

It is recommended that the methodology used in this study be applied in similar investigations of the effectiveness of stapedius-eliciting earmuffs with impulse noise at higher peak SPLs, and where the earmuffs are subject-fitted and/or damaged, as may occur under field conditions.

AR earmuffs may also prove beneficial for armoured vehicle crews are exposed to impulse noise. Armoured vehicle personnel wear a helmet with earmuffs incorporated in it. If the muffs do not seal well, thus reducing the protection against impulse noise, stimulation of the stapedius reflex could add to remaining aural protection and so counter some of the effects. The integration of a white noise generator to the weapon system and the transmission of the white noise through the existing communication system should not present a technical challenge.

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AUDIOGRAMS OF SYMPHONY ORCHESTRA MUSICIANS

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1. INTRODUCTION

It has been argued that hearing loss and tinnitus are the natural and inevitable results of being a musician. The literature show a mixed picture and no clear hearing loss risk is seen [1]. Some investigation show a risk (e.g. [2, 3, 4, 5, 6]) while others do not show a risk (e.g.[7, 8, 9]). The risk is partly depending on the type of orchestra (symphony or rock band). Some investigations concentrate on audiogram determinations and others on sound level measurements. Generally it seems that the noise limits which are set for industry noise may not be correct in relation to the risk of hearing loss from music.

Based on a literature study [1] it was decided to perform an investigation on classical symphony orchestra musicians and contact was made to four professional Danish symphony orchestras through the musicians own organisation and representatives. The orchestras were The Danish Radio Symphony Orchestra, Sjællands Symphony Orchestra, Aarhus Symphony Orchestra and Sønderjyllands Symphony Orchestra. The investigation comprised an interview with the musicians, determination of their pure tone audiogram and sound level measurements in the orchestras during rehearsal and concerts. The audiograms were compared to the median audiogram from ISO 7029 [10] for the same age and gender. The sound level measurements – combined with the information from the interviews – were used to compare the audiograms with the calculated hearing threshold levels from ISO 1999 [11].

2. TEST SUBJECTS AND MEASUREMENT METHODS

Subjects who have been exposed to loud non-musical noise sources were excluded from the investigation. No other selection of the subjects were performed and thus all subjects participated voluntarily in the investigation. The musicians were informed about the investigation by their representatives and they were strongly encouraged to participate. The subjects were interviewed about various topics which were expected to be important for their hearing ability such as work experience, normal working hours, music playing during spare time, spare time activities, military activities, etc. Fifty-seven musicians took part in the investigation. The fifty-seven persons were in the age range from 22 to 65 years and comprised 26 female and 31 male persons.

The pure tone audiograms of the fifty-seven musicians were determined in the frequency range from 125 Hz to 8 kHz using a manual audiometer (Madsen electronics Midimate 602) equipped with Sennheiser HDA 200 earphones which have a very good attenuation of the background noise compared to the conventional TDH 39 earphones. This made it possible to perform the threshold determinations in a quiet room near the concert hall. The audiometer was calibrated according to recent investigations of the reference equivalent sound pressure level (RETSPL) for these earphones [12].

Measurements of the sound level were performed during rehearsal and during concerts where a Sound Level Meter was positioned in various instrument groups. At the same time a Noise Dose Meter was used to evaluate the dose perceived by individual orchestra members.

3. HEARING THRESHOLD RESULTS

The average audiogram of the 57 musicians is shown in figure 1. A decrease at higher frequencies similar to an age related hearing loss is seen. The variability in the data is illustrated with the dashed curves showing plus and minus one standard deviation from the mean values.

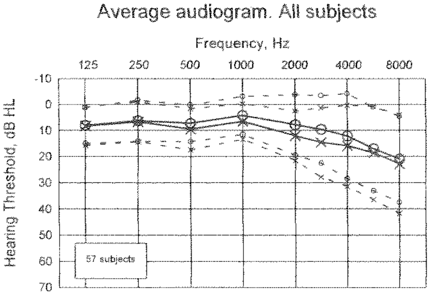

Figure 1. Average audiogram of the 57 subjects. O = right ear. X = left ear. Dashed curves: plus and minus one standard deviation.

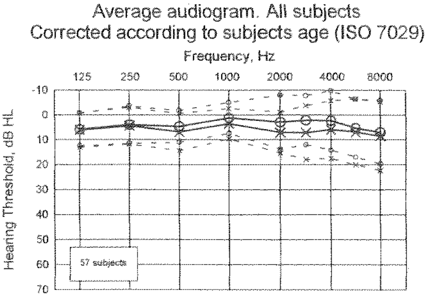

Figure 2. Average age corrected audiogram. Correction based on median values from ISO 7029 applied to the individual person. O = right ear. X = left ear. Dashed curves: plus and minus one standard deviation.

In order to extract the age effect from the data, the individual audiograms were corrected according to the age of the person by means of the median from ISO 7029. The average audiogram from these age corrected individual audiograms show no signs of hearing loss. See figure 2.

If the data are divided into instrument groups the same no-hearing-loss picture is seen in almost all cases. Examples are given in figure 3 (four viola players who usually sits in front of the brass players) and in figure 4 (twelve violin players).

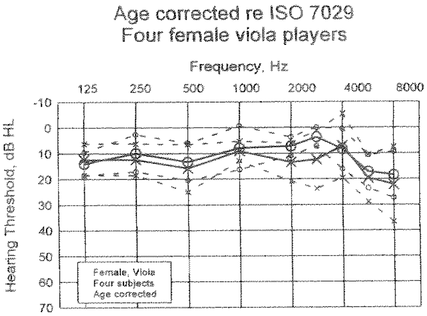

Figure 3. Average age corrected audiogram for four viola players. O = right ear. X = left ear. Dashed curves: plus and minus one standard deviation.

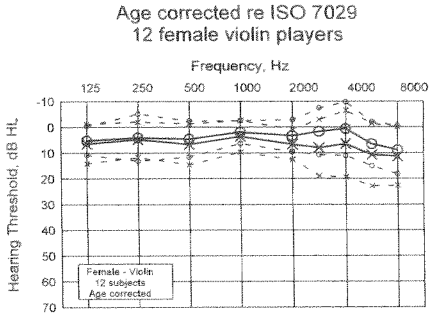

Figure 4. Average age corrected audiogram for twelve violin players. O = right ear. X = left ear. Dashed curves: plus and minus one standard deviation.

4. SOUND LEVEL RESULTS

Examples of the results of the sound level measurements are given in table 1 (sound level meter in different instrument groups) and table 2 (noise dose meter at individual musicians). In both tables the duration of the measurement is given in minutes. The levels are similar to the levels found in [2, 6 and 13].

Table 1. Measurements with a Sound Level Meter

Instrument group	Meas. dur.	L_{Aeq} dB SPL	Peak dB SPL
Violin I	15	82,2	108,9
Violin II	15	84,9	112,2
Viola	20	86,3	116,4
Horn	15	91,6	115,2
Tuba/Tromb.	25	89,6	119,4
Flute	15	93,6	96,8
Clarinet	10	89,2	117,5
Percussion	22	83,6	125,0
Piano	40	84,1	111,1

Table 2. Measurements with a Noise Dose Meter

Instrument	Meas. dur.	L_{Aeq} dB SPL	Peak dB SPL
Violin I	153	86,7	124,7
Violin II	156	86,4	127,9
Viola	138	90,2	123,7
Horn	113	90,5	140,6
Clarinet	90	88,4	116,1
Flute	105	92,9	119,3
Oboe	161	91,0	135,4
Trumpet	143	95,1	121,9
Trombone	68	88,2	119,3
Double-Bass	94	84,5	134,0

Based on the L_{Aeq} data in the two tables the various instruments were divided into three level groups around 85 dB, 90 dB and 95 dB and the measured audiograms were then compared to theoretical audiograms from ISO 1999. The comparison took into account to the interview's information about the number of years at work, number of playing hours per week and average sound level in the orchestra for the instrument group. The L_{Aeq} levels were normalised to an 8 hours working period.

Examples of the measured age-corrected audiograms and the expected audiograms are shown in figure 5 and figure 6. In almost all cases the audiograms looked better than the predictions from ISO 1999.

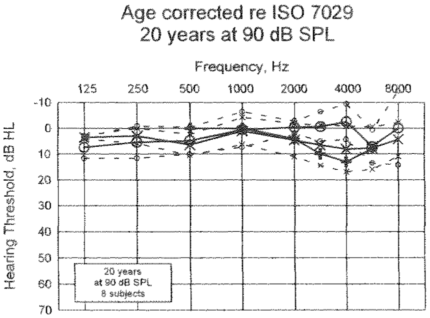

Figure 5. Average audiogram for eight musicians who have worked 20 years at 90 dB SPL. O = right ear. X = left ear. Dashed curves: plus and minus one standard deviation. ✚ = Expected audiogram from ISO 1999.

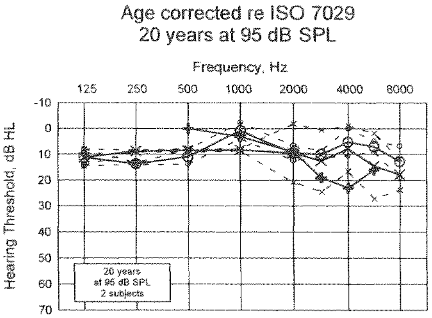

Figure 6. Average audiogram for two musicians who have worked 20 years at 95 dB SPL. O = right ear. X = left ear. Dashed curves: plus and minus one standard deviation. ✚ = Expected audiogram from ISO 1999.

5. CONCLUSION

Based on the measured audiograms it may be concluded that musicians can not expect to achieve pronounced hearing losses from playing in an symphony orchestra. It should be noted though that the data material in this investigation is limited and that the subjects have not been selected in a systematical or representative way. From the present investigation it may also be indirectly concluded that the audiogram is not the right tool for early hearing loss detection.

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The effects of age and noise on hearing thresholds at 4kHz in the better ear – a comparison of the log-normal model with the normal model

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1. Introduction

Lutman and Davis (1996) [1] have reviewed some of the major problems in assessing the effects of noise immission on hearing threshold levels through the literature. Three of the major problems that exist are (1) the lack of large random samples to establish pertinent baselines (2) the absence of good details concerning noise immission *per se* and (3) lack of agreement on how to incorporate age and noise immission in any model of hearing threshold levels. In much of our work we have modeled the effects of demographic variables and noise (as well as other biographical and medical factors) in two ways (i) using an appropriate General Linear Model (GLM) ie a log link and binomial error distribution to model prevalence [2], (ii) using a GLM with normal errors and proceed as normal, but making appropriate hand-waving to analyses that use a variance-stabilising transformation (eg log), that show no difference in statistical interpretation of parameters [1]. This approach, whilst it is the best we can currently use for routine analysis of data from the National Study of Hearing [2] does violate some basic statistical assumptions. A natural candidate for appropriately modeling the distribution of hearing impairment has been the lognormal distribution. This distribution has three parameters the first of which is a location parameter (α) that is subtracted from the hearing threshold (y) such that log $(y-\alpha)$ has a normal distribution with mean μ and variance σ. Lutman and Davis [1] have used this distribution to model the effects of age and noise on the hearing thresholds assuming a constant variance and location parameter, and found that it gave similar results in terms of the significance of the noise parameters as the normal additive model. They presented only the results of the normal model to aid simplicity of interpretation of the model.

Using traditional GLMs a major shortcoming is that it has not been possible to model the concomitant change in underlying variance that may be present in hearing threshold data. Furthermore assuming a constant α for each frequency is not always appropriate as this is related to the skew of the distribution which changes considerably from 250 Hz to 6kHz, for example. Utilising all three parameters of the lognormal distribution should give the most powerful statistical to model of the effect of noise and age on hearing thresholds. Bowater et al (1996) [3] showed that this was possible using a two stage GLM that was fitted to the mean and variance iteratively. Two of the problems with this analysis are: first, the sparseness of the data for those with noise immissions which exceed 80 dBA Leq 40 for a 50 year lifetime equivalent exposure in women and non-manual workers and second the model does not cope with the possible asymptotic nature of damage to hearing function from noise [4,5]. These two problems make the results on the effect of noise immission difficult to interpret. The analysis presented here attempts to overcome these problems by using a sub-set of the data which are reasonably well conditioned for noise immission and age.

2 Methods

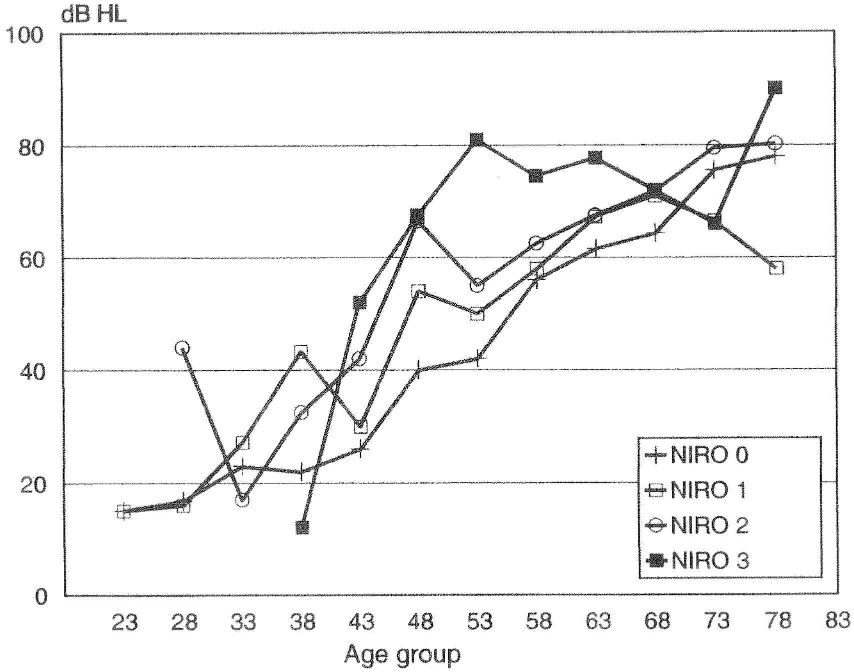
The data from the UK National Study of Hearing were analysed with hearing thresholds and noise immission being measured as previously reported (Davis, 1995; Lutman and Davis, 1996) [6,1]. In this analysis the sub-set of people who were male and whose main occupation was classified as belonging to SEG IIIM, IV and V (manual occupational group) were included. We present only the analysis of data for 4kHz hearing thresholds in the better ear where the air-bone gap is 10dB or less. Noise immission ratings for occupations (NIRO) was retrospectively estimated and coded as 0, 1, 2 and 3+ for NILs of <97, 97-106, 107-116 and 117+ dBA, respectively.

The main statistical analyses fitting the lognormal model were carried out in GLIM using an adapted version of the method reported in Bowater et al (1996) [2]. The location factor α was originally estimated by fitting a quadratic function to the log-likelihood function obtained by stepping over a range of likely values. The model was adapted to use factors and interactions between factors for both the variance and mean estimations. Only two factors, age group and NIRO were fitted.

3 Results

Figure 1 shows the upper quartile of the distribution of the 4kHz threshold in the better ear as a function of age for the four NIRO groups. The age range is divided up into five year age bands with the centre age for each band shown. Previous modeling has used a linear function of age to model the data, but the results shown here show that the separation is most uniform around the age groups 40 to 70 years. Below 40 years there are few data for NIRO 2 and 3 and the rate of change with age is low, and above 70 there is some convergence of hearing thresholds ie there seems to be an asymptote and again the the rate of change with age is low. This is reasonable because noise and age damage are probably self-limiting. Once noise or age has impaired the function of a hair cell it can't do it again.

Figure 1. The upper quartile of the 4kHz hearing thresholds in the better ear as a function of age group and NIRO for a sample of 653 male manual workers with air-bone gaps of 10 dB or less.



This introduces yet another complication into the statistical modeling of the effect of age and NIRO on hearing thresholds, because they all assume a common underlying model over age, independent of the degree of hearing impairment. However these data suggest varying rates of change dependent on age and NIRO. We decided to model the central portion of the data between 40 and 69 years of age where there appears to be a more stable change (and more numbers of subjects) as a function of age in five year bands and of NIRO at four levels. Table 1 gives the parameter estimates for the two models of the data. The log normal model accounts for 30.0% of the variance in the 4kHz better ear thresholds, with NIRO accounting for 4.8% after age has been fitted. The normal model accounts for 29.2% of the variance, with NIRO accounting for 4.8% as well. Both age and

NIRO were fitted as factors so that any pattern over these variables could be observed. For the lognormal model the second level of age was only marginally different to the first level, whereas for the normal model there was a highly significant 9 dB effect. The lognormal model shows a significant effect of NIRO 1 (p=0.01), with the normal model showing a 4.3 dB effect (p=0.04). All other effects on the mean are highly significant. The lognormal model shows a dependence of the variance on age, which is accounted for in the model of the mean component. The resulting fits for the male non-manual population enable the percentiles of the distribution to be derived.

Table 1. Parameter estimates for two statistical models of hearing thresholds at 4kHz in the better hearing ear, for 403 random male manual workers aged 40-69, with air-bone gaps of 10 dB or less. The first model is the lognormal model, with separate estimation of the location, mean and variance parameter sets. The second model is an additive model assuming a normal distribution and constant variance over age and noise immission.

		Log normal model		Normal model	
	Parameter	Estimate	se	Estimate	se
Location	α	-21.460	-	-	-
Model of mean component	Grand mean	3.677	0.049	16.82	2.338
	Age 45-49	0.108	0.065	9.45	3.349
	Age 50-54	0.236	0.060	11.71	3.128
	Age 55-59	0.395	0.059	21.46	3.123
	Age 60-64	0.476	0.060	26.51	3.334
	Age 65-69	0.545	0.060	29.52	3.133
	NIRO 1	0.089	0.040	4.30	2.285
	NIRO 2	0.152	0.044	41	2.587
	NIRO 3	0.291	0.064	19.12	3.996
Model of variance component	Grand mean	-2.590	0.141		
	Age 45-49	0.885	0.200		
	Age 50-54	0.317	0.183		
	Age 55-59	0.327	0.180		
	Age 60-64	0.319	0.183		
	Age 65-69	-0.056	0.183		

The upper quartile predictions and data are shown in Table 2. When these are inspected it is clear that as age increases the model predicts an increase in the effect of NIRO eg the effect of NIRO 2 increases from about 3 dB at age 40-44 to 13.4 dB at age 65-69. In general the effect of NIRO increases twofold over the age range of this analysis. These data suggest that there is a positive interaction between age and noise, which is inherently greater in terms of dB, for higher percentiles.

Table 2. Modeled upper quartile predictions for 4kHz better ear thresholds for each age group and NIRO group for the log normal model together with the data estimates

	Upper quartile predicted from log normal model				Upper quartile data			
Age group	NIRO 0	NIRO 1	NIRO 2	NIRO 3	NIRO 0	NIRO 1	NIRO 2	NIRO 3
40-44	26.1	30.5	33.9	42.2	26	29	26	16
45-49	33	42.8	46.9	51	40	40	68	30
50-54	40.7	46.5	50.9	61.7	36	40	50	81
55-59	51.5	58.3	63.5	76.1	55	61	55	65
60-64	56	64.9	70.5	84.3	59	58	79	86
65-69	60.2	68	73.6	88	59	61	62	73

4 Discussion

The criteria for which model is to be preferred over another are not straightforward. On the one hand the distribution of the residual is a criterion that we can use, and based on that the lognormal model is slightly better [3]. In terms of variance accounted for, the lognormal model is slightly better. There are more parameters for the lognormal model. We have also modeled the underlying variance and adjusted the mean model iteratively to take this into account. Age was found to be a significant factor, with a greater variance at age 45-65 than at the two extreme groups. The lognormal model has greater flexibility in modeling the data, but on the other hand it is a more difficult procedure to use, and its implications are not as easy to see. The frequency modeled here (4kHz) is central to the understanding of the joint impact of age and noise. Its distribution is less skewed than thresholds at other frequencies and hence the advantage of using a lognormal model are less than with lower frequencies.

The lognormal approach does enable proper comparison of the upper percentiles of the distributions of hearing thresholds over age and noise. However, as we can see from Figure 1 and Table 2, there is considerable see-sawing of the data over age for the upper quartile for the NIRO 1, 2 and 3 levels of noise immission. It would be a considerable advantage if the lognormal model could be fitted to a larger dataset.

In conclusion, there are several advantages of the lognormal model in describing the 4 kHz hearing threshold over the normal additive model [1]. For data at or below the median, there are few benefits, but for percentiles above the median the model yields predictions concerning the effect of NIRO that suggest (i) that the effect is not constant over age but increases, almost doubling over 25 years and (ii) that there is a systematic effect of NIRO 1 that varies from 4.4 to 6 dB depending on age. We hope to extend this type of analysis to other frequencies within this dataset and to different datasets in due course. However, this does not tackle the more difficult problem of modeling the effects at the extremes of age ie 18-40 and over 70 years of age. Taken together with our analyses of the progression of hearing impairment over time these analyses suggest that a purely additive model of noise and age, whilst probably appropriate for median values is not adequate at extremes of age or susceptibility.

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COMPARISON OF OTOACOUSTIC EMISSIONS AND PURE-TONE AUDIOMETRY MEASUREMENTS FOR MONITORING HEARING LOSS IN NOISE-EXPOSED WORKERS

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1. ABSTRACT

The aim of the study was to assess the sensitivity of otoacoustic emissions in monitoring early changes in the cochlea due to prolonged exposure to industrial noise in the workplace. The study group included 23 metal-factory workers, ages 19 to 32 years, exposed to industrial noise at an intensity of 85-97 dB(A). Two sessions of hearing evaluation were performed in the period of one year. The following hearing tests were included: pure-tone audiometry, transient-evoked otoacoustic emission (TEOAE) and distortion product otoacoustic emission (DPOAE). In the exposed-to-noise group of persons, pure-tone audiometry did not reveal significant changes in mean hearing threshold, while statistically significant decrease in otoacoustic emissions were observed in both TEOAE and DPOAE. In the control sex- and age-matched group changes were not observed either in the pure-tone audiometry or in otoacoustic emissions. We conclude that otoacoustic emissions measurement would appear to be a more sensitive method of monitoring the effects of prolonged exposure to industrial noise comparing to pure-tone audiometry.

2. OBJECTIVE

Otoacoustic emissions offer objective information about preneural mechanical elements of the cochlea which are very vulnerable to noise-induced trauma. It has been shown that in soldiers exposed to noise during military service otoacoustic emissions were more sensitive in assessing the early changes to the cochlea caused by noise than conventional pure-tone audiometry [1, 2].

The aim of the study was to assess the sensitivity of otoacoustic emissions in monitoring early changes in the cochlea due to prolonged exposure to industrial noise in the workplace.

3. DESIGN OF THE STUDY

The study group included 23 metal factory workers, ages 19 to 32 years (mean 26.9 +/- 4.3), with the length of employment from 2 months to 2 years. They were exposed to the industrial broad-band, steady state noise at an intensity ranging from 85 to 97 dB (A), depending on the location in the factory. They had no history of ear disease and had type A tympanogram. Bilateral pure-tone thresholds were below 40 dB HL, at the octave levels ranging from 250 through 8000 Hz. The control group consisted of 14 age-matched men, ages 23 to 35 years (mean 28.6 +/- 3.7), otologically healthy, with audiometric thresholds no higher than 20 dB HL at any frequency tested, and not exposed to noise at workplace.

Two sessions of hearing evaluation were performed on all subjects in the period of one year. The following hearing tests were included: pure-tone audiometry, transient-evoked otoacoustic emissions (TEOAE) and distortion-product otoaocustic emissions (DPOAE). Audiometric thresholds were measured in 1 dB steps using Clinical Audiometer OB 822 (Madsen). TEOAE and DPOAE were recorded and analysed using ILO 92 Otodynamics Analyzer hardware and software (Otodynamics, Ltd).

4. RESULTS

Pure-tone audiometry

Pure tone audiometry did not reveal significant changes in mean hearing thresholds either in the exposed-to-noise group or in the control group at any frequency tested (figures 1 and 2).

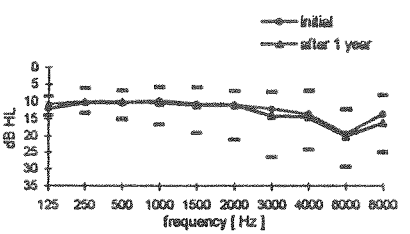

Figure 1.Pure-tone audiometry in the exposed-to-noise group in the period of 1 year.

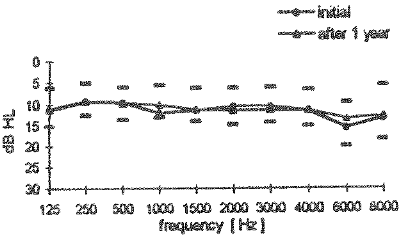

Figure 2.Pure-tone audiometry in the control group in the period of 1 year.

TEOAE

During one year of observation in the exposed-to-noise group, mean echo levels decreased from 8.94 to 7.42 dB SPL ($p<0.05$, paired samples t-test) (figure 3). A small decrease in echo level was also observed in the control group, but the changes were not statistically significant (figure 4).

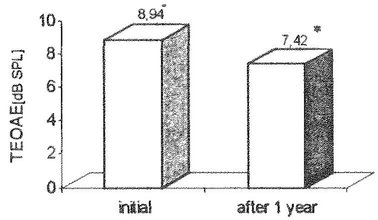

Figure 3.TEOAE echo level in the exposed-to-noise group in the period of 1 year.
* $p<0.05$

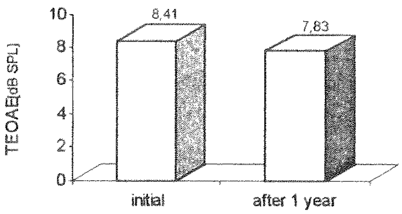

Figure 4.TEOAE echo level in the control group in the period of 1 year.

DPOAE

By measuring DPOAE a decrease in amplitudes was observed only in the exposed-to-noise group. Significant changes during the year of observation were seen at frequencies 2 kHz, 5 kHz ($p<0.01$) and 4 kHz ($p<0.05$) (figure 5), while the level of DPOAE remained stable in the control group (figure 6).

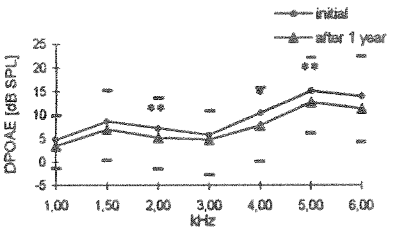

Figure 5.DPOAE levels in the exposed-to-noise group in the period of 1 year.
* p<0.05
** p<0.01

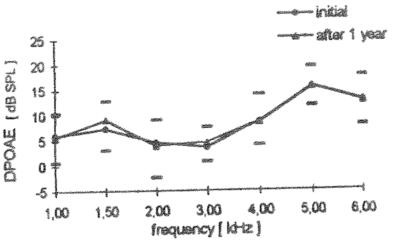

Figure 6.DPOAE levels in the control group in the period of 1 year

5. CONCLUSION

Otoacoustic emissions measurement would appear to be a more sensitive method of monitoring the effects of prolonged exposure to industrial noise in comparing to pure-tone audiometry.

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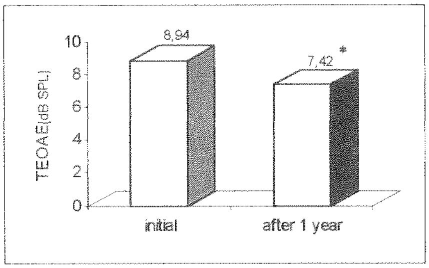
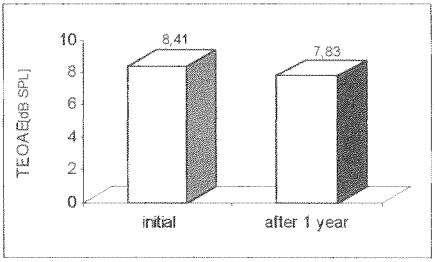
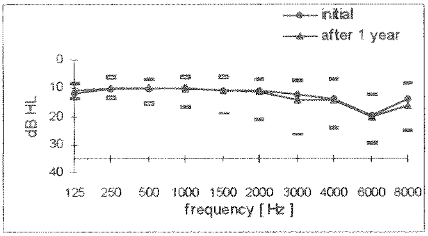
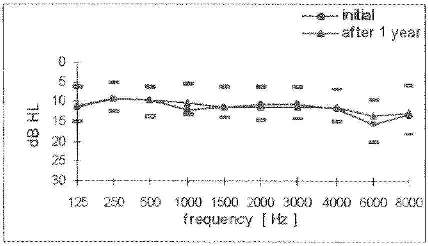
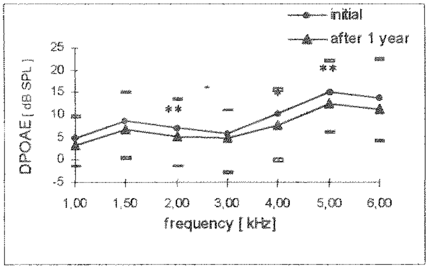
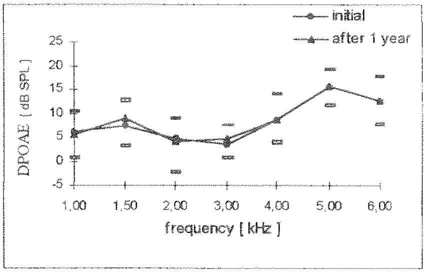

TEOAE[dB SPL]
10
8
6
4
2
0
8,94
7,42
*
initial
after 1 year


TEOAE[dB SPL]
10
8
6
4
2
0
8,41
7,83
initial
after 1 year


initial
after 1 year
dB HL
0
10
20
30
40
125
250
500
1000
1500
2000
3000
4000
6000
8000
frequency [Hz]


initial
after 1 year
dB HL
0
5
10
15
20
25
30
125
250
500
1000
1500
2000
3000
4000
6000
8000
frequency [Hz]


initial
after 1 year
DPOAE [dB SPL]
25
20
15
10
5
0
-5
**
*
*
**
1,00
1,50
2,00
3,00
4,00
5,00
6,00
frequency [kHz]


initial
after 1 year
DPOAE [dB SPL]
25
20
15
10
5
0
-5
1,00
1,50
2,00
3,00
4,00
5,00
6,00
frequency [kHz]

A LONGITUDINAL STUDY OF COCHLEAR DAMAGE AND HEARING IN AN ORCHESTRA, TESTED WITH CLICK-EVOKED OTOACOUSTIC EMISSIONS AND PURE TONE AUDIOMETRY

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Introduction

For fifty years prevention of hearing loss in industry has occupied a great deal of attention. Only more recently has there been a realisation that playing music, and classical music at that, can also be a noisy occupation. Studies have involved pure tone audiometric testing of members of orchestras playing in concert halls and/or the pit of a theatre(1-6). However, based on a study where we have shown that, on a population basis there is a long period of decline in the strength of otoacoustic emissions before any hearing loss is evident, our hypothesis is that otoacoustic emissions may provide a better early warning measure of hearing loss *in individuals* than pure tone audiometry(7). The Australian Opera and Ballet Orchestra who play in the pit of the Sydney Opera House has provided an opportunity to investigate this.

Subjects and Method

Each year for five years members of the Orchestra have been tested with both pure tone audiometry and click-evoked otoacoustic emissions. A detailed quesionnaire was administered each year regarding their current and past aural health, other factors associated with hearing loss such as heredity and tinnitus, length of time they had been a musician, total hours of active music exposure per week and recreational noise exposure such as power tools and listening to personal stereo headsets. Out of a total of 119 players tested, 74 have been tested on more than one occasion. Ages ranged between 19 and 61 years. Their mean *total* music exposure time was 37.4 hours per week.

Sound level measurements currently taken into consideration were carried out by the WorkCover Authority of NSW using integrating sound level meters in 6 different locations in the pit during both rehearsals and performances of all operas and ballets over one season.

Pure tone audiometry was also carried out by two operators from WorkCover, the same two for each of the five years, using calibrated screening audiometers. Frequencies tested were from 0.5 to 6 kHz. For this comparison we have chosen 6 kHz as the most sensitive frequency associated with a noise induced heaing loss(8). "Normal" hearing levels were taken as being less than or equal to 25 dBHL and a significant change from baseline of greater than or equal to 15 dB at 6kHz⁽⁹⁾.

Click-evoked otoacoustic emission testing was carried out by the first two authors on all occasions, using the Otodynamics ILO88 Analyser. For each ear, 260 repetitions of each record were averaged at a constant "nonlinear" stimulus level of 80 dBSPL. Results for this study have been established using the empirically derived parameter Coherent Emission Strength (CES dB SPL), defined as the measure of the rms sound pressure of the emission scaled by to the record WAVEREPRO% squared so as to separate highly coherent records from highly noisy records and which we take as an estimate of the net emission strength. By analogy with pure tone audiometry we have determined that, on average, subjects with a greater CES than -3.5 dB should have normal hearing. In other study we have determined that day to day test-retest variability for CES is ≥4 dB⁽¹⁰⁾.

RESULTS

Figure 1 shows the sound levels at the various microphone positions relative to player positions recorded during performances over one season of all operas and ballets[11]. The largest circles represent the maximum levels. The levels immediately in front of the brass are, therefore about 90 dBA average with a maximum level of 95 dBA while at the conductor the level is 85 dBA. Overall, the average weekly exposure level for all orchestra members except the conductor is in the 85-90 dBA range.

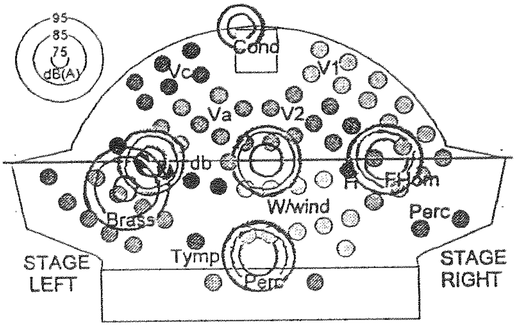

Fig. 1.Sound levels at six microphone positions relative to player positions.

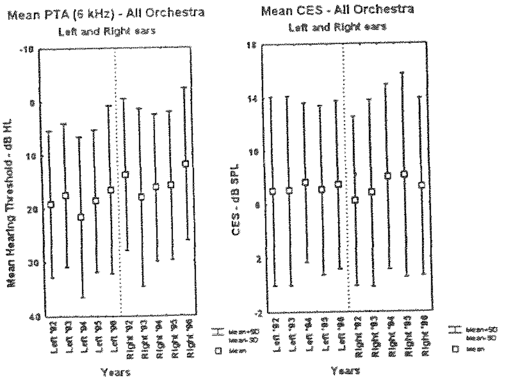

Fig. 2. Mean ±1 SD PTA and CES for each year for all the Orchestra.

It would appear from Figure 2 that the sound levels have not had a marked effect on either the pure tone thresholds or the ototacoustic emission results for the Orchestra as a whole. When ALL ears are taken together both the hearing thresholds and the CES values remain within normal limits for the five years. This is similar to results for the parameter WAVEREPRO% reported previously⁽¹²⁾. Results of an ANOVA disclose that although remaining within normal limits CES results for the left ear in 1994 and the right ear in 1995 vary significantly from the remainder (p=0.02 an p=0.04 respectively).

Concern for establishing the effect of the sound levels on individual musicians led us to identify those players (a) whose CES values and PTA had both declined significantly from their baseline (2 left ears and 1 right ear); (b) whose CES values had declined significantly while their pure tone audiometric thresholds had remained within normal limits (13 musicians - 6 left and 7 right ears), and (c) whose PTA thresholds declined significantly while CES values remained stable (6 musicians - 4 left and 2 right ears)

The question now arises as to whether decline in hearing capability is due to the instrument these musicians play, or possibly the desk at which they are seated in the orchestra. Figure 3 shows the CES results for each of the desks occupied, grouped according to instrumental sections, with those in each of the above categories a, b or c marked appropriately. Table 1 is a summary of the instruments played by those in each of those categories (a), (b) and (c).

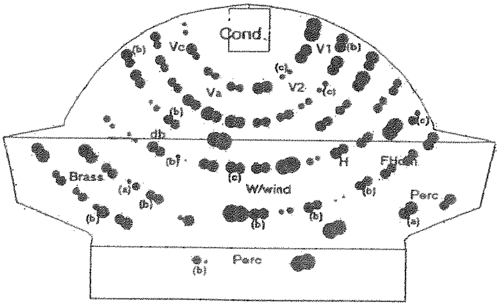

Fig. 3. Mean CES for each desk occupied (Dark circles - left ears; light circles - right ears). Instrumental sections and changes as for Table 1 shown.

Table 1. Significant changes in CES values or PTA thresholds ≥test/retest values.

(a) CES down;PTA down	(b) CES down; PTA stable	(c) CES stable; PTA down
2 Percussion (1 Left, 1 Right ear) 1 Trumpet (Left ear)	1 1st Violin (Right ear) 2 2nd Violins (Right ears) 1 'Cello (Right ear) 2 Double Bass (2 Left, 1 Right ear) 1 Trumpet (Left ear) 1 Trombone (Left ear) 1 French Horn (Right ear) 1 Oboe (Left ear) 1 Clarinet (Left ear) 1 Tympani (Right ear)	1 1st Violin (Left ear) 1 2nd Violin (Left & Right ears) 1 Oboe (Left & Right ears) 1 Trumpet (Left ear

DISCUSSION AND CONCLUSIONS

In our study sound levels and weekly durations of music exposure were similar to those found by Axelsson & Lindgren (1979)[1] and because these exceed recognized damage risk criteria, the musicians in the AOBO could be considered to be at risk of sensorineural hearing loss by music. Indeed such has been the concern over sound levels that measures have been taken to extend the pit and to isolate the brass section to the front left of the orchestra.

From Figure 2 it can be seen that although there is a lot of scatter in the data, with large standard deviations, results for CES and PTA mostly fall within the normal range. This is consistent with our previous findings[7] based on a normal *population*. The individual musicians we would be most concerned about are those who appear in Table 1 (b) or (c) whose CES or PTA thresholds have declined significantly over the time they have been tested. Within the timeframe of this study we have 12 musicians whose emissions have declined significantly with no associated change in pure tone thresholds. There are also 4 musicians whose pure tone thresholds have declined significantly with no associated change in CES values. These musicians, it is believed, would benefit most from early warning advice. They are aged between 21 and 42 (mean age 27.19 years), play a variety of instruments and play at desks scattered throughout the orchestra (Figure 3). Twelve left ears and ten rights ears have been affected. There appears to be no common factor between them except that they were all exposed to similar sound levels during the same operas and ballets in the same orchestra pit. Indices of ear function do not depend strongly on which instrument is played or for how many years. Instrumentalists from all sections of the orchestra have been found who display a decline in hearing capabilities over time, as well as those who remain stable. There are also those entering the study with high CES values who have not displayed any changes over time; the results of these musicians will be investigated to see if, in fact, these are the people who are less susceptible to the effects of noise.

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"MUSIC LEVELS IN THE ENTERTAINMENT INDUSTRY, REVELATIONS OF AN ONGOING STUDY"

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1. INTRODUCTION

In 1996 the Division of Workplace Health and Safety received complaints against nightclubs and bars about music noise levels from some patrons and security guards. The complaints from the security guards were about the noise exposure levels and the positions they were required to perform their work in. They reported that their duties often required them to stand directly in front of the stage and so the speaker stacks. These complaints turned out to relate not just to bars or nightclubs but also to venues such as concert halls and stadiums.

Resulting from these complaints the Division of Workplace Health and Safety conducted an audit program into the noise levels present in 30 music entertainment venues in the Brisbane Central Region. The music ranged across the entire spectrum and included classical, techno, rock and western.

The 1996 survey found in all but two venues noise levels in excess of the limits imposed by legislation. Some operators said to conduct their own sound level measurements and, were within the legal limit. Those limits however, referred to Liquor Licensing or Environmental Legislation. At that stage several operators had no knowledge of their Workplace Health and Safety obligations. Because of this, and the fact that all operators were visited for the first time by Divisional inspectors, extensive information was provided to the operators about their obligations under the Act and how to achieve compliance.

Between March and July 1998 fifteen of the original nightclubs and hotels of the 1996 survey were revisited and noise surveys conducted. Shortly after the surveys these venues were audited to gauge information on the measures taken by the venues to comply with the legislation for noise exposure since the 1996 surveys as well as any other health and safety measures implemented. It was found that knowledge about health and safety obligations had increased in most venues with several having instigated noise controls noise management programs. However, there was no significant difference between the 1996 and 1998 noise exposure levels inside the venues.

2. BACKGROUND

A person frequenting a nightclub with loud music would generally not feel pain but notice a 'temporary threshold shift' in hearing. As exposure is regularly continued the temporary shift becomes gradually more permanent and eventually reaches a stage where the person would suffer from noticeable noise induced hearing loss. Many people identify loud music with "having a good time", and so the affected person would be unlikely to complain or stay away from the venue. The venue may therefore not necessarily receive complaints. The music entertainment industry is made up of a very transient, and predominantly young, work force and patronage. Dible (1989) suggests that the average tenure of a nightclub employee is 11 months. Venue operators therefore, do not normally see the long term effects of exposure to their music.

Research into the effects of "leisure" noise on teenage hearing revealed that "leisure" noise contributes significantly to hearing loss (Struwe, et al 1995). Many Australian teenagers are being shown to suffer from hearing impairment equivalent to that of people in their mid-forties (Cribb 1996). This is consistent with findings from Europe, where France has found in a survey of 2268 secondary school students sponsored by the Rhone-Alpes regional government, that 1 in 5 young people are experiencing hearing loss compared to 1 in 10 a decade ago (Noise and Vibration 1996; Patel 1996).

Personal stereos, live concerts, discos and sports are all included in the definition of "leisure noise". Live concerts include rock concerts and symphony orchestras. While the effects of orchestral music on hearing loss is still being debated, though generally accepted as such (Palin 1994; Chasin and Chong 1992; Casey 1996), rock or modern music has no such contest. Live rock music in particular, has been established as a contributing factor (Palin 1994). Disco music and personal stereos are also included because of the damage that can be caused to hearing by loud music from speakers (Nichols 1996).

Around 25000 young people every year in Holland have suffered hearing damage due to music emanating from loud speakers (Nichols 1996). The people affected by this hearing loss are not just youth who wear walkmans or the patrons of establishments like nightclubs, but are also the staff. In the United Kingdom a survey by the Chartered Institute of Environmental Health (CIEH) found that bar staff in discotheques were typically exposed to between 82 and 102 dB(A) and that their average shift was 6 hours. The CIEH also found that the music was generally made the venues on four nights per week. At 100 decibels 15 minutes exposure is enough to exceed the allowable Queensland exposure limit for an 8 eight hour day and cause hearing damage.

Moves have been made in France to address the issue of irrepairable hearing damage in young people. A Law was passed in March 1996 to limit the level of output of walkmans which can legally be sold (Patel 1996). Also, a proposal to require sound measuring devices to be installed in all venues in France has been tabled before the French National Assembly.

In Queensland the Workplace Health and Safety Regulation 1997 in Part 10 Noise, states in Section 68 two limits which legally cannot be exceeded. The first limit is averaged over an eight hour period to an $L_{Aeq,8h}$ of 85 dB(A). The second states a peak limit of 140 dB(Lin) which must never be exceeded.

3. METHODOLOGY

During the 1996 surveys 30 venues were monitored for compliance with the then Workplace Health and safety (Noise) Compliance Standard 1995. These venues consisted of pre-recorded performances (17), of which three had complaints against them, kareoke (1), and live performances (7), All were located in the central Brisbane area. Four rock concerts and one symphony orchestra where selected as they were in town during the investigation. Each venue was contacted prior to conducting the noise level surveys. Contacts included advice on the legislative requirements under the Workplace health and Safety Act 1995, as it was found that this was poorly understood by the operators. None incorporated hearing protection, or other controls, for workers.

Noise levels were measured with sound level meters and noise dose meters at worker and patron positions in accordance with the requirements of Australian Standards 1269-1989 "Acoustics - Hearing Conservation". Measurements used the A-weighting filter network to obtain $L_{Aeq,T}$ levels, and linear to obtain peak sound pressure levels. The noise dose meters measured these parameters simultaneously. Results were downloaded on a PC and provided printouts of the recorded exposure levels and a complete histogram of each measurement showing L_{Aeq}, L_{Amax} and Peak (Lin). Where noise levels were found to be excessive, Improvement Notices were issued to the venue owners. The venue was then reassessed at the expiry date of the notice for compliance and further follow up in the case of non compliance.

For the 1998 surveys venues that had closed down, renamed, or changed ownership were excluded on the basis that the owner would not have received the information from inspectors in 1996. Fifteen of the original nightclubs and hotels remained and were revisited. Similar noise surveys as in 1996 were conducted for compliance with noise exposure limits. Of these venues, 4 were of live bands at nightclubs or hotels, 6 were pre-recorded music by a DJ at a nightclub, and 5 were a mix of both live and pre-recorded music. This time the venues were not warned beforehand. Inspectors announced themselves on arrival to the owner or duty manager and explained the purpose of their visit.

Knowledge assessment concentrated on the owners as they had received information during the 1996 surveys and the difficulty experienced in talking to workers due to their short tenure and high mobility, which made it difficult or impossible to locate them.

4. FINDINGS

Of the venues monitored during the 1996 surveys Live concerts produced the highest noise levels with a reading of $L_{Aeq.8h}$ of 105.7 dB(A). The next highest level was for live performance, $L_{Aeq.8h}$ of 96.5 dB(A) followed by the pre recorded music at $L_{Aeq.8h}$ of 95.0 dB(A). Peak levels for glassies and bar attendants exceeded the limit of 140 dB by up to 3.6 dB. At no time did any venue operate sufficiently short to allow exposure of unprotected ears or incorporated any form of hearing protection for workers. Therefore all these venues breached the Workplace Health and Safety (Noise) Compliance Standard 1995. Knowledge of Workplace Health and safety obligations with respect to noise was generally non- existent or limited and often confused with liquor licensing or environmental legislation requirements.

During the 1998 surveys Live concerts were not included. The highest level for live performance, $L_{Aeq.8h}$ of 98.0 dB(A) followed by the pre recorded music at $L_{Aeq.8h}$ of 96.8 dB(A). Peak levels exceeded the exposure limit by up to 5.4dB for glassies and this was attributed to emptying glass in bins. The results of the 1998 surveys show that the operators' knowledge of their obligation to prevent exposure of workers to excessive noise had increased. However, employers still considered hearing protectors the principal method of noise control. Seven employers formalised their mandatory use in employment contracts. Four employers implemented a comprehensive hearing conservation program including sound limiters, monitoring and proper training and enforcement. Three venues incorporated maximum sound levels in contracts with live bands Compared to the 1996 survey findings these are vast improvements

5. CONCLUSION

It appears that both studies have lifted the profile of health and safety in Brisbane inner city nightclubs and hotels (Thomson 1998). This is especially true for the prevention of exposure to excessive noise.

Disclaimer

The views expressed in this paper are those of the authors and not necessarily those of the Division of Workplace Health and Safety.

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LONG-TERM EFFECTS OF MILITARY JET NOISE EXPOSURE DURING CHILDHOOD ON HEARING THRESHOLD LEVELS

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1. INTRODUCTION.

It has been suggested [1, 2] that young children may be relatively more susceptible to noise-induced hearing loss than adults, and that the unique noise footprint associated with military jet aircraft is particularly damaging to hearing.

To examine these hypotheses, this study looked for evidence of noise-induced hearing loss in adults who have been exposed to military jet noise in early childhood. The exposed population consisted of young adults who, by virtue of their parents' Royal Air Force career, lived on married quarters in and around fast jet bases during childhood - most would have lived within 70 dB(A) Laeq contours, some within 83dB(A) contours.

The scientific literature [3, 4] records that children are likely to exhibit some degree of sensory-neural hearing loss at low frequencies, and that exposure to civil airport noise is not associated with the 4 kHz dip of noise-induced hearing loss. With this in mind a cross-sectional pilot study was undertaken to look specifically at noise from military jet aircraft.

2. METHOD.

Participants were 153 RAF non-commissioned air and ground crew aged between 16 and 25 years, with less than 12 month's service, posted to general service or specialist training wings. Forty-eight were the children of RAF personnel and had lived in married quarters on stations where fast jet squadrons were based. The remaining 105 participants acted as non-exposed controls. All but two participants held the entry rank of Aircraftman/woman (AC / ACW) at the time of survey. A further 8 jet noise exposed and 18 non-exposed participants were identified, but did not complete the full procedure, or had significant civil jet noise exposure.

Random sampling was not practicable due to the frequent movement of personnel between bases. Non-exposed participants came from targeted training squadrons. Recruit intakes between April and June 1997 were canvassed for jet noise exposed individuals.

On enlistment into the RAF, all non-commissioned entrants undertake general service training at No1 Recruit Training Squadron where a full air-conduction audiogram is recorded in the frequency range 0.5 - 8 kHz. Audiograms are recorded using a bank of ten Graystad Microlab 10 audiometers using TDH-39 type earphones, calibrated with an NBS type 9A coupler and operated by RAF medical officers.

Participants completed a questionnaire asking for details of their age on RAF entry, gender, education, parental occupation, places of residence before age 16 years, auditory health and any exposure to leisure or industrial noise. All participants gave written consent for the release of audiograms held on their medical files and were advised of their rights concerning this request, in accordance with the 1988 Access to Medical Records Act.

3. RESULTS.

Table (1) Group characteristics

Item	Exposed	Non-exposed
n	48	105
Gender	29% female	19% female
Mean age	20.1 (standard deviation 2.5) years	20.1 (standard deviation 2.0) years
Mean exposure to age 16	6.8 years	0 years
Mean exposure to age 5	2.5 years	0 years
Mean exposure at school	3.0 years	0 years
History of ear disease	10.4%	3.8%
Pre-RAF exposure to industrial noise	6.3%	15.2%
Frequent disco attendance	85.4%	84.8%
Hobby shooting	14.6%	18.1%
Motor sport	8.3%	10.5%
Orchestra	2.1%	7.6%

Table (2) records the characteristics of the exposed and non-exposed groups. No significant differences between groups were found (p>0.05), as measured by Chi-square tests.

The exposed group reported more ear disease up until the age of 16 than did the non-exposed group, though this difference was non-significant (10.4% versus 3.8%). Most reported only conductive disorders. One reported a loss of "60% of hearing in one ear and 40% in the other"; the audiogram revealed no hearing loss sufficient to bar RAF entry to any trade.

The non-exposed group were marginally more likely to have reported regular exposure to leisure or industrial noise, though this difference was non-significant.

Table (2) Mean left-right average hearing threshold levels (dB)

Frequency	All subjects		Male subjects		Female subjects	
kHz	Exposed	Control	Exposed	Control	Exposed	Control
0.5	10.2	12.3	9.8	12.4	11.1	11.9
1	4.3	5.9	4.2	6.0	4.6	5.5
2	3.4	4.3	2.7	4.5	5.0	3.6
3	4.6	4.8	5.0	4.9	3.6	4.0
4	4.4	4.8	4.6	4.7	3.8	4.9
6	10.4	11.6	10.4	11.5	10.5	11.8
8	7.3	9.0	7.0	8.8	8.1	10.0

Hearing levels for left and right ears were averaged (see Table 2). If a left or right reading only was available, this was substituted; if neither was available it was excluded from the analysis. When hearing thresholds were analysed for all participants only one significant difference ($p<0.01$ as measured by exact Chi-square tests using Monte-Carlo simulations on tabulated data) was detected between the two groups, at the 0.5 kHz frequency.

In order to eliminate the possibility of a confound due to gender, the analysis was repeated for males only, being more numerous than females. A significant difference ($p<0.01$) was detected between the two groups at the 0.5 kHz frequency; male exposed group averaged hearing threshold levels of 9.8 dB, male non-exposed 12.4 dB. As this pattern reflected the whole group pattern, gender difference does not explain this result, particularly as the male: female ratio across groups is not significantly different (exact Chi-square; $p>0.05$).

Correlation coefficients calculated using GENSTAT revealed no significant relationship between military jet noise exposure (as measured by the number of years each person spent living on or near flying stations up to the ages of 5 and 16 years, and the number of years spent in schools on or near stations) and raised hearing threshold levels at 4 kHz ($r = -0.02$, 0.03 and -0.04 respectively; $p>0.05$).

To examine whether a "survivor group" was examined in this study, Careers Information Office medical records (held for two years before destruction) from all applicants to the RAF rejected on grounds of hearing loss since 1 January 1995 were reviewed. Most applicants complete RAF Form 7193 "Application for Service in the Royal Air Force" which asks if any family members have served in HM Forces.

Table (3) Service connections: current RAF personnel and unsuccessful applicants

Service connection	Current RAF personnel		Unsuccessful applicants	
RAF / other service	40	(10.6%)	13	(10.8%)
No connection	336	(88.7%)	66	(55.0%)
Not known from available documents	3	(0.8%)	41	(34.2%)
TOTAL	379		120	

Percentages do not total 100 due to rounding. A further 4 rejected applicants were wrongly classified as hearing loss. Applicants marked "permanently medically unfit" do not complete RAF Form 7193; no record surveyed gives place of birth near an RAF station.

From Table (3) it is seen that the proportion of applicants with a Service connection of any kind is equivalent to that of the intakes to No 1 Recruit Training Squadron. This indicates that the main analysis in this study has not necessarily excluded a large body of RAF children who display significantly raised hearing threshold levels.

4. DISCUSSION.

There is no indication that childhood exposure to military jet noise is associated with raised hearing thresholds. The hypothesised noise-induced hearing loss in jet noise exposed children has not been demonstrated.

A consistent result seen in the audiogram data for both groups is the 6 kHz notch. There is evidence that this is a testing artefact rather than a true threshold shift [5]. This is supported by the high prevalence of a 6 kHz notch in audiometric data from young otologically normal people [6]. This may also explain the apparent low-frequency hearing loss displayed by both exposed and control groups [7]. The equipment used here to record audiogram data was of the sort associated with testing artifacts. It is therefore argued that raised thresholds at 0.5 and 6 kHz do not indicate noise-induced hearing loss.

A potential confound in the difference in hearing thresholds at 0.5 kHz between the exposed and non-exposed groups exists as no comparison of socio-economic status based on the main breadwinner of the household was possible.

Calculation of participants actual noise dose has not been attempted for fear of lending spurious accuracy to measures of noise exposure reported by participants. This may be seen as a potential shortcoming of this study; it remains that the exposed group has experienced military jet noise associated with activity around fast jet stations, in excess of that likely to have been experienced by non-exposed controls.

The RAF does not carry out air-conduction audiometry at frequencies higher than 8 kHz, for there is no clinical significance to audiometric thresholds in this range and considerable evidence of the spread of the "normal" range of high frequency thresholds. Therefore claims of hearing loss up to 16 kHz in the existing literature [2, 3] are unchallenged.

There is currently very little data on how much military or civil jet noise, or indeed leisure noise [8], that any population is likely to experience during childhood. There are problems in assessing noise exposure retrospectively, especially in early childhood which may not be accurately remembered. Any future work needs to consider these issues to be of further use in examining this contentious hypothesis.

5. CONCLUSIONS.

Firstly, this study has found no evidence that RAF personnel who have lived on fast jet stations in childhood display evidence of noise-induced hearing loss.

Secondly, there is no indication that applicants to the RAF who may have lived on active flying stations during childhood are less likely to be successful than non-exposed applicants.

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NEW NONLINEAR EARPLUGS FOR PROTECTION AGAINST IMPULSE NOISE

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1. INTRODUCTION

Because the impulse noises produced by weapons are frequently the cause of acoustic trauma [1], we start to improve the nonlinear characteristics of an earplug. This earplugs allow speech communication, detection and localization of the acoustic sources in about the same conditions as for unprotected ears [2]. We transformed the geometry of the nonlinear filter insert in the Racal Gunfender earplug and optimize its nonlinear behavior

2. IMPROVEMENT OF THE NONLINEARITY

The RACAL Gunfender earplug is made nonlinear by means of a metallic plate which is inserted inside the earplug perpendicular to its axis and perforated in its center by a hole. The acoustic resistance through the orifice increases with the peak level [3], [4]. An expression for orifice resistance (R_o) might, as a first approximation, be a linear combination of kinetic and viscous terms as follow : $R_0 = R_v + k\frac{\rho u}{2S}$, where R_v is a viscous resistance k a real constant, u the particle velocity in the orifice, ρ the air density and S the orifice area. This earplug has been proven to act as a nonlinear mechanism allowing the attenuation to increase with the stimulation level beyond 120 to 140 dB [5].

We decided to look for a new nonlinear earplug design with better performance and better ergonomics. Given the original RACAL Gunfender earplug, we modified the dimensions of the metallic plate (the nonlinear component) and measured the corresponding changes in Insertion Loss. Systematic variations in thickness of the plate, in diameter, shape and position of the hole, in the number of holes... led us to an optimized configuration. The best nonlinear characteristics were obtained with a plate of 0.10 mm in thickness and one hole of 0.30 mm in diameter. As it seemed impossible to get better performances with a single plate arrangement, we decided to

study the characteristics of small cylindrical cavities terminated by two perforated plates. Extensive measurements allowed to determine the influence of the dimensions of the cavity, the thickness of the plates, the diameter of the holes..., on the nonlinear performance. All measurements are performed with the help of the ISL ATF [6].
The "filter" which is represented in Figure 1 corresponds to the best dimension/performance compromise.

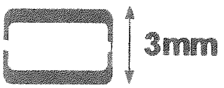
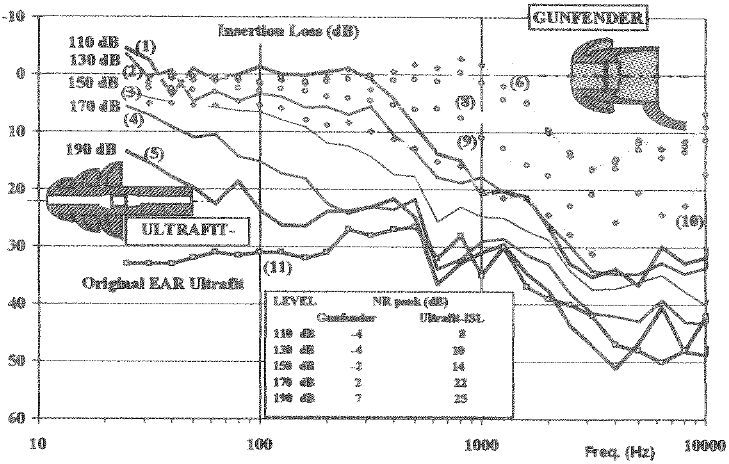


Figure (1) Schematic representation of the ISL "filter" (overall length: 3.7 mm, outside diameter: 3.0 mm, inside diameter: 2.0 mm). The thickness of the perforated plates is 0.10 mm and the diameter of the holes is 0.30 mm.

In its final version it is made by plastic injection moulding (in two parts). As it is necessary to get precise and reproducible dimensions of the plates and of the holes as well as sharp edges and even surfaces to ensure good and uniform performances, the factory limits must be very strict. Figure 2 presents the IL of the nonlinear ISL-EAR Ultrafit earplug as a function of frequency for impulses of 110, 130, 150, 170 and 190 dB peak (A-duration: 2 ms).



LEVEL	NR peak (dB) Gunfender	NR peak (dB) Ultrafit-ISL
110 dB	-4	8
130 dB	-4	10
150 dB	-2	14
170 dB	2	22
190 dB	7	25

Figure (2) Insertion Loss afforded by the ISL-EAR Ultrafit [(1) to (5)] and Racal Gunfender [(6) to (10)] earplugs for different levels (110 130 150 170 and 190 dB) of the impulses (1/3 oct. bands). Insertion Loss afforded by the original EAR Ultrafit earplug when measured with a pink noise at 120 dB [(11)]. All measurements are performed with the help of the ISL ATF [6].

We can note the increased nonlinear performances compared to the original RACAL Gunfender. The frequency range for which the nonlinearity is significant goes from 0.025 to 10 kHz. The nonlinearity begins at 110 dB and increases by about 0.4 dB/dB around 0.3 kHz. The NR peak increases by 17 dB from 110 to 190 dB.

3. CONCLUSION

The new nonlinear earplug design afford a protection adapted to occasional exposure to impulse noise such as those produced during training or combat. It allows speech communication, and detection and localization of acoustic sources in about the same conditions as an unprotected subject, thus avoiding problems of overprotection. The final design of these plugs will also allow to get a full attenuation even at moderate levels in the case of exposure to continuous noise (by manually plugging the sound passage between the two ends). These new earplugs, which represent a good compromise between the so far opposed requirements: hearing protection and operational capabilities, will be used by the French infantrymen in the near future

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Retrospective Study of Diver Hearing

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1. INTRODUCTION

Noise-induced occupational hearing loss reduces job performance and safety as well as significantly reducing quality of life. There have been a number of studies investigating the hearing status of divers [1,2,3,4,5,6,7]. They have regularly shown that divers frequently have a hearing loss, but several issues require that a study be done on current US Navy divers. First, the most recent study [4] of US Navy diving is based on data that are almost 20 years old and Navy diving has changed significantly during that period [8]. Second, evidence suggests that not all Navy personnel are at equal risk for noise-induced hearing loss [9,10,11]. Third, most of these studies were done before the advent of hearing conservation programs. Finally, these data are needed to provide a framework for determining damage risk criteria for divers. Field data are needed to provide a context for evaluating laboratory data and for doing risk/benefit analysis.

More recent studies of US Navy personnel show percentages of significant threshold shift (STS), as defined by Navy standards, exceeding 30% [9,10]. These findings suggest that there is still considerable hearing loss among both enlisted and officers; however, the studies did not report diver hearing loss separately. Furthermore, some studies have reported only hearing loss [10], whereas others have reported only significant threshold shift [9].

US Navy divers come from many specialties in the Navy and are exposed to noise in air as well as underwater. Thus, the pattern of hearing loss would seem to be the same as for non-diving personnel. However, there is a different frequency weighting for the hearing sensitivity function underwater compared to in air [12]. The potential exists that divers will have different patterns of hearing loss than for personnel with solely in-air exposure.

The aims of the present study were to measure the incidence of significant threshold shift for a representative sample of US Navy divers and report the audiograms for a representative sample of US Navy divers.

2. METHODS

Subjects

417 active duty male divers selected from 7 ratings: BM - 142; EM - 39; EN - 73; ET - 20; HT - 97; MM - 33; QM - 12.

Procedure

Each of the subject groups was selected using occupational rating and recruited through the Bureau of Personnel. Based on previous studies [10,11], ratings were chosen which had shown less hearing loss (EM, ET, and QM) and ratings were chosen which had shown more hearing loss (BM, EN, HT, and MM). Ratings having fewer than 10 divers were excluded from the study.

There is no centralized database for audiometric information in the Navy. Therefore, individual commands were solicited for permission to obtain initial/entry audiograms and the most current audiograms from the medical records. This required the cooperation and assistance of over 20 commands.

The data were recorded on record sheets prepared for this study. Data included entry date, primary and secondary specialties, initial and most recent ("current") audiograms, and date of test for each audiogram recorded. Each data sheet was checked by a second data entry person prior to leaving the command. The data sheets were reviewed a third time upon returning to home base and commands were contacted for any missing data. Data loss due to incorrect or missing data was estimated at approximately 1%.

Data were then entered into a database constructed for this study. Data were checked and confirmed against the data sheets. This review was repeated twice. Data entry error is estimated to be less than 1%.

The database computed difference audiograms for initial versus current audiograms, length of service, test interval, and presence or absence of a significant threshold shift. These data were then transferred to a spreadsheet for plotting.

3. RESULTS

The probability STS as a function of test interval in years and personnel specialty was examined. STS is defined by the US Navy to be a hearing threshold shift of 15 dB at any frequency between 1000 and 4000 Hz or an average hearing threshold shift of 10 dB at 1000, 2000, and 3000 Hz. The threshold shift is computed relative to a reference audiogram that is measured at entry into the service. Since some of the personnel (those with 25 years of service) entered the Navy prior to the advent of hearing conservation programs, the reference audiogram was taken from their entry physical.

The probability of STS increases from 0 for an interval of 1 year to almost 90% after 25 years. The overall percentage of STS for this sample of divers was 41%, which is slightly higher than the 33% reported for the US Navy in other work [1]. STS as a function of specialty showed the expected trends, with the EM, ET, and QM ratings having the least STS and the BM, EN, HT, and MM ratings having the most STS.

Review of the audiograms shows that the pattern of hearing loss across frequency as a function of test interval is very typical of that for noise-induced hearing loss in air, suggesting that the divers will show the same patterns of loss as occupational noise exposed workers in air. The group at the 25-year interval is showing a moderate high frequency hearing loss at the age of about 45, earlier than the normal aging process.

The relationship between percent STS and amount of hearing loss, collapsed across frequency, showed that STS increases with the amount of hearing loss and increases at a comparable rate although not to an equal magnitude, i.e., 90% STS does not equal 90 dB hearing loss.

4. DISCUSSION AND CONCLUSIONS

There is a slightly higher percentage of STS among the US Navy diving population than among the general US Navy population. There is significant hearing loss experienced by Navy divers over the course of a 25-year career. This conclusion must be tempered by the small sample size (8) at this test interval, but even at a 20-year interval, there is already significant high frequency hearing loss.

The pattern of hearing loss is very typical of that for noise-induced hearing loss in air. Percent STS and degree of hearing loss are highly correlated, although high percentages of STS do not indicate hearing losses of equal magnitude in dB. Research programs investigating the noise responsible for the hearing loss and improving hearing protection must be increased because Hearing Conservation programs alone appear insufficient to protect the hearing of US Navy diving personnel.

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6. ACKNOWLEDGMENTS

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RESULTS OF THE HEARING TESTS CONDUCTED IN THE VICINITY OF KADENA U.S. AIRFIELD.

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1. INTRODUCTION

The estimation of temporary threshold shift due to aircraft noise exposure recorded in the vicinity of Kadena US airfield suggests the possibility that the noise exposure could have caused the some of the inhabitans living around the base noise induced hearing loss.

2. MATERIAL AND METHOD

Hearing tests was conducted at three wards A, B and C, in two towns neighbouring the base. Wards A and C are in Sunabe, Chatan Town, ward B in Yara, Kadena Town. The noise exposures expressed in WECPNL are over 90 inclusive in the ward A, 90 to 95 in the ward B, and 85 to 90 in the ward C. The subjects were limited to the individuals aged from 40 to 69 years, the numbers of whom were 207 in the ward A, 475 in the ward B and 474 in the ward C. Hearing tests were conducted in the ward A in 1996, and in the wards B and C in 1997. Before the test, the subjects were asked about hearing difficulty, tinnitus, otological anamnesis, occupational and recreational noise exposure, head injury,ototoxic drugs, military service and so on. Tests were carried out by experienced and qualified medics in audiometric booths where the A-weighted SPL of the background noise was under 30dB. Hearing levels of the subjects were measured by means of the ascending method of limits with 5dB step at 7 test frequencies from 500 to 8000Hz. One hundred fifteen individuals attended the test at the ward A, 104 at the ward B and 59 at the ward C. Thirty six among them who showed significant hearing loss in the frequency range of 3 to 6kHz in the audiograms, were suspected to have noise induced hearing loss and sent to the Oto-rhino-laryngology section of Okinawa Chubu Hospital for the secondary examination. In the secondary examination the external and middle ears were first checked by visual inspection of eardrum and by tympanometry and then air-bone gap of hearing acuity was investigated in order to omit the subjects with conductive hearing loss. Thirdly, SISI test was conducted to detect recruitment phenomenon. Positive recruitment phenomenon suggests that the hearing loss is sensori-neural,not retrocochlear.

3. RESULTS AND DISCUSSION

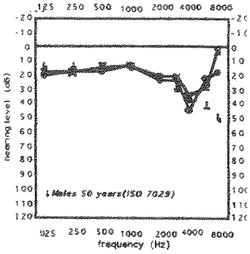
Eleven subjects were selected whose hearing loss is very likely noise induced hearing loss. The results of anamnesis and hearingtests of these 11 subjects are showed in table. They were 10 males and 1 female, from 44 to 68 years old. Six have lived in the area over 95 WECPNL, four in 90 ~ 95 WECPNL and one in 85~90 WECPNL. The resident years in the same area ranged from 19 to 40 years. They had no histoy of disease having possibly caused hearing loss or occupational noise exposure. The microscopic inspection of their eardrums prooved normal.

Table Subjects suspected to have noise-induced hearing loss

No.	Sex	Age	WE	Desidence yrs	Disease *1	Noise Exposure *4	Eardrum	Tympano	AB gap	SISI-1k Lt/Rt	SISI-4 Lt/Rt
1	M	57	95	40	none	none	normal	A*3	none	+-/-	+/+
2	M	47	90	19	none	none	normal	A	none	+/-	+/+
3	M	57	95	40	none	none	normal	A	none	-/-	+/+
4	F	52	95	39	none	none	normal	A	none	-/-	+/+-
5	M	48	95	32	none	none	normal	A	none	+/-	+/+
6	M	68	90	21	none	none	normal	A	none	-/-	+/+
7	M	44	95	40	none	none	normal	A	none	-/-	+/+
8	M	59	95	35	none	*2	normal	A	none	+/-	+/+
9	M	63	90	38	none	none	normal	A	none	-/-	+/+
10	M	64	90	43	none	none	normal	A	none	-/-	+/+
11	M	68	85	40	none	none	normal	A	none	-/-	+/+

*1 Disease having possibly caused hearin
*2 Watchman in the base(Sunabe) for few years around 56 y.o.
*3 Normal(No abnormality in sound conductive system of middle ear in the majority)
*4 Occupational noise exposure

Case 1



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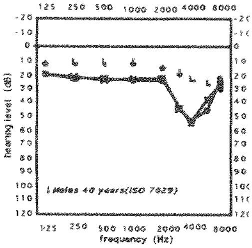

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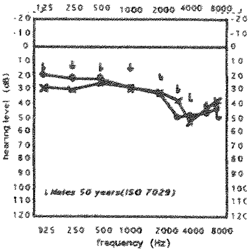

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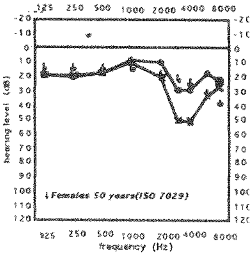

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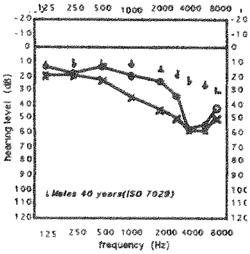

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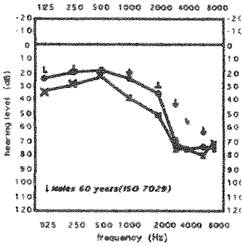

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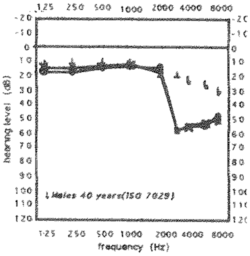
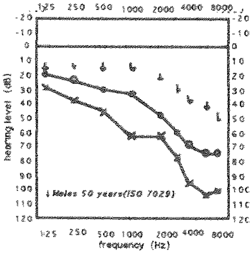
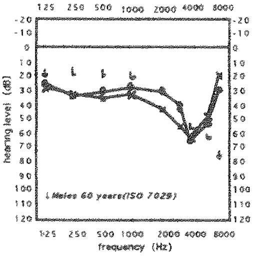


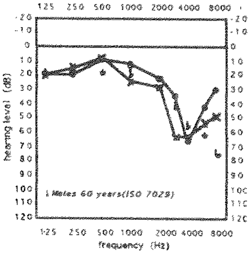
Case 8



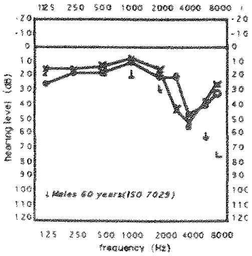
Case 9



Case 10



Case 11



Figur 1. Audiograms of subjects suspected of noise induced hearing loss caused by aircraft noise. Arrows in audiograms show 90 percent teil hearing level corresponding subjects' age and sex.(ISO 7029)

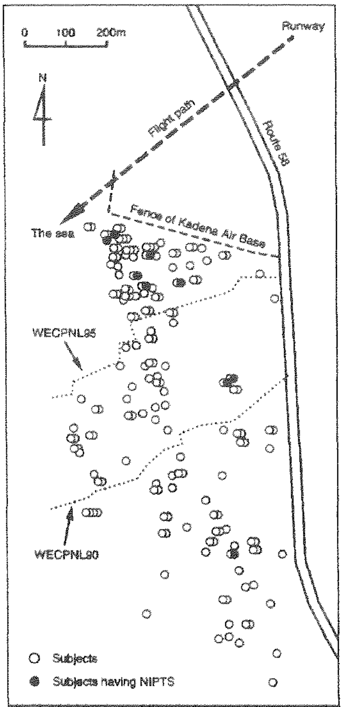


Figure 2. Geographical location of the subjects' residences

Their tympanograms were all type-A. Air-bone gaps in the pure tone audiograms were all in the normal range. SISI tests at 4kHz were all positive but one ear. Seven audiograms of these subjects showed typical c^5-dip and four progressive figure of c^5-dip. The examiners interviewed thus selected subjects to confirm that they had not experienced habitual or repeated intense noise exposure at their residential or working site other than aircraft noise exposure. In additon, the geographical location of the subjects' residences are concentrated to the very vicinity of the airfield (Figure 2). Statistical test indicates the concentration is significant with p-value of 0.027 (one-tailed), which strongly supports one to reach a conclusion that the cause of their hearing loss is most likely their exposure to the intense noise of aircraft's take-offs, landings and tune-ups at Kadena Air Base.

4. CONCLUSION

Eleven inhabitans were found to have NIPTS. The authors found it was due to aircraft noise. Reasons are as follows:

(1) Aircraft noise exposure have been intense enough to cause hearing loss.
(2) Results of hearing tests indicate their hearing loss showed typical figure of noise induced hearing loss.
(3) No other factor except aging was found to cause hearing loss.
(4) Clear geographical concentration of the subjects' residences to noise source was found.

5. ACKNOWLEDGMENTS

The authors wish to express their gratitude to Okinawa prefectural government for its support to carry cut the study.

TINNITUS AND ATTENDANCE AT NIGHT-CLUBS

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1. INTRODUCTION

Social noise exposure, such as found in noisy night-clubs, has increased in the last 15 years giving rise to growing concern over potential damage to the auditory system. Studies carried out in this area, particularly in regard to hearing loss, have produced conflicting results. This in part may be due to a time factor as up to 30% of outer hair cells within the cochlea can be permanently damaged before a hearing loss is detectable (Bohne and Clark, 1982).

Tinnitus is the sensation or perception of noise in the head or ears and it is a condition that ranges from mildly annoying to totally intrusive. Noise exposure is one of the known major factors in the emergence of tinnitus, which can be chronic or transient. This study was aimed at investigating associations between the attendance of university students at night-clubs and the incidence and duration of post exposure tinnitus (PET) and spontaneous tinnitus (ST). ST is here defined as tinnitus which occurs spontaneously and lasts for longer than 5 minutes.

Due to the recent concern over the possible adverse effects of taking social drugs while exposed to loud music the study also looked at the associations between the taking of social drugs while at noisy nigh-clubs and the incidence and duration of PET and ST. Other possible triggers of tinnitus were examined including other types of loud noise exposure.

The emphasis placed on night-club noise exposure in this study was prompted by the findings of preliminary work by the Medical Research Council Institute of Hearing Research - Hearing in Young Adults and the Effect of Social Noise Exposure (1997), which indicated greatest exposure to leisure noise came from the frequenting of night-clubs. Personal stereos and Hi-fis were found in general to be used sensibly by young people and were not thought to be a high risk factor. Although the sound levels at rock concerts tend to be extremely high, attendance is considerably less frequent than attendance at noisy night-clubs.

The City of Manchester has a large undergraduate population, with a well developed culture of night-club attendance, making it a good location to carry out such research.

2. METHOD

A questionnaire was used to collect data from 545 science students attending The Manchester Metropolitan University, 308 of whom were female and 434 were aged between 18 and 25 years. Respondents with established causes of tinnitus, eg. perforated ear drums, were excluded from the analysis as were any inconsistent or substantially incomplete replies. This reduced the sample to 494. The questionnaire was kept to one A4 size sheet to encourage good compliance (Figure 1).

Average sound levels in Manchester night-clubs were obtained from the Environmental Health division of Manchester City Council. The mean values of 97 - 106dB(A) on the dance floors equate well with data from French night-clubs (Meyer-Bisch, 1996).

Data analysis consisted of descriptive analysis and Chi squared association analyses. In order to ensure adequate numbers in expected data cells ie. five or greater, some categories were pooled. Eg. frequency of taking drugs at night-clubs, 'usually' and 'always' were combined. The data was subdivided into gender and age band categories but insufficient data was available to carry out meaningful association analyses.

The significance criteria used was $\alpha < 0.05$.

3. RESULTS

Descriptive data

Table 1 Sample numbers and % of night club attendees, total, male, female, 18 -25 year olds and over 26 year olds.

	Total	Male	Female	18 - 25	26 +
Sample number	494	183	308	434	52
%Night club attendees	87	91	84	87	81

Table 2 % results amongst night-club attendees, subdivided for gender.
PET = post exposure tinnitus lasting for longer than 5mins.
ST = spontaneous tinnitus lasting for longer than 5mins.

Attendees n = 428	Total	Male	Female
% with PET	80	77	81
% with PET > 2hrs	22	26	19
% with ST	31	30	32
% take drugs more than rarely	19	23	17
Non-attendees n = 66			
% with ST	21	24	20

Chi squared association analyses

Table 3 Null hypothesis probabilities for Chi squared association analyses.
PET = post exposure tinnitus lasting for longer than 5mins.
ST = spontaneous tinnitus lasting for longer than 5mins.
NC = night-club

Association	P(Ho)
NC attendance and duration of ST	0.008
NC attendance and duration of PET	0.0177
NC drug taking and duration of PET	0.0229
NC drug taking and occurrence of PET	0.049 *
NC attendance and occurrence of PET	not significant
NC attendance and occurrence of ST	not significant

* found not to be significant when columns combined due to lack of

pattern in standard residual values.

4. CONCLUSIONS

This study shows that the attendance of university students at noisy night-clubs is high and that there is a significant association between the attendance at night-clubs and the duration of tinnitus, both post exposure tinnitus and spontaneous tinnitus. This may indicate that although night-club attendance does not cause tinnitus it may enhance tinnitus in susceptible ears. The amount of drug taking at night-clubs was not found to be as high as expected, although it is thought the incidence may be under reported. It would appear that taking social drugs at night-clubs does not cause tinnitus but it may enhance tinnitus in susceptible ears. Future study of the effect of social noise exposure on tinnitus should include information about the duration of tinnitus as this appears to be a significant factor.

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Environmental Health Division, Manchester City council (1997). Sound level data from Manchester night-clubs.
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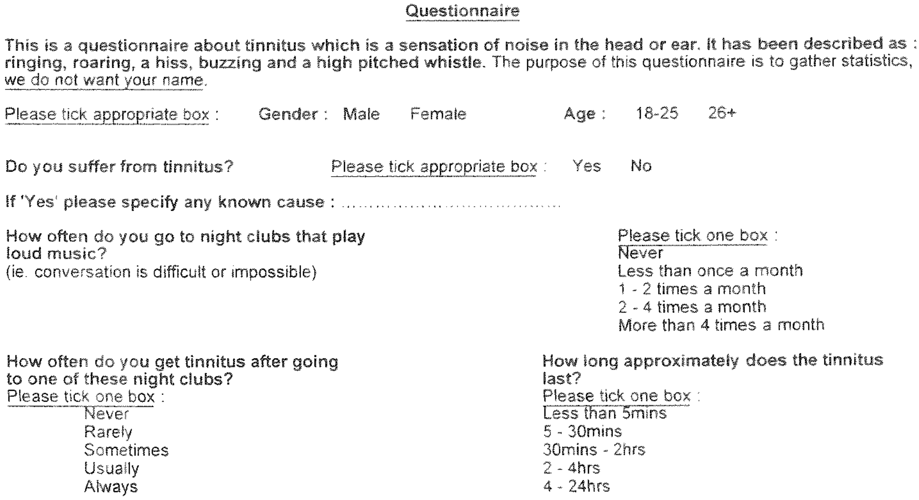
Meyer-Bisch C (1996) Epidemiological evaluation of hearing damage related to strongly amplified music. Audiology 35 : 121 - 142.

Figure 1 The questionnaire used in the study.



Questionnaire

This is a questionnaire about tinnitus which is a sensation of noise in the head or ear. It has been described as : ringing, roaring, a hiss, buzzing and a high pitched whistle. The purpose of this questionnaire is to gather statistics, we do not want your name.

Please tick appropriate box : Gender : Male Female Age : 18-25 26+

Do you suffer from tinnitus? Please tick appropriate box : Yes No

If 'Yes' please specify any known cause : ....

How often do you go to night clubs that play loud music?
(ie. conversation is difficult or impossible)

Please tick one box :
Never
Less than once a month
1 - 2 times a month
2 - 4 times a month
More than 4 times a month

How often do you get tinnitus after going to one of these night clubs?
Please tick one box :
Never
Rarely
Sometimes
Usually
Always

How long approximately does the tinnitus last?
Please tick one box :
Less than 5mins
5 - 30mins
30mins - 2hrs
2 - 4hrs
4 - 24hrs

More than 24hrs

Do you take any drugs/ substances at these night clubs?
(The questionnaire is anonymous, its okay to answer honestly!)

Please tick one box :
Never
Rarely
Sometimes
Usually
Always

If you have no objection please would you specify drugs/substances taken? : ....

Do you get tinnitus lasting for more than 5mins after any of the following?
Please tick one box on each line :

	Never	Rarely	Sometimes	Usually	Always
Swimming					
Using personal stereo					
Drinking 0-4 pints or equivalent (no loud noise exposure)					
Drinking 5+ pints or equivalent (no loud noise exposure)					
Illness/infection					
Taking drugs/substance (no loud noise exposure)					
Rock concerts					
Other Please specify :					

Do you get tinnitus that starts for no particular reason?
(ie. spontaneous)

Please tick one box :
Never
Rarely
Sometimes
Much of the time
All of the time

How long does this tend to last?

Please tick one box :
Less than 5mins
5 - 30mins
30mins - 2hrs
2 - 4hrs
4 - 24hrs
More than 24hrs

Thank you for your time.

AN ESTIMATION OF HEARING LOSS DUE TO AIRCRAFT NOISE EXPOSURE RECORDED AROUND KADENA US AIRFIELD IN THE RYUKYUS

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1. INTRODUCTION

Noise-induced hearing loss is considered to become a detectable permanent hearing loss through the repetition of temporary hearing loss and its recovery that starts an undetectable infinitesimal permanent hearing loss and its accumulation. A method for calculation of average temporary hearing loss is available if the temporal and spectral features of noise exposure are given; in its turn, permanent average hearing loss can be estimated with an adequate margin of accuracy from past measurement of noise exposure. In this paper, the past noise exposure around Kadena Air Base during the Vietnam War era is estimated, and noise induced temporary threshold shift (NITTS) is calculated from the estimated time history of sound level.

2. NOISE EXPOSURE IN THE PAST

There exist past noise measurements recorded in the vicinity of Kadena Air Base in 1968 and 1972. Figure 1 shows the positions of measuring points. The measurements at Fire Station were carried out in the room with windows open and the records include time, peak level and duration of each noise event. The records of measurements are shown in Table 1. The index, Max. PL, indicates the daily maximum sound level. The lower values of $L_{\mathrm{Aeq,24h}}$ and WECPNL in the table are obtained when the peak level of the noise of engine tuning continues for 10% time of the recorded duration, and the higher values for 100% time of the duration. In

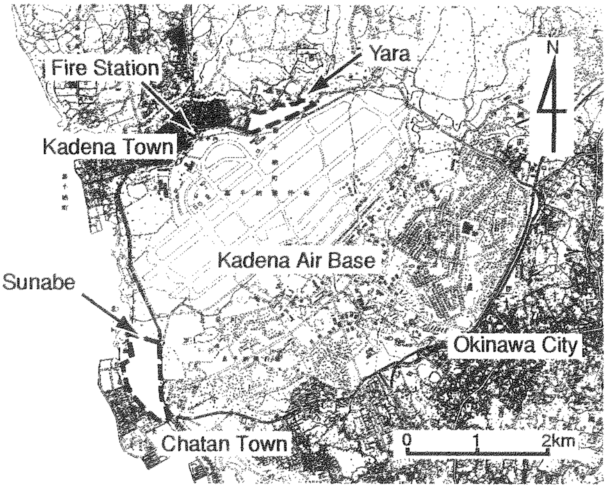

Figure 1. Kadena Air Base and measuring points. Sound level was measured at Fire Station in 1968 and at Sunabe in 1972. Hearing tests were conducted for the inhabitants within the broken line[1].

Table 1. Records of measurements at Fire Station (12–17/2/1968)

Date	Number of noise events					Max. PL	$L_{\mathrm{Aeq,24h}}$	WECPNL
	0–7	7–19	19–22	22–24 (hrs)	Sum	(dB)	(dB)	
12/2/1968	34	44	12	6	96	107	79–86	100–106
13/2/1968	41	49	24	11	125	107	80–89	101–110
14/2/1968	28	49	10	5	92	110	83–93	100–110
15/2/1968	9	25	9	5	48	100	68–73	88–92
16/2/1968	37	45	13	4	99	104	80–88	100–109
17/2/1968	41	51	23	16	131	112	79–87	99–107
Mean	32	44	15	8	99	108	80–88	99–108

* $L_{\mathrm{Aeq,24h}}$ and WECPNL are the estimated values.

Table 2. Records of measurements at Sunabe (4–10/11/1972)

Date	Cumulated duration (sec)						Max.	$L_{\mathrm{Aeq,24h}}$	WEC
	–110	–100	–90	–80	–70 (dB)	Sum	PL (dB)	(dB)	PNL
4/11/1972	0	80	1,660	6,105	6,985	14,830	106	80	100
5/11/1972	0	105	920	2,865	3,165	7,055	108	79	99
6/11/1972	15	25	735	3,970	4,220	8,965	117	79	99
7/11/1972	0	165	1,485	4,685	4,685	11,020	103	80	100
8/11/1972	0	150	1,410	4,200	3,220	8,980	106	80	100
9/11/1972	15	530	1,340	3,450	2,245	7,580	112	84	104
10/11/1972	60	1,015	1,830	3,550	2,970	9,425	118	87	107
Mean	13	295	1,340	4,118	3,927	9,694	113	82	102

* WECPNL is the estimated value.

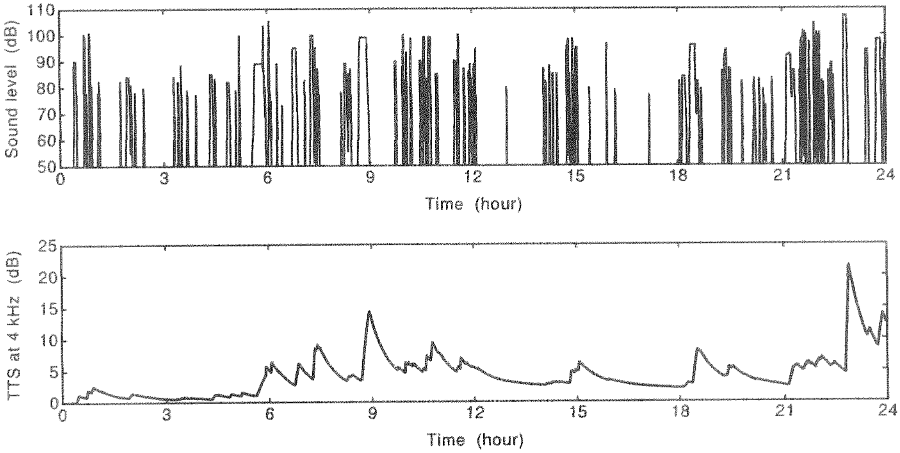

Figure 2. Estimated sound level (top) and NITTS (bottom) at Fire station (13/2/1968).

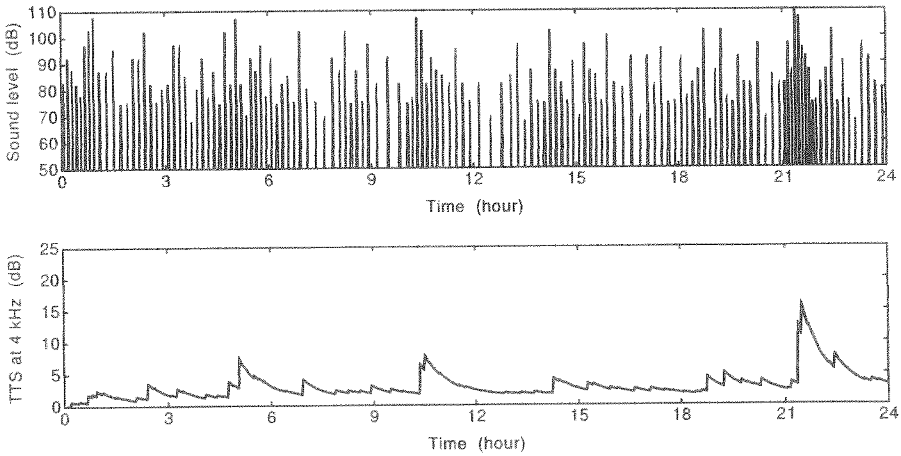

Figure 3. Estimated sound level (top) and NITTS (bottom) at Sunabe (10/11/1972).

the calculation of WECPNL, the relation, PNL = dBA + 13, is assumed.

The measurements at Sunabe were made outdoors and the records include only the cumulated duration of each level range during one day. The records of measurements are shown in Table 2. Since the information of the time of event which is required to estimate WECPNL, is lacking in the records, it is assumed that the proportion of noise events in the hours of a day is the same in Sunabe as in Fire Station.

The estimated WECPNLs and and $L_{\mathrm{Aeq,24h}}$s are around 105 and 85 dB respectively. One will realize that these noise exposure may well cause hearing loss when compared with the permissible criteria for occupational noise exposure for hearing conservation recommended by Japan Association of Industrial Health which is 80 dB for 24 working hours a day. The criteria is provided so that average hearing loss does not exceed 20 dB at the test frequency of 4kHz after prolonged exposure of over ten years.

3. ESTIMATION OF NITTS

The time history of sound level during 24 hours is estimated from the recorded data in 1968 and 1972, and the sound level is converted into the critical band level with respect to NITTS. NITTS is calculated from the time history of critical band level using Ito's formulae[2].

Figures 2 and 3 show the time history of sound level and NITTS at 4 kHz during 24 hours. In Figure 2, the duration of engine tuning noise is set to 70% time of the recorded one. In Figure 3, the duration of each noise event is based on the average measurements at Fire Station, and the number of noise events and the peak level of each noise event are adjusted so that the cumulated duration of the estimated time history of sound level is equal to that of the recorded data.

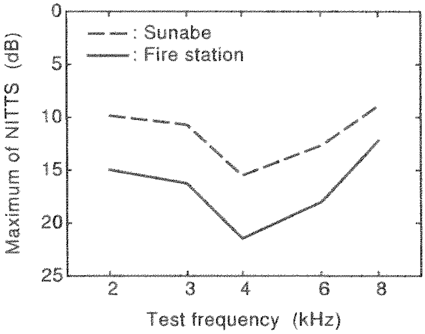

Figure 4. Estimated maximum NITTS during 24 hours.

The maximum of NITTS is shown in Figure 4. Results of calculation indicate the noise exposure around Kadena Air Base causes hearing loss in excess of 20 dB. This is an average estimation for the exposed groups; further hearing loss is possible for some highly susceptible individuals.

4. CONCLUDING REMARKS

The noise exposure in the vicinity of Kadena Air Base during the Vietnam War era was so intense as $L_{\mathrm{Aeq,24h}}$ was 85 dB, and NITTS was up to 20 dB. These results suggest the existence of residents having permanent hearing loss due to military aircraft noise.

The authors wish to express their gratitude to Okinawa prefectural government for its support to carry out the study.

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METHODICAL POSSIBILITIES OF EARLY DETECTION OF HEARING IMPAIRMENT IN PREMATURE INFANTS

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1. INTRODUCTION

Hearing is the primary sensory modality for acquisition of speech and language. Hearing impairment (HI) during infancy and early childhood can have devastating effects on speech and language development, affecting learning and social/emocional growth.

Approximately one of every thousand infants is born deaf or becomes deaf as a result of diseases overcame during the first year of life [1]. The prevalence of hearing loss (HL) varies with the criteria for HL used, the technique for detection employed, and the population studied. Among groups of neonates at high risk the incidence of severe bilateral HL ranges from 1 to 14 % [2].

The early detection of HL in newborn babies has been favoured by the development of electrophysiological methods such as brainstem auditory evoked potentials. However, the cost and complexity of auditory brainstem response (ABR) preclude its general use as a screen. Its use has been restricted on high risk infants for HL. During the last 10-15 years several authors recommended the use of a test that measures otoacoustic emissions (OAEs). It is a quick, inexpensive, accurate test of hearing sensitivity [3]. Nevertheless, most authors agreed that OAEs is the most efficient procedure as an initial screening test and infants who fail OAEs are able to be referred for ABR. Moreover some authors [4], [5] recommended that initial screening would involve all infants soon after birth and not to be restricted to high-risk group.

The ideal and reliable method for initial hearing screening requires sensitivity nearly the same as ABR and simplicity, quickness and inexpensiveness. Most of these requirements have been found in ALGO-Plus method. In the present study ALGO test as an initial method for early detection of HI in neonatal period was used [6].

2. MATERIAL AND METHOD

One hundred sixty-seven infants (87 males, 80 females) were tested for hearing sensitivity using ALGO-Plus. Some perinatal factors of the cohort of 167 infants see in Table 1.

Table (1) Perinatal factors of the cohort of 167 infants

Perinatal factors	n	[%]	Perinatal factors	mean±SD
male	87	52.1	gestational age [wk]	35,7±3,5
female	80	47.9	actual age [days]	26,7±20,5
multiple pregnancy	17	10.2	birth weight [g]	2337±752
single pregnancy	150	89.8	birth length [cm]	44,8±4,9
small for gestational age	35	21	birth head circumference [cm]	31,5±2,6
appropriate for gest. age	132	79	incubator therapy duration [days]	16,61±17,6

Screening procedure is based on the ABR. ALGO uses signal detection theory to determine the presence or absence of an ABR to a 35 dB normal hearing level click stimulus. During a screening, an infant measured is compared to a clinically determined normative ABR template for infants. The ALGO automatically presents a "pass" or "refer" decision. Apparatus has two acoustic tubes attached to an ear coupler and three electrodes. Every electrode was placed over the prepped area of baby's skin. The most commonly clinically used sites are shown in Figure 1. The high cheek site was used as it is more acceptable by the screener than the mastoid site. To obtain the most accurate screening results with the least amount of stress to the infant, it has been recommended to screen babies who are almost ready to go home, 34 weeks gestation or greater at the time of screening, quiet, having been fed recently, resting in an open crib. Although the average time per test was only ten minutes, testing was often delayed because the baby was crying, was restless or being fed, changed, or examining. However, delay in the test time can also occur with hearing impaired patient.

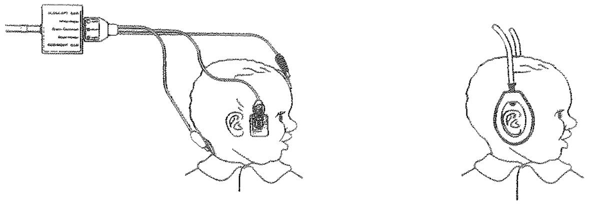

Figure (1) Commonly used sites of electrode and application of ear couplers of ALGO-Plus

3. RESULTS AND DISCUSSION

Of 167 infants, 151 had normal hearing bilaterally, 9 (5.4 %) had unilateral HI (7 right HI - 4.2 %, 2 left HI - 1.2 %ň, 7 (4.2 %) had bilateral HI. Thus 16 (9.6 %) of our subjects had some degree of HL in at least one ear (Figure 2). The frequency of right HI was higher among females (85.7 %) than males (14.3 %). However, the frequency of bilateral HI was nearly the same in males (43 %) and females (57 %). The frequency of HI in newborn infants in our hearing assessment program was lower than noted by most other studies [7], [8]. The lower frequency of HI in our study reflects the fact that the babies in high risk (very premature and/or sick) were not examined. Factors which may contribute to discrepancy between studies include statistical sampling errors, variations in sick criteria, referral base and the level of care, and lack of standardization of auditory screening methods and criteria.

The occurrence of perinatal risk factors and some other added variables in subjects with HI compared with subjects without HI were done. The first comparison revealed that the bilateral HI infants had a significant lower birth weights ($p<0.01$), lower Apgar scores at 5 min ($p<0.001$), longer period of incubator therapy ($p<0.001$), longer duration of assisted ventilation treatment ($p<0.01$) than no HI infants group. No significant difference were seen in the highest bilirubin levels in blood, days of aminoglycoside therapy, furosemide dose/kg, days of oxygen administration or phototherapy duration. Moreover, there was a significant increase in the frequencies of anatomical malformations ($p<0.01$), hypoxic ischaemic encephalopathy ($p<0.001$), intraventricular haemorrhage ($p<0.01$), respiratory distress syndrome ($p<0.01$) in infants with HI than those without HI. There was a higher incidence of HI infants who had gestational age 30 weeks or less than in those infants with gestational age more than 30 weeks. Finally the main possible causes of HL are shown in Figure 3.

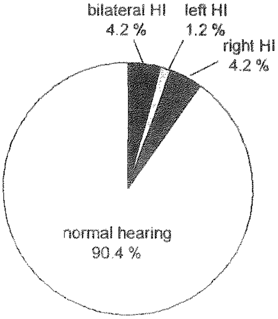

Figure (2) Incidence of HI in 167 infants

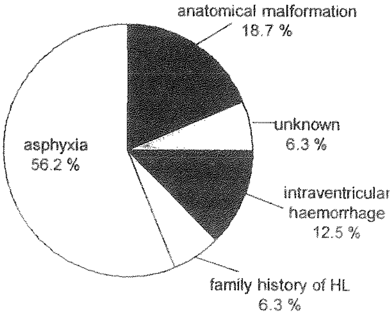

Figure (3) Main possible causes of HL

Whenever "refer" results are obtained with ALGO, the patient must be referred to electrophysiological test (ABR) within three months before a prediction of the hearing ability is given. Six from the seven bilaterally hearing impaired patients were examined by ABR and one could not be examined due to death. Only two of the six infants showed persistent HI. ABR tests were not done on all babies with unilateral HI at the initial ALGO test as infant with impairment of one ear are not in need for rehabilitation. However, we did ABR test at about 3 month of age on 3 babies with unilateral HI. The first one had anatomical deformity, the other two cases ABR test revealed normal hearing of both infants.

Overall, ABR tests revealed a high false positive results, only 33.3 % of babies who had "refer" with ALGO showed HI with ABR in one or both ears. However, many of the infants who fail the initial test and are subsequently determined to have normal hearing may not necessarily be false positive, but actually may have auditory impairment at the time of the test. Our follow-up results of ABR tests done at the age of 3 months showed transient HL in subjects who were sick, very low-birth-weight (LBW) but persistent HL in less premature, more healthy infants who had family history of deafness or congenital malformations.

4. CONCLUSIONS

ALGO test is a diagnostic tool for early detection of HI (35 dB normal hearing level). ALGO screening is a practical and viable procedure in a non-ideal environment. It requires no specialist, only one trained individual (a general practitioner or a nurse) and typically takes 10 minutes provided the test is correctly timed. It is essential to refer all abnormal cases (with "refer" results) to ABR at 3 months of age for evaluation of the degree and type of HL.

Analysis of the risk factors revealed that the most important risk factor is perinatal asphyxia requiring assisted ventilation treatment. Very LBW per say could not be a risk factor but complications of prematurity may be the original causes of HL. HI due to perinatal asphyxia is often transient. However, HI due to family history of deafness or anatomical malformations showed persistent HL examined at 3 months of age by ABR. Prolonged incubator care may be an additive factor to other risk factors for HL, if noise levels inside incubator exceed potentially damaging level to infant's ear.

ALGO neonatal screening program would have an effect in initiation of early treatment for infants with severe sensorineural HL and in lowering the age in which parent-infant program services are initiated.

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COSTS OF HEARING LOST AT WORK

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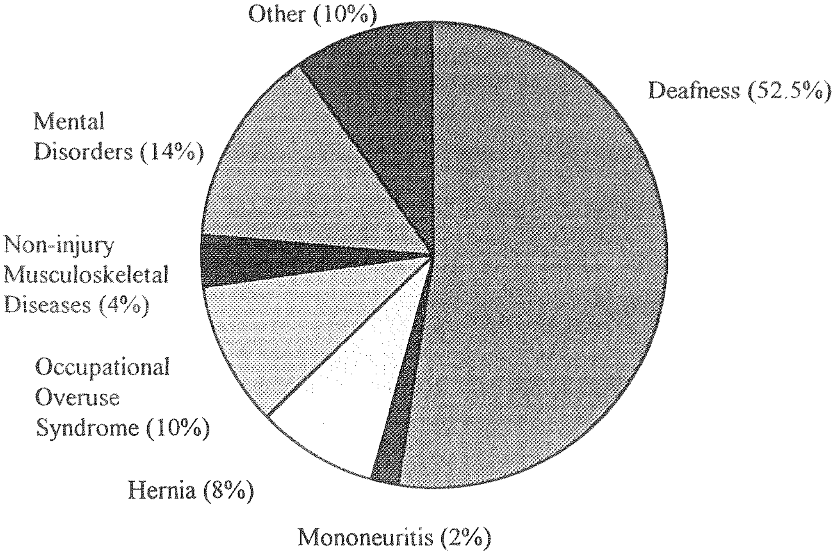
1. INTRODUCTION

Of all industrial disease in Australia, occupational noise-induced hearing loss (NIHL) is most common in terms of the number of claims but relatively small as a percentage of the total cost of insurance payouts. This paper investigates the social and economic costs arising from NIHL, concluding that compensation payments to employees underestimate the total cost borne by the community. Engineering noise control is recommended to reduce noise exposure as it is probably cheaper than paying compensation and certainly better than just complying with regulations that are clearly ineffective.

Graph 1. Occurrence of Deafness as an Industrial Disease



2. BACKGROUND AND HISTORICAL DATA

The graph from the WorkCover Authority of NSW [1] shows deafness is 52.5% of the number of workers compensation disease claims in the year 1996/97. In 1996/97, the payment of $70.6 million [1] for costs relating to 5,979 NIHL claims accounted for nearly 40% of all disease related costs for that year. Deafness as a percentage of cost of disease and injury claims at just under 4%, is however so small it might explain some of the lack of effective action to reduce its incidence.

The graph reflects the recent extent of compensation claims for noise induced hearing loss. The proportion and magnitude of claims for NIHL increased dramatically up to 1994/95 with a peak of more than 11,000 claims in that year. In 1995/96, compensation claims for NIHL reached $101 million [1], also reported by J. H. Macrae [2]. Employees have been paid this compensation despite regulations, in force since 1979 in NSW, which they and employers might have thought were designed to set safe limits. The claims experience in NSW and other Australian States demonstrates that regulations have been ineffective.

Common law claims for NIHL reached a peak by around 1989 and 1990. In 1993/1994 non-compensation payments amounted to $8.4 million for NIHL which accounted for 19% of the $44 million of payments made relating to all NIHL. Workers compensation is now by far the more commonly used avenue for payments relating to NIHL. Various NSW governments attempting to reduce insurance payouts for NIHL have eroded the rights to compensation for sufferers of NIHL. Since recent judgements in the NSW Court of Appeal, plaintiffs are finding it harder to obtain an extension of the statute of limitations against all earlier employers. Failure to get an extension of time to pursue a common law claim covering the period up to 30 June 1987, may substantially reduce damages.

Workers Compensation for NIHL was introduced in 1957. New legislation was passed in 1987 and 1988, meant to reduce the strain and reduce payouts caused by common law court cases for negligence claiming NIHL. The use by insurance companies of a medical panel, whose decision is binding on both parties, normally arrives at a finding of the minimum, undisputed disability. Following those changes, there has been a decline in the number of claims and payments for NIHL as still more recent legislation in NSW increased the threshold before a worker can claim any loss, from a 20 dB hearing level representing 0% disability to the much greater 6% disability.

3. COSTS

The real cost of hearing lost at work is greater than compensation payments, even to the fraction of the workforce able to claim successfully. The costs include:

- **recognition / identification** - there is a cost associated with the identification and recognition of NIHL, such as the cost of an appointment at a specialist for hearing tests.

- **rehabilitation** - includes the costs associated with bringing the sufferer to terms with NIHL and the loss of a very important all round sense which assists with maintaining balance and direction and those costs associated with medical treatment, fitting hearing aids and the cost of other audio devices to reduce the inconvenience of the disability.

- **workers compensation payments** - payments made directly to sufferers of NIHL in an attempt to lessen the financial burden of their injuries, at no direct cost to the worker.

- **common law suits** - the costs associated with the "more probable than not" standard of proof required in a civil negligence action are greater than when claiming workers compensation. Some of the costs are time, stress, a clogging up of the judicial system and of course the financial costs, which include; solicitor's fees (commonly $20,000), barrister's fees ($12,000), an engineer's report ($5,000), site measurements ($3,000), doctor's fees ($1,000), doctor's evidence ($1,000) and an expert witness' evidence ($2,000). The plaintiff not succeeding with a common law claim results in the plaintiff being ordered to pay the defendant's costs, risking further hardship to the plaintiff and family.

  Common law claims for NIHL typically pay ten times more than workers compensation payments and are therefore thought to more accurately reflect some of the cost of "pain and suffering". When juries decide the reasonableness of a claim and the size of an award to an injured worker, the jury has tended to be even more generous than a Judge sitting alone.

- **social costs** of loss of hearing - perhaps one of the most neglected but costly aspects of NIHL. The social problems of NIHL are incurred by not only the sufferer, but also by their friends and family and may include feeling isolation, risk of family break-up, a cost to the community, perhaps the cost of purchasing another television and airconditioning additional rooms, alienation from family, friends, workmates and general public, possible stigmatisation as an idiot and shorter life expectancy are at least possibilities.

- the non-compensable factors additional to workers compensation include real damage (detected objectively with otoacoustic emission) that precedes the permanent threshold shifts detected with pure tone air conduction audiometry. Some of these are the annoyance of tinnitus, difficulties understanding speech in noisy environments, reduced appreciation of music, pitch discrimination and ability to localise noise sources.

4. PREVENTION OF HEARING LOSS AND ASSOCIATED COSTS

Employers and organisations endeavour to minimise noise exposure of their workforce if it becomes a legal requirement. At present, the NSW regulations relating to noise in the workplace are neither supervised nor enforced. There were two prosecutions of noisy workplaces in the eighteen years the previous regulation was in force from 1979 to 1997.

Engineering noise control or reducing the noise exposure of employees is more desirable and probably cheaper than doing nothing to remedy the situation and paying compensation. "**Design Quiet**" and "**Buy Quiet**" are two most effective approaches to avoid problems in new workplaces. Robert Dobie [3] considers the noise source, path and receiver when implementing engineering noise control. For the noisy source, Dobie recommends maintenance, substitution of machines and/or substitution of process. For the path, he recommends barriers, silencers, enclosures, acoustic absorbing materials and confining high-noise machines to insulated rooms. To reduce noise at the receiver, Dobie suggests isolating the operator in a personal shelter or control room and using hearing protection.

A temporary method of reducing workplace noise is to provide **hearing protection** which appears to be cheap. But as Dick Waugh said in 1997 at a Standards Australia Committee meeting, as a solution, "that approach is about as effective at stopping hearing damage as filter tips on cigarettes are at preventing lung cancer." The effective methods described here may be expensive, but when contrasted with the payments of compensation made for NIHL, seem relatively small. Noise exposure could be reduced substantially if the $101 million spent on compensation in 1995/96 were instead available to fund workplace noise control.

5. CONCLUSION

If workers knew their rights had been alienated, they might feel aggrieved. Employers continue to try and comply with regulations although there are few prosecutions. The NSW WorkCover Authority is responsible for regulations and at the same time for managing the workers compensation insurance fund. There is a real possibility it will continue to avoid being effective, torn between alerting employees to the risk of losing their hearing if it were to publicise the need for noise control, to delay a run on its insurance pool.

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PRINCIPLES OF HEALTH CARE OF WORKERS AT RISK FOR OCCUPATIONAL NOISE-INDUCED HEARING LOSS IN POLAND

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1. BACKGROUND

Occupational noise-induced hearing loss (ONIHL) is commonly considered as one of major causes of disability in all highly industrialized countries and the monetary costs of compensation are projected to exceed a billion sum by the end of the century (1,2, 3).

It is estimated that in Poland the number of workers exposed continuously to noise averaging 85-90 dBA or higher approximates in Poland 600 000 out of the total of 5 million employed in industry, as compared with a whole population of 39 million citizens (4).

According to Polish Register of Occupational Diseases more than 3000 new cases of compensable ONIHL are recognized every year (Table 1), being a most widespread and leading nosologic unit among the all 20 work-related diseases (5).

Table 1. Prevalence of the occupational noise-induced hearing loss (ONIHL) in Poland in the years 1991-1997

Year	New cases in absolute numbers			Number of occupational diseases per 100 000 employees	
	All occupational diseases totally	ONIHL	%	All occupational diseases totally	ONIHL
1991	11988	3198	26,7	111,4	29,7
1992	10639	2904	27,2	119,5	32,6
1993	10955	2809	25,6	128,7	33,0
1994	11156	3096	27,7	131,1	36,6
1995	11320	3273	28,9	117,0	33,8
1996	11318	3072	27,1	116,0	31,6
1997	11685	3221	27,6	116,9	32,2

The analysis of workers' compensation records points out that mostly affected are those aged 50-59 years and exposed to hazardous noise levels for over 20 years, mainly in iron and steel, transport equipment and coal mining industries (6).

Such alarming data oblige for urgent implementing the effective preventive activities as the only alternative since ONIHL is not curable.

The short overview of recent approach, resulting from transition of socio-economic system in country, is the aim of this paper.

2. LEGAL REGULATIONS AND IMPLICATIONS FOR HEARING CONSERVATION PROGRAM

The legal base for all health care organizations is the Health Care Facilities Act (1991) according to which health care units may be a public (founded and kept by the government or local authorities) and a non public (e.g. private health foundations and private medical enterprises(7).

The similar forms may set up occupational health services which on the basis of an additional regulation i.e. the Occupational Health Services Act, that came into force on January 1, 1998 consist of two levels. At primary level (industrial plant out-patient units or another) different shapes of organisations and practices may function, whereas at regional (voivodeship) level there are only public health care clinics (one in each of 16 regions) named Voivodeship Occupational Medicine Centres (7, 8); the latter have the power to control all primary units and are responsible for consulting doctors and for education of medical personnel. The costs of services in public health care units are covered by the state budget, while non-public ones may contract its services with different clients (industrial plant management) on their cost.

In agreement with the Labour Code Amendments (1991, 1996) only the authorised physicians with the specialization in occupational medicine may perform prophylactic examinations (8). Their scope, among others, for the noise-exposed workers is specified in the Guidelines of the Minister of Health and Welfare (1996), listed in Table 2 (9).

The directives on pre-employment and follow-up tests define the minimum extent of examination carried out by an authorised doctor and the kinds of consultations which have to be performed by appropriate specialist.

As an obligatory rule, the otolaryngologists with postgraduate training in occupational medicine take part in prophylactic examinations. Consequently, an adequate interpretation of audiograms surveyed by audiometricians, as well as, an otologic evaluation of possible outer, middle or inner ear pathology and other predictors of individual susceptibility is ensured. Removing a worker from the noisy job is recommended if the audiometrical threshold (pure-tone average at 1, 2, 4 kHz) is ≥ 30 dB (1, 10).

Prior to organization and schedule of prophylactic examinations the employer is owed to give to occupational health unit full information on the working conditions of a given employee at a given work post (9). The noise measurements can be done by any of the occupational hygiene laboratories which are supervised by the State Sanitary Inspection and costs of surveys are covered by the employer. The majority of the laboratories are placed in the district and voivodeship state sanitary-epidemic stations and their validation is periodically performed (8).

Regulatory efforts to prevent occupational noise-induced hearing loss (ONIHL) are also embodied in Polish Noise Exposure Standard (PN- 93/N- 01307), derived from the ISO 1999 (1990); the maximum permissible daily (8 hours) dose level of occupational noise exposure is established at Leq 85 dBA with allowance of a 3 dB increase for each halving of duration (4, 10).

Employers are required to utilize engineering and administrative controls for excessive noise. However, if lowering noise exposure or shortening its duration is not feasible, employers are obliged to provide the workers with personal hearing protectors (ear plugs, ear muffs, canal caps) to diminish the noise reaching the ear. Although the hearing protectors are compulsory in noisy working environment unfortunately, according to our estimates, they are worn only by about 60 % of employees (1); thus an education program on prevention of hearing loss should be intensively and more efficiently propagated.

Table 2. Guidelines on prophylactic examinations of noise-exposed workers

	Pre-employment	Follow-up	Last follow-up	Remarks
Range of exami-nations	ENT investigation by otolaryngologist Pure-tone air and bone conduction audiometry (125-8000 Hz)	ENT investigation by otolarynologist Pure-tone air and bone conduction audiometry (125-8000 Hz)	ENT investigation by otolaryngologist Pure-tone air and bone conduction audiometry (125-8000 Hz)	In the case of exposure to impulse noise and other noises with levels (Leq) exceeding 110 dB-A the audiometric tests should be performed at least every year.
Fre-quency	Before starting work in noisy environment (base-line audiogram)	Every year for the first 3 years of employment; then every 3 years	Just before retiring	

3. COMPENSATION AND REHABILITATION

As was mentioned earlier, more than 3000 workers receive every year a disability pension and financial award for loss of faculty due to ONIHL.

According to the obligatory formula hearing loss is considered compensable if pure-tone average at 1, 2, 4 kHz is at least 30 dB (low fence) in the better ear after subtraction of the age corrections; it is understood as disabling hearing impairment (affecting personal efficiency in activities of real life environment) and for compensation purposes has to be converted into the whole body damage in percentage (50 % is the upper limit) (6, 10).

The above medico-legal evaluations ordered by the social insurance company, as well as, the clinical diagnosis of ONIHL are carried out at the level of Regional (Voivodeship) Occupational Medicine Centres or in the Institute of Occupational Medicine which deals (besides research and control) mainly with difficult diagnostic cases, referred from the whole country.

It must be emphasized that pure- tone audiometry is a subjective measure, requiring full cooperation of the compensation claimants if optimal thresholds are to be obtained; any exaggeration, either intentionally or subconsciously may preclude a precise determination of the true extent of the ONIHL. Objective verification of the audiogram in such cases enables the frequency-specific brain stem evoked responses audiometry (F-spec BERA) and should therefore be used in the battery of tests employed (11). Helpful, as the part of the evaluation battery, are the otoacoustic emissions measurements, however they can not estimate the threshold (12, 13).

According to our experience, when dealing with medico-legal complaints of hearing loss due to noise, one should be alert to non-occupational causes of deafness to be found in population at large, e.g. Meniere's disease, acoustic neuroma, cochlear otosclerosis, which may occur in subjects working in a noisy environment, and masquerade ONIHL (11).

Unfortunately, any attempts of a medical treatment of the ONIHL, like other sensorineural hearing losses, are failure. Therefore, the point of great importance becomes rehabilitation of the hearing ability by providing hearing aids (equipped with masker if ONIHL is accompanied by tinnitus) for sufferers; their costs are reimbursed from the voivodeship fund for disabled persons.

It is hoped that recent legislation to lower levels of noise at work and greater use of hearing protectors, as well as the organizational changes in functioning the occupational health services responsible for the hearing conservation program will lead to an essential limitation of number of diagnosed and compensated cases of occupational deafness.

Acknowledgments

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DESIGN OF A NOISE CONTROL FACILITY IN METAL FABRICATING INDUSTRY

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1. INTRODUCTION

A metal fabricating company is involved in the fabrication of pre-engineered metal buildings. The fabrication processes of metal building operations require extensive shearing, forming, drilling and cutting of metal. All of these operations contribute to the overall noise level in the plant. One of these operations involves the use of a metal cut-off saw. This machine has an intense noise level during these periods.

The general plant noise level and the noise of this machine in particular are a concern to the plant management. The plant management has instituted a hearing conservation program and now requires all plant employees to wear earplugs. The management is beginning to investigate engineering controls in an attempt to reduce the general noise level in the plant. As part of this effort, management wishes to examine the metal cut-off saw because of its intense noise during operation.

The objective of this study was to analyse the noise levels produced by the metal cut-off saw. Then, if the noise levels were found to be excessive relative to the Occupational Safety and Health Administration (OSHA) standards, to design appropriate measures for the noise control of this machine.

The benefits of reducing the noise level in the plant are, first, improved working conditions for the plant personnel and, second, compliance with Federal OSHA regulations. According to OSHA, the acceptable sound intensity for an eight-hour working day is 90 dBA. Above 90 dBA, the allowed duration for exposure is reduced in half for each 5 dBA increase; thus, the allowed exposure for 95 dBA is four hours, and for 100 dBA, it is 2 hours. Workers must not be exposed to sound levels greater than 115 dBA for any duration.

When employees are subjected to sound exceeding prescribed levels, the employer is required to institute feasible engineering or administrative controls designed to decrease noise levels in the working areas. If these controls fail to reduce noise levels below the prescribed level, personal protective equipment must be provided, and management must enforce their proper use.

2. METHODOLOGY AND RESULTS

Metal Cut-off Saw Noise Measurements

The purpose of noise measurement was to determine the existing noise levels and duration's in the vicinity of the saw and then to determine if the noise level is excessive as compared to the OSHA standards.

Instrumentation

An Audio-Spectrum Analyser, by IVIE Electronics, Inc., Model No. IE-10A, was used for the noise measurements. This instrument has the capability of measuring the sound level at each of the following octave band centre frequencies: 32, 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16,000 Hz. The reason for measuring the noise level in each band, instead of the overall noise level, is that if the sound level is found excessive, the readings at the octave band centre frequencies can be used to select appropriate material for the noise control measures.

Method and Data

Noise measurements were made after the normal shift ended, so noise from the other processes would not affect them. Recorded measurements are presented in Table (1). From the noise measurements, it is necessary to calculate the noise level of the machine. These calculations are shown in Table (2). The average sound pressure level in decibels for different octave band centre frequencies was computed for the three different positions. A-weighted correction factors were added to the average sound pressure level to obtain the dBA levels at different frequencies. The equivalent overall noise level in dBA was then calculated using the standard equivalent noise equation for various octave band frequencies.

TABLE (1) Noise Measurements

Frequency (Hertz)	Position 1 (dB)	Position 2 (dB)	Position 3 (dB)	Average (dB)
32	78	79	77	78
63	81	80	82	81
125	82	82	82	82
250	82	83	83	82
500	86	85	87	86
1000	94	95	93	94
2000	110	110	110	110
4000	112	112	112	112
8000	119	119	119	119
16000	119	119	119	119

Table (2) Measurement Results and Calculations

Frequency Hz.	Mean SPL (dB) (Measured)	A-Weighted Factor	dBA	Equivalent dBA
32	78	- 39.4	38.6	120.51
63	81	- 26.2	54.8	
125	82	- 16.1	65.9	
250	82	- 8.6	73.4	
500	86	- 3.2	82.8	
1000	94	0	95.0	
2000	110	1.2	111.2	
4000	112	1.0	113.0	
8000	119	- 1.1	117.9	
16000	119	- 6.6	112.4	

Noise Duration

The noise duration was computed by obtaining a listing of saw's production requirements for 25 jobs. For these 25 jobs, a total of 286 pieces were cut on the saw. The cutting length for each cut is 203 mm and requires 8 seconds. The saw has a fixed travel rate of one second per inch.

The total tonnage for these 25 jobs was 692.85 metric tonnes. Thus, the noise duration for this tonnage was

$$\frac{(8\text{ Min.}) * (286\text{ pieces})}{(60\text{ pieces})} = 38.13\text{ minutes}$$

Since the average weekly production is about 711.55 metric tonnes, the average noise duration is

$$\frac{(38.13\text{ minutes})*(711.55\text{ metric tonnes})}{(692.85\text{ metric tonnes})} = 39.16\text{ minutes/week}$$

$$\frac{(39.16\text{ Min/week})*(1\text{ week})}{(5\text{ days})} = 7.84\text{ minutes/day}$$

Enclosure Design

It is not possible to completely enclose the cut-off saw, because the machine is fed with sectional pieces from one side, and cut-off sections are recovered from the other side. Further, some portion of the top must be open for light and ventilation.

It is possible, however, to use a partial enclosure to bring the noise within OSHA guidelines. Provisions were made for the operator to enter into the enclosure.

Four designs were evaluated as to their noise reduction abilities and cost. Each design was the same except that the material used for construction was different. The basic design. The materials selected for the enclosure were 19-mm plywood, polyvinyl curtain material and foam. Polyvinyl curtain material is made of polyurethane foam (fused) with barium loaded polyvinyl.

3. CONCLUSIONS AND RECOMMENDATIONS

From the results of the sound measurements and the operations duration's, it was found that the machine produces a noise level of 120.51 dBA for about 7.84 minutes a day at a production rate of 711.55 metric tonnes per week. The OSHA requirements have an upper limit of 115 dBA; thus, the noise level of the cut-off saw is excessive, and engineering controls should be designed to reduce the noise level of this machine. Due to potential production increases, it was decided to design engineering controls to accommodate 30 minutes per day of exposure, which is about four times the present exposure per day.

As part of investigation on engineering noise controls, the management of a metal fabrication company wished to examine a Metal Cut-Off Saw because of its intense noise during operation. The examination of the saw was in two phases. First to determine if the noise generated by the machine was excessive. Second, if the noise was found excessive, to design an enclosure to bring the noise under control.

From the results of the sound measurements, OSHA found. Therefore, a design of an enclosure was undertaken. As a basic criterion for the design, the enclosure should reduce the noise level to under 110 dBA.

Four enclosures were designed using polyvinyl curtain material, plywood and foam. Of these, a simple polyvinyl curtain enclosure would suffice to bring the noise levels within the design criterion. Polyvinyl and foam type enclosure would reduce the noise level further, but at a substantially higher price. However, if the operation duration increases to about two hours a day, then foam could be applied on the existing polyvinyl curtain enclosure, and the necessary noise reduction could be achieved.
Ear protectors are presently available that the operator can wear during operation and that will provide the necessary ear protection inside the enclosure. It is recommended that the company construct a polyvinyl curtain around the cut-off saw.

NOISE AND HEARING IN THE CONSTRUCTION INDUSTRY: A STUDY OF WORKERS' VIEWS ON NOISE AND RISK

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This research project aimed to identify some of the reasons why noise injury in the building and construction industry persists, despite the existence of Hearing Conservation Regulations in Victoria since 1978. In particular, it sought workers' views of the relationship between noise, hearing and their own hearing safety behaviour. The aim of the research program was to gain a better appreciation of hearing behaviour in the workplace, and to use the knowledge and experience of those working within the construction industry in the development of new practical noise management strategies which might be willingly used by both workers and management.

More than 150 workers on Australia's largest construction site, the Crown Casino in Melbourne, participated in the study over 1995-6. Data were obtained in two ways: quantitative measures were recorded of sound levels in the work environment and the average daily noise dose to which workers were exposed; qualitative data were obtained from twelve focus group discussions, the results of which were transcribed and subject to analysis.

Damaging effects of noise

Injury from noise in industry is a persistent problem. In 1994-5, $19 million dollars was spent in Victoria on compensation for work related noise injury. Present Hearing Conservation Regulations in Victoria (Occupational Health and Safety, 1992) define maximum permissible sound levels in the workplace. However, there is continuing evidence that significant injury to workers in the construction industry persists.

In 1978, it became mandatory for all employers to investigate their work site for excessive noise exposure. Where sound levels exceed an Leq 8h (equivalent to an 8 hour working day) of 85 dBA, employers were encouraged to reduce the sound at the source to a safe level. Where it is not possible or practicable to reach safe levels, employers were required to provide hearing protection to workers and arrange for them to receive audiometric assessment (hearing tests) every two years. In addition, where workers have been shown to have significant hearing loss, suitable training and education should be provided.

Despite the importance of obtaining evidence regarding the cost/benefit of hearing conservation programs, there is in fact little substantial data which support the value of such programs, despite their prevalence throughout a number of Western countries (Bruhl & Ivarsson, 1994; Dobie, 1995; Feldstein, 1993; Leinster et al., 1994; Ivarsson et al., 1992). Education and training requirements must consider workers' views of the risk of noise damage as well as actual exposure levels since research has shown that workers' perception of risk may not agree with the measured danger (Behrens & Brackbill, 1993) .

Aims

To identify, by sound level measurement, the major sources of noise on a large construction site, and to establish which of those noise sources were hazardous to workers' hearing health.

To ask workers what they considered to be hazardous noise sources and to describe the effects of noise on their communication, hearing ability and personal protective behaviour.

To examine the extent to which workers' perceptions of risk were in agreement with the measured noise risk.

To seek workers' views on existing and possible future strategies for reducing noise injury.

METHOD

Data Collection. A combination of quantitative (physical measurements of sound and the noise exposure of workers) and qualitative (discussions with workers and other site personnel) methods were used

Sound Level Measurements of individual items of equipment as used on site were taken to record the level and type of noise they produced. Dosimeter readings were taken to record the total amount of noise individual workers were exposed to during the working day. Workers' job activity and use of hearing protection was noted during the time they were wearing dosimeters. Twelve small group focus discussions were carried out with workers and other site personnel to gather workers' views on noise and hearing protection.

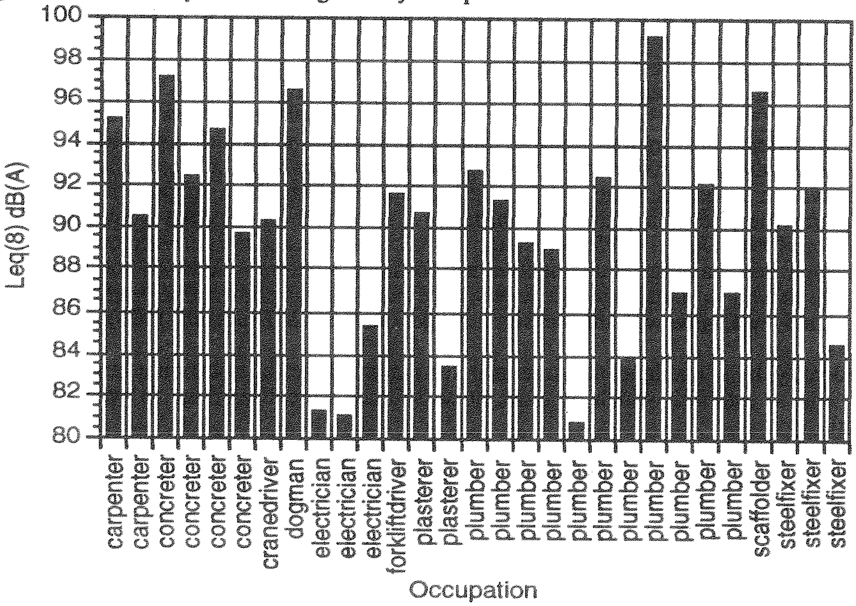
Questions in discussion groups addressed workers' views on:

- Risks associated with noise (including site areas, equipment, tools, the loudness and duration and nature of sound and who produces it).
- Hearing needs on the work site (including vigilance, and the effects of noise on hearing, communication, work, social and family life)
- Beliefs about the use of hearing protection (including advantages and disadvantages, stigma, comfort, access and choice)
- What is being done and what should be done to improve hearing safety (including safe work practices, education, responsibility for changes, and audiometry)

SUMMARY OF MAIN FINDINGS

Quantitative Data. Most types of equipment used on site produced excessive noise clearly above the limit acceptable under current Hearing Conservation Regulations, meaning that hearing protection should have been worn by all workers operating that equipment, and in many cases hearing protection should have been worn by all workers nearby. The majority of workers studied were exposed to noise doses and noise peaks beyond the safe limit according to the OH&S (Noise) Regulations, 1992.

Figure (1). Dosimetry Time Histograms by occupation



79% of workers were exposed to dangerous doses of noise. The workers studied were exposed, on average, to more than six times the safe noise dose. The average noise exposure levels of all workers sampled over an eight hour working day (Leq 8h) was 89.93 dBA, with the minimum recorded level being 80.8 dBA for a plumber working in the tower, and the maximum being 99.2 dBA for a welder/plumber working in the plant room. As well, 75% of the workers studied were exposed to impulse sounds exceeding the 140 dBA limit. The average maximum peak noise exposure was 142.5 dB (lin), with a standard deviation of 3.77 dB. The peak exposures ranged from 132.4 to 145.5 dB (lin).

Qualitative Data. Workers see noise as only one of many hazards on site, and gave a relatively low priority to the risk of noise injury. The majority of workers did not consistently use ear protection. Many workers felt ear protection reduced the ability to hear warning signals and to communicate with fellow workers. Better information is required for workers and employers regarding noise hazards, hearing test results and hearing conservation practices on site.

Practical solutions to continuing noise damage need to be developed from within the industry, with the co-operation of workers and employers. Workers described noise in terms of the range of equipment used, the variations in the areas in which work occurred and the number of workers operating at the same time. Workers described noise by its multiplicity, intermittency, variability, and effects on concentration, communication, hearing ability, and general safety. Noise was seen as inevitable but unavoidable due to the nature of the construction industry.

Measurements of noise levels generally agreed with workers' perceptions of dangerous noise sources. Workers commented that noise levels varied depending on the material being worked on and the areas in which equipment was used. Noise was also seen as constituting an interference with communication on the job, entailing both annoyance and decreased job efficiency. Workers described the adverse effects of noise on concentration with consequences on job efficiency. There were references to the ability or necessity to adapt to the general noise of the working environment.

Workers saw their workplace as hazardous in a number of ways, including risk of fatal injury and of losing employment, with a low priority assigned to risk of noise injury. They felt ear protection reduced awareness of dangers on site. 65% of the workers observed on site did not use hearing protection at all. 35% of workers studied used ear protection for some tasks.

Discussions with workers indicated that some workers decided not to use ear protection because they felt noise was not damaging unless it was uncomfortably loud, others because hearing protection was not always easily accessible, but most because they felt that wearing hearing protection increased the risk of serious injury from accidents such as being hit by machinery or through falls. Therefore standard ear protectors as currently assumed to be used do not seem suitable for many workers in the complex, multiple hazard environment of a large construction site.

Workers were aware of the harmful effects of excessive noise, but did not have a corresponding knowledge of its effects on their own hearing. Continued exposure to excessive noise was seen as the outcome of factors including a perceived inability to complain about noisy working conditions for fear of losing their job, fear of failing to hear danger or to be able to communicate whilst wearing hearing protection, and doubts about significant risk of hearing loss.

Workers comment on hearing conservation practices. There was large variation in workers' experiences of audiometry. The amount and quality of information given to workers about hearing test results was also variable, and in some cases clearly unsatisfactory. Workers had limited knowledge of their own hearing levels as measured by tests. Workers saw the conduct of hearing tests as a valuable point of interface between employer knowledge (about the worker's hearing levels) and employee need for information.

Yet for this information to influence workers behaviour it must be fully explained to the worker.

Workers' suggestions for improvement of hearing safety on construction sites included:

- independent monitoring of hearing safety behaviour on site
- better feedback to workers and employers about hearing test results
- restricting especially noisy tasks to particular times of the day
- engineering controls and improved design of tools
- warning signs on all tools
- consistent, industry wide education about hearing conservation
- ear protection better suited to the special needs of the construction industry

Workers believed that a range of options to engineer noise out of the work site exists, but that there was insufficient attention paid to the problem because of low cost effectiveness. Workers clearly accepted their responsibility to change working conditions relating to noise exposure but were not confident that management shared these views. They indicated the importance of mutual co-operation to effect change.

RECOMMENDATIONS

1. Re-evaluation of the Hearing Conservation Regulations from the perspective of the special characteristics of the construction industry. There is a need to determine how noise reduction, hearing protection and hearing tests may be better implemented. Protocols are needed which take into account the variability in employers and work sites for workers, the intermittent, unpredictable and high levels of noise, and the need for multiple contractors and trades to work in close proximity to each other.

2. Investigate new forms and ways of using ear protection. Urgent research is needed to address the safety issues raised by workers. Ear protection protocols are necessary that will reduce the noise hazards for workers without reducing safety and the ability to communicate on site.

3. Re-examination of the way hearing tests are done, explained, and used. Research is needed to determine how workers and employers obtain information about workers' hearing levels and how the information is stored and analysed. The present study showed that workers and employers need more adequate information than is presently available to them in order to make properly informed decisions.

4. Conduct further on-site research into decision-making in hearing conservation by people in the construction industry. Research is needed to discover how workers use information about noise hazards and their own hearing levels to make decisions about hearing conservation behaviour on site. Research is also needed into employer decisions about engineering and/or administrative controls to limit noise damage and the monitoring of worker's hearing. This research should be aimed at developing practical solutions that address the joint concerns of workers and employers.

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KNOCK OUT NOISE INJURY: AN EVALUATION OF THE INFLUENCE OF EDUCATION ON WORKERS' UNDERSTANDING AND MANAGEMENT OF NOISE HAZARDS IN THE BUILDING AND CONSTRUCTION INDUSTRY

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There is ample evidence that noise constitutes a risk to hearing health for construction workers and that effective hearing conservation practices are needed in the building and construction industry. Demographic studies have shown that the incidence of noise induced hearing loss is as high as 60% in noisy workplaces. However, despite the implementation of Hearing Conservation Regulations, noise injury persists. Studies of the construction industry in Australia and overseas have indicated that there is a low awareness of the risks posed by continuous and impact noise, with consequent minimal self protective behaviours (Behrens & Brackbill, 1993; Milhinch, Dineen & Doyle, 1997). Hearing conservation as currently practiced in the building and construction industry appears to be having little influence on the level of hearing injury to workers.

The use of personal hearing protection devices (HPDs) is prevalent as a form of noise control within hearing conservation programs (HCPs). Conventional passive HPDs have been shown to enhance speech intelligibility in low frequency noise for normal hearing adults, but diminished intelligibility in noise for those with high frequency hearing loss, with factors such as non-fluency with the language adding a further decrement (Abel et al., 1982; Wilde & Humes, 1990). Previous research has established that, with the high noise levels prevalent on construction sites and the low level of HPD use, there is a high likelihood that workers with more than 5 years experience in the industry will have a degree of hearing injury.

A new style of HPD, incorporating channels, dampers and diaphragms within a custom-moulded plug designed to uniformly attenuate all speech frequencies, has been developed (Berger, 1991). 'Uniform attenuation' HPDs, such as the Hearsaver, manufactured by Ternans Prosthetics, are designed to reduce the distortion of high frequency sounds commonly experienced with conventional HPDs and therefore improve awareness of speech sounds and high frequency warning signals in noise. Whilst there is anecdotal and theoretical evidence of the benefit of uniform-attenuation HPDs in low to moderate noise exposures of 90 dBA or less, empirical evidence is lacking (Berger, 1991). Investigations into the extent of use of HPDs indicate that workers' perceptions of risk, and their need for communication are important aspects of the decision to use or not to use HPDs (Lusk et al., 1994). Uniform-attenuation HPDs may be particularly useful for workers with pre-existing high frequency hearing loss as they could provide effective protection in moderate noise environments with less reduction in perception of speech and warning sounds.

There has been little research into the impact of HCPs on workers beliefs about noise hazards in the industry, their use of hearing protective behaviour, and the impact of such behaviour on the efficiency of communication and production. An education program about noise hazards within the construction industry, entitled "Knock out Noise Injury" has been developed. The education program was designed to address problems relating to workers' identification and management of noise hazards prevalent on large building and construction sites (Milhinch et al., 1997). A study evaluating the efficacy of the Knock out Noise Injury education program in influencing workers perception of noise hazards and their propensity to take protective behaviour was carried out. As well, the efficacy of use of the custom-made Hearsaver Earplug on a construction site was evaluated.

Method

Workers' beliefs about, the nature of the noise hazards in the industry, their current management strategies and the frequency of use of HPDs, were surveyed immediately before, and 4 months after attending the Knock Out Noise education program, and compared to a control group of workers who were assessed but did not attend the education program. The education package included a video of workers discussing their personal experiences of occupational hearing loss, a comprehensive booklet that reiterates the major points of the course, and relevant group activities, one of which uses an audio tape of noises recorded on site. The topics covered include: Warning signs of permanent hearing loss; How to determine whether noise is hazardous; Appropriate and correct use of hearing protection devices; Maintenance of hearing protection devices; Strategies to enhance effective communication in noise; and, Strategies for reducing the amount of noise on site. As illiteracy is not uncommon in the construction industry, all materials were presented orally and visually as well as in printed form.

Subjects. 50 male construction workers from a variety of building trades, whose age ranged was from 19-62 years (mean = 38 years, S.D.= 10.6 years). The subjects had worked in the construction industry for varying periods, ranging from one to 40 years, with a mean of 15 years. Only 26% of workers in the study had previously been trained in HPD use. Forty-six percent had completed an apprenticeship in one of the building trades. Twenty workers were supplied with the Hearsaver custom-made ear plugs.

Results

Prior Use of HPDs. The majority of workers (n = 28) reported using HPDs no more than 10% of the time over the three months prior to attending the education program. Forty percent of workers in the sample reported that they never wore HPDs. Only 22% of workers reported wearing HPDs over 50% of the time in the last three months, and only 4% reported using HPDs all the time. Eighty-six percent of workers in the study had been supplied with HPDs by their employers.

Prior Beliefs About The Noise Hazard. Seventy-two percent of the workers perceived the building and construction industry to be very noisy, and 76% believed there was a high likelihood that they would develop a hearing loss. 53% were aware that they had developed hearing problems. The majority of the sample perceived that the noise could damage their hearing, even when it was not loud enough to cause physical discomfort. However, a significant minority of the sample (20%) thought that only painfully loud noise was damaging and 22% believed that short bursts of loud sound were not dangerous to their hearing. The majority of the workers believed that something could be done to reduce the level of noise within the industry. However, 30% believed that there was no point in complaining about the noise, that doing so could have a negative effect on their prospects for further employment in the industry.

Workers Prior Beliefs About HPDs. Almost half the workers in the study believed that HPDs only needed to be worn when they were using noisy equipment, or when the noise was loud and constant, only a small minority of workers (16%) believed that using HPDs reduced their level of safety in the workplace, 45% believed that using HPDs reduced their ability to communicate effectively in noise, and 30% believed that HPDs prevented the wearer from hearing sounds that they wanted to hear. However, only 8% believed that using HPDs caused them to have more accidents.

Awareness Of Hearing Injury Symptoms. Fifty three percent of the workers reported some hearing difficulties, 53% reported awareness of tinnitus, and 47% reported awareness of temporary threshold shift, over the previous month. Fifty-eight percent of the workers reported family complaint about their hearing ability during the previous month, while 54% had received complaints about the TV volume.

Pure tone audiometry indicated 40% had a notifiable level of hearing injury according to the OH&S (Noise) Regulations (1992), 70% of the noise injured workers were less than 45 years. Under the OH&S (Noise) Regulations, workers who are exposed to hazardous levels of noise are required to have regular hearing screening tests every two years. Sixty-four percent of the workers in this study had been tested within the previous two years. However, 24% of the workers were not being regularly tested, with the average time since their last hearing test being 5.2 years, and 12% had never had a hearing test, despite averaging 9.2 years experience in the construction industry.

Influence Of The Hearing Education Program "Knock Out Noise" On Workers Beliefs

Four months after participating in the hearing education program, significant changes were noted in workers beliefs about the nature of the noise in the building and construction industry and the hazard posed by intermittent loud noise (Table 1). Workers recognised that noise levels in the building and construction industry are high, but they could protect their hearing.

Table (1). Change in workers beliefs four months after attending the hearing education program (n = 30) (scale range from 0 = strongly disagree) to 6 = strongly agree).

Statements about noise in the building and construction industry	Initial mean	Initial S.D.	Initial Mode	F/Up mean	F/Up S.D.	F/Up Mode	t value	p
If you want to work in the construction industry you just have to accept the noise.	4.1	2.0	6	2.7	2.2	0	3.03	.003
Overall the noise levels in the construction industry are high.	2.5	1.9	3	1.6	2.0	0	2.014	.03
Very few construction workers develop hearing problems.	2.3	2.1	2	1.3	1.5	0	2.346	.01
Noise is only dangerous when it is so loud that it hurts.	2.3	2.3	0	1.0	1.7	0	2.844	.004
Short bursts of loud noise are not dangerous to my hearing.	2.2	2.1	0	.4	.7	0	3.906	.001

The education program, "Knock Out Noise Injury", was well received by the participants. Significant changes were recorded in workers perception of the benefits of wearing HPDs, and the situations where HPD use was appropriate (Table 2) .

Table (2). Changes in workers beliefs about HPD, 4 months after attending the hearing education program (n = 30). (scale range from 0 = strongly disagree) to 6 = strongly agree)

Statements about the use of HPD in the building and construction industry	Initial Mean	Initial SD	Initial Mode	F/Up Mean	F/Up S.D.	F/Up Mode	Paired t	p
Only need to wear HPDs when using noisy equipment.	3.3	2.1	0	2.4	2.2	0	2.011	.03
You only need hearing protection if the noise is loud and constant	3.3	2.2	0	2.3	2.4	0	2.05	.03
Wearing hearing protection is unsafe because it blocks out danger signals&warning sounds.	2.5	1.8	3	1.8	1.7	0	1.761	.04
People who use hearing protection regularly get ear infections.	2.0	2.0	0	1.3	1.6	0	2.282	.02
Wearing hearing protection doesn't stop you getting a hearing loss.	2.8	2.0	3	1.7	2.0	0	2.057	.02
People wearing hearing protection are hard to work with.	2.2	1.9	1	1.7	1.8	0	1.751	.05

However, despite the majority of workers reporting significant increase in HPD use after attending the education program (Table 3), 25% of workers still reported not using HPDs, and many workers recognised that they were still not always wearing HPDs when they should be, reiterating the need for ongoing encouragement, education and supervision to develop safer work practices.

Table (3). Change in reported use of HPD after attending the hearing education program.

Reported use of hearing protective devices	Group	Initi Mean % use	Initial SD	F/Up Mean % use	F/Up SD	paired t	p
During the past three months in your work area, what percentage of time would you say you actually used hearing protection?	Education	23.2	25.3	35.3	29.6	2.332	.01
	Control.	24.7	35.8	26.1	30.9	-.257	ns

Evaluation of Uniform Attenuation Ear Plugs. The uniform-attenuation ear plugs were trialed as a means of addressing the increased communication problems that workers with a hearing injury experience when wearing traditional HPDs. Workers who were aware that they had a hearing loss tended to use the custom-made plugs more frequently than hearing injured workers using traditional HPD, and report less impact on their ability to communicate. However, these differences were not statistically significant. A further study involving only hearing injured workers is required to establish the appropriateness of the protection provided by these uniform-attenuation earplugs. The improved comfort of the Hearsaver earplug as a result of it being custom moulded was frequently cited as its' major benefit. However, this form of HPD does not appear to be suitable for all activities on a building and construction site. For example, a crane crew participating in the trial, found that, despite the improved perception of high frequency speech sounds, they were still not able to hear conversation over a two-way radio, and had problems hearing their mobile phones.

In Summary. Four months after completing the "Knock out Noise Injury" hearing education program, construction workers reported significant changes in their beliefs about the hearing hazards prevalent in the industry, and a significant increase in their use of hearing protective behaviour. Workers responded favourably to an education program based on examples of situations and equipment to which they are commonly exposed on building and construction sites. The finding that some workers were still inadequately protected indicates the need for ongoing education to reinforce consistent use of hearing protective behaviour, and further research to examine alternative forms of HPD suitable for the particular needs of the building and construction industry.

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THE INFLUENCE OF NOISE EXPOSURE IN MIDDLE EAR MECHANICS

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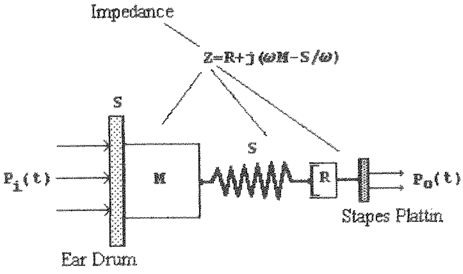
1. INTRODUCTION

Exposure of ears to pressure changes in the order of hundreds of daPa (deca Pascal), may cause permanent decrease in the rigidity component of middle ear impedance. In practice, middle ear flaccidity causes quick speech intelligibility degradation, even if the tonal thresholds are normal. The aim of our study is evaluate if prolonged exposure to high sound pressure levels witch are between 0.355 Pa (85 dB SPL) and 20 Pa (120 dB SPL) can also induce permanent flaccidity of the middle ear.

2. MIDDLE EAR AS A MECHANIC SYSTEM



$$S>>M \longrightarrow S\approx 1.8\times10^{6}\ \text{dines/cm}^{3} : M\approx 0.05\text{g}$$

Figure 1. A simplified representation of the middle ear as a mechanical system

Middle ear behaves like a complex mechanic system with several components of mass, rigidity and friction. The mass of the ear bones, the rigidity of the eardrum and of bone ligaments and the friction of bone articulations and of the air in the tympanic box.

When we apply a pressure on the eardrum we induce a displacement of it, and all middle ear transmits a pressure to the oval window that results itself in a displacement of the endolymph in cochlea. The way as the tympanum motion behaves due to a given pressure is dependent of the physical characteristics of the bones, ligaments, tympanum rigidity, etc. and this set of variables is called impedance (Z in Figure 1). Normal middle ear has a mechanical impedance that changes with frequency variations in some of its components. Friction is not frequency dependant, the component of rigidity has prevalence in low and middle frequencies up to about 900 Hz and mass has prevalence in higher frequencies. Figure 2 shows the behaviour of Admittance (Y) witch is the reciprocal of Impedance and its components.

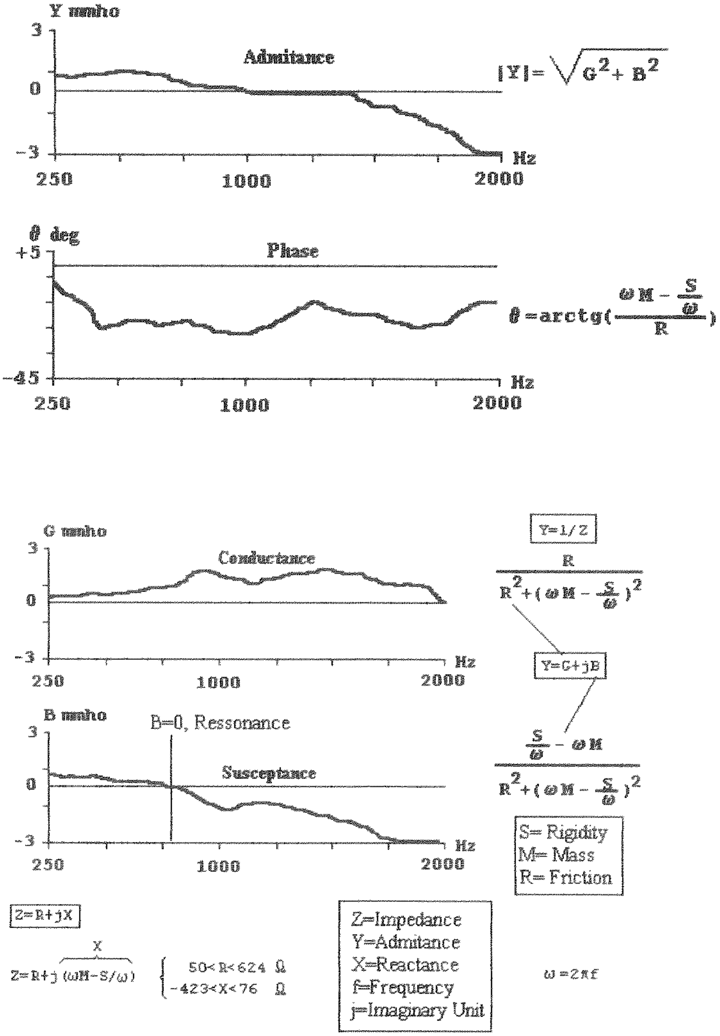


Figure 2. Behaviour of middle ear mechanical response to frequency

3. INFLUENCE OF RIGIDITY DECREASE ON SPEECH INTELLIGIBILITY

As seen on Figure 2, if the rigidity (S) decreases middle ear will have mass prevalence at lower frequencies.

We have made a study on crew people of our national air company TAP-Air Portugal, evaluating audiologicaly their hearing conditions. The first interesting conclusion we got is that most of them had enlarged admittance values in middle ear tests, above 1.6 mmho and this proves that prolonged exposure to pressure changes of the order of hundreds of daPa induces permanent middle ear rigidity decrease. The second conclusion was that people with normal threshold audiograms and with low rigidity of middle ear showed their speech intelligibility quickly compromised (Figure 3).

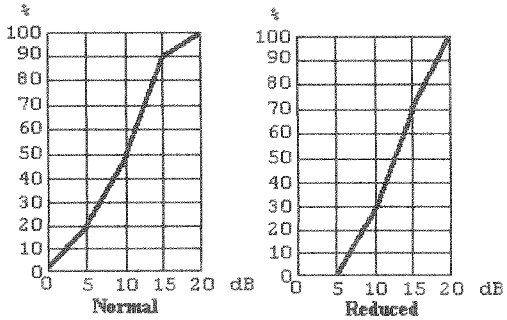


Figure 3. Speech intelligibility curve for disyllabic words. At right the curve found in people with middle ear low rigidity and normal tonal hearing thresholds

From this study we concluded that people who get permanent middle ear flaccidity has his speech intelligibility compromised witch can be an occupational problem in pilots.

4. STUDY ON PEOPLE EXPOSED TO NOISE

From our data base we selected from a group of 3903 people exposed to noise above 85 dB A weighted and not exposed to significant pressure changes, those who had their

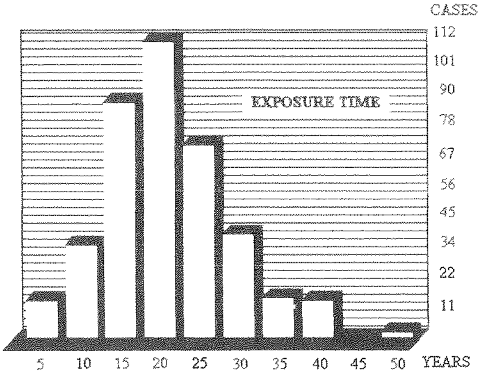


Figure 4. Time of exposure to noise of the population in the study

middle ear with admittance above 1.5 mmho at least in one ear. On the other hand, we selected from a reference group of 799 people with no exposure to noise and not exposed to significant pressure changes, those who had their middle ear with admittance above 1.5 mmho at least in one ear. We found 393 cases (10.1%) in the study group and 108 cases (13.5%) in the reference one. The time of exposure to noise of the study group is represented in Figure 4 and Table 1 shows the results for that group.

Y (mmho)	**freq.**	**Av. Age**	**Av. Time Exp.**
1.6	65	47	21
1.7	50	46	21
1.8	30	50	23
1.9	40	49	22
2	18	44	21
2.1	20	48	20
2.2	20	46	21
2.3	6	52	24
2.4	18	44	19
2.5	14	46	17
2.6	19	49	23
2.7-3	31	48	20
3.1-3.5	26	44	17
3.6-4	14	45	21
>4	22	46	21

Table 1. Results for people exposed to noise above 85 dB (A)

The percentage of flaccidity incidence is not very different in both groups and in the exposed group we didn't found any correlation between the value of Y and noise levels nor time of exposure. In conclusion, it seems that the highest sound pressure levels doesn't induce permanent flaccidity of the middle ear, hence not contributing to jeopardise the already bad situation in speech intelligibility that exists in people suffering of noise induced hearing loss.

COMPARISON BETWEEN SUBJECTIVE AND OBJECTIVE OF AUDIOMETRIC HEADSET AND MILITARY HELMET ATTENUATION

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1. INTRODUCTION

Hearing protection device (HPD) attenuation evaluation methods may be broadly categorize into subjective and objective procedures. Loudness balance (LB) technique offer no methodollogical advantages over real ear attenuation at threshold procedures, except for less stringent requirements on background noise. Weinreb et al[1] evaluted two circumaural HPD's and two headsets, crabtree et al[2] evaluated active noise reduction headsets by (LB) procedure. Zera et al.[3] used miniature microphone at subject's concha to measure the insertion loss (IL) of communication headset.

The aim of this study is to provide some further data on the acoustical process involved IL and LB measurements, and the relation between both quantities under diffused field condition.

2. EXPERIMENTAL ARRANGEMENT AND PROCEDURE

A. Measurements of loudness balance

The subjects participated in the two experiments were five trained listeners who had normal hearing and their age ranges from 22 to 52 years. The audiometric Headset, and Military Helmet tested by the LB procedure. In this procedure, the subject is required to compare the loudness of test stimulus when the protector is first worn, and then not worn. The adjustment process requires the subject to don, or doff the protector before presentation of the next stimulus. Thus, the subject task requires memorizing sounds (reference stimulus = 60 dB), while the measurements are changes. The cycle of the protector (on – off) was repeated 4 times at each test frequency. The algebraic difference, in dB, between the SPLs of the two stimulus at LB was the attenuation of the protector under test. All measurements of LB were conducted in diffused-field and performed at 6 Frequencies 0.25, 0.5, 1, 2, 4 and 8 kHz. The octave noise was deliverd from loudspeaker positioned at corner of the

NIS reverberation room facing the subject who sat on the chair at 2 meter apart from it.

B. Measurements of insertion loss

The attenuation of the two devices has been obtained from SPLs measured by a miniature microphone in the subject concha. The measurements were conducted using the same sound source. The noise were presented continuously at the same frequencies and the level of it measured at centre head position with subject absent was 80 dB. The insertion loss is the algebraic difference, in dB, between SPLs measured by the microphone at conch under specific condition with device off and with device on. Each measurement of device (on–off) was repeated 6 times for each subject. Subjects readjusted the position of the device on the head between consecutive measurements.

3. RESULTS AND DISCUSSION

The attenuation obtained using subjective (loudness balance) and objective (insertion loss) methods for Audiometric noise excluding headset and Military Helmet headset is shown in Figures 1 and 2 respectively. Individual results for five subjects are shown in different panels, as well as the mean and the corresponding standard deviations calculated from results of all subjects.

For Audiometric Headset (Fig.1), the attenuation changes from approximately 15 dB at 500 Hz to about 40 dB at 4000 Hz. The IL measurements provided larger estimates of the attenuation than the LB measurements at frequencies 1,2 and 4 kHz by 2.5, 4 and 4 dB respectively (see mean values). The tendency to obtain the smaller estimates of attenuation by LB method is consistent across all five subjects except at 2 kHz for the subjects S2 and S4.

Overall the two methods provided similar results, though some intersubject variation can be seen in the data. The attenuation measured at 1,2 and 4 kHz by IL method was substantially larger than measured by LB method by 3 dB for subjects S1, S3 and S5. A similar difference with negative value, in attenuation at 2 and 4 kHz was only observed for the subject S2 and S4 respectively. This pattern of results remained even after extensive repetions of LB measurements.

The attenuation of Military Helmet is shown in Fig. 2. The attenuation changes from approximately 5 dB at low frequencies to about 35 dB at high frequencies. The Military helmet displayed the smaller intersubject variability in the results than the Audiometric Headset. Also results obtained using LB method were consistently smaller than those obtained by IL method at frequencies 0.5, 1 and 2 kHz (see mean values), as observed by the Audiometric Headset. Finally, we can say, the measurements of IL will depend on the position of the microphon within the earupp of device, and may poorly represent the pressure at the eardrum. Hence the subjective measurements may yield results that differ from the IL measurements obtained using the microphone in the concha. Also the intersubject variation again suggest that the same device performed differently on each subject.

4. CONCLUSION

This investigation indicate that, the Audiometric Headset attenuate ambient noise particulary in the 0.5 – 8 kHz region some what more effectively than does the standard supra-aural audiometric headset. School and Industrial conservation program should be benefited by attenuation of ambient noise by Audiometric headset in this study.

We conclude that the noise attenuation of greater 20 dB is needed because modern fighters and helicopeters often have a noise level higher that 100 dB in the cockpit. Therefore, the noise attenuation properties of aviatiation helmets should not be forgotten in helmet headset design.

Further work should be done to establish the relation between the two

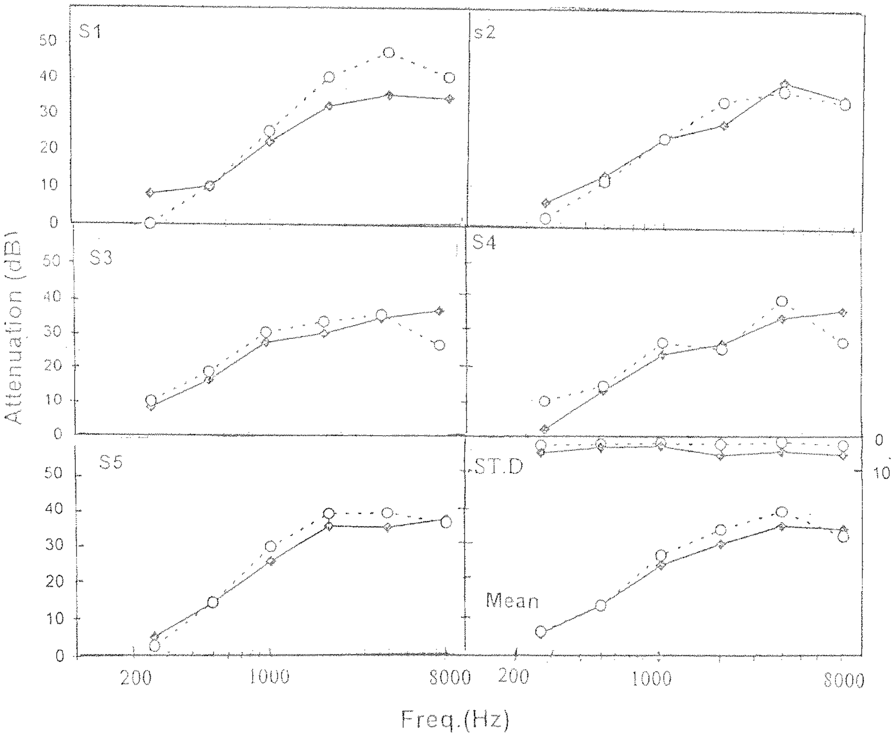

Figure (1) Comparison of Adiometric headset attenuation measured using LB (—◆—) and MIRE (···○···) procedures .The mean values and the corresponding ST.D. are shown .

methods of measuring attenution so that realistic values can be utilized for calculating exposure time and ear damage risk. Also for standardization purposes it is acceptable to limit the number of measurements performed by each person on one device and increase the number of subjects and the number of device samples.

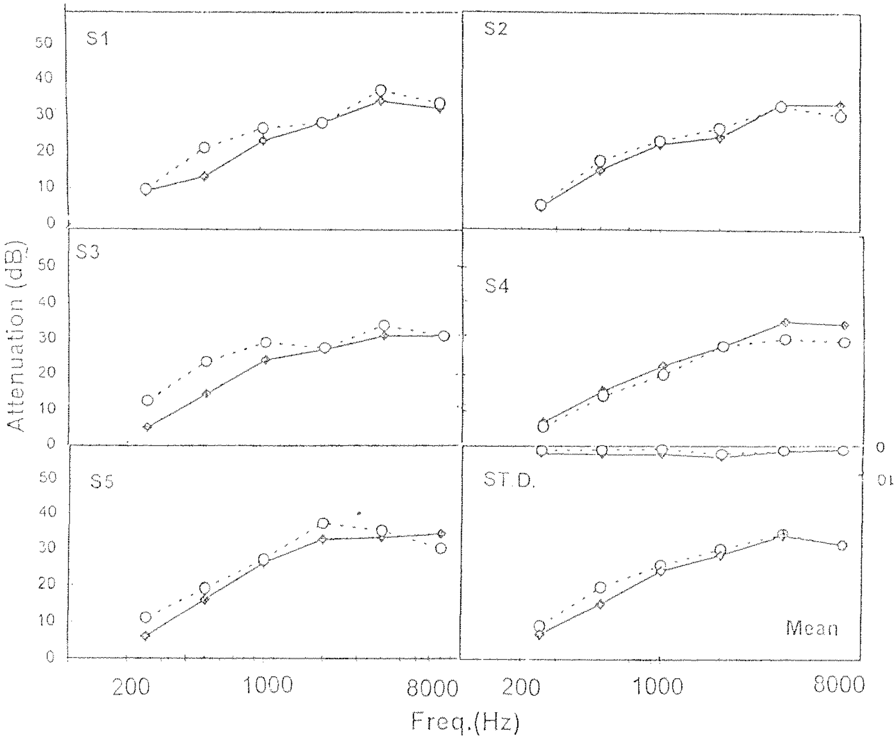

Fig.2 Comparison of Milatery Helmet attenuation measured using LB (——◇——)and MIRE (- - -o- - -) procedure. The mean values and the corresponding ST.D. are shown.

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WARNING PEOPLE THROUGH NOISE

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1. INTRODUCTION

People working in noisy, as well as quiet, environments are often exposed to warnings during the normal course of the day. These warnings can exist in a variety of formats, ranging from warning signs, through symbols, speech, to nonverbal auditory warnings, and they can vary in their range of severity from simply notifying people about normal everyday events to signalling potentially life-threatening events for which immediate action is necessary. In addition to there being a range of warning types and significant variation in the severity of the hazard of which the warning is informing, there is significant variation between the skills that the recipients of warnings may bring to a situation. At one extreme there is the highly trained individual working in a well-learned situation, where the meanings of each of the warnings may be overlearned and experienced as a matter of course during his or her everyday work. At the other extreme there is the public at large, often with no special training, being exposed to a steadily increasing number of warnings of all types during the course of a normal day both at work and at play. There is no doubt that there has been an increasing tendency to warn over the last few years, stemming largely from both an increase in safety awareness and an increasing trend towards accident litigation. Thus as a research topic warnings are worthy of considerable attention.

The issues which surround the proper use of warnings are thus wide-ranging and encroach on a number of academic disciplines from psychology, through typology and design (for warning signs and symbols), through acoustics and psychoacoustics (for auditory warnings), through engineering and speech technology, to legal issues and standardization and other practical and pragmatic issues such as deciding when to warn and when not to warn. Even within a single discipline such as psychology, the issues which surround warnings range from those which are the concern of perception, cognitive psychology and cognitive engineering, through to those typically the concern of social psychology such as compliance. In this paper I will be looking at several of the specific questions and issues surrounding warnings in noise, whilst calling on the more general warnings field where necessary and appropriate.

2. SELECTING A WARNING MODALITY

If an environment is noisy, and/or possesses a complex and fluctuating noise spectrum, then the decision as to whether providing yet more auditory stimulation in the form of auditory warnings needs careful consideration. A well-used table by Deathridge [1], presented in Table 1, gives us a general guide as to when it might be best to use one or other of the major sensory modalities of sight and hearing depending on the prevailing conditions.

Use auditory presentation if:	Use visual presentation if:
The message is simple	The message is complex
The message is short	The message is long
The message will not be referred to later	The message will be referred to later
The message deals with events in time	The message deals with locations in space
The message calls for immediate action	The message does not call for immediate action
The visual system is overburdened	The auditory system is overburdened
The receiving location is too bright or dark-adaptation integrity is necessary	The receiving location is too noisy
The person's job requires moving about	The person's job allows them to remain continually in one position

Table (1). Guidelines showing when to use visual or auditory forms of information presentation (from Deathridge, 1972)

In noise therefore, the most appropriate modality for warnings is not necessarily the auditory sense, and alternatives should be sought. Sanders & McCormick [2] suggest that the auditory medium is preferable to the visual when the origin of the source itself is a sound; if the message is simple; if the message will not be referred to later; if the message refers to events over time (especially if sound is being used to monitor an ongoing event); if continuously changing information of the same type is presented; if the visual system is overburdened; if speech channels are fully employed; if illumination limits vision; and if the receiver is moving from one place to another. Advances in auditory displays, particularly 3-dimensional head-up displays, means that location in space can now be dealt with by either the auditory or the visual modality. In addition, speech technology and the design of hearing protectors are both areas in which enormous advances have been made, with the result that some of the constraints which might have been placed on the use of the auditory modality in noisy environments in the past are no longer as relevant nowadays. One compelling reason for favoring the auditory sense for warnings even though it may be technically difficult to implement them in a noisy environment is that our hearing is generally regarded as our 'warning sense' far more than our vision, which in order to function as such relies on us both looking at the right place at the same time and then, importantly, doing something about the warning we have just received. Experiments which have tested a range of warning formats tend to show that compliance levels are much higher for warnings presented in an auditory, rather than a visual, format. A study by Wogalter et al [3] for example showed that a voice warning increased levels of compliance fivefold when compared to other experimental manipulations such as posted signs, pictorials, and strobe lights. Thus the decision as to which modality or modalities to use requires serious thought, although fortunately there are tables and guidelines to help us.

3. AUDITORY WARNING DETECTION

Detectability

If a decision is made to implement auditory warnings in noisy environments, the first essential requirement is that they must be heard. Fortunately much is known about the detection of sounds in noisy environments (see for example Sorkin [4]) and at least two expert systems with supporting software are available for determining the appropriate levels for auditory warnings in noisy environments. Patterson [5] proposed a set of guidelines based on earlier work on the auditory filter [6], [7], [8]. The main recommendation for detectability to be ensured is that alarm sounds should not be less than 15dB above masked threshold and not more than 25dB above masked threshold. Similar recommendations are made by Sorkin [4], although the higher limit is set at 30dB. The lower level can be computed by taking noise measurements in frequency bands and predicting threshold for each band by applying auditory filter models. By 25dB above masked threshold, a warning (or any other signal) is hard to miss. Thus there is nothing to be gained by making warning signals louder than this, and in fact there is much to lose as people will do a number of things if an alarm is too loud: they may disable it, and then fail to turn the alarm back on again for a future incident; they may have their speech disrupted at the very time that the need to communicate; or they may be startled, which will affect their performance on the task in hand.

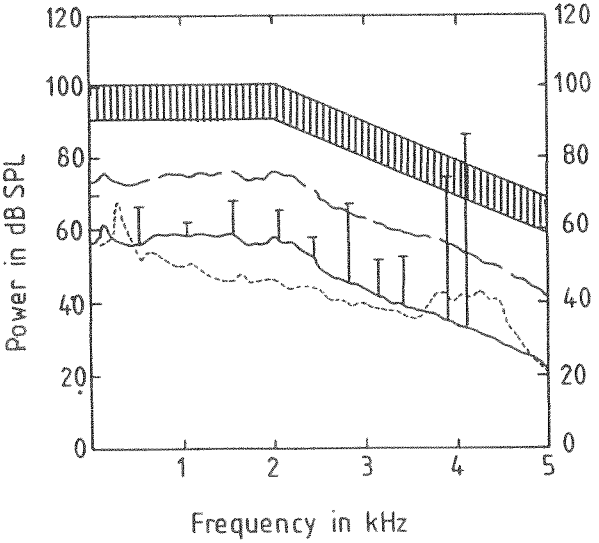

Figure (1). Noise spectrum, threshold, appropriate band and warning component levels for a BAC 1-11 aircraft (from Patterson [5]).

Patterson's guidelines are useful not only for establishing appropriate levels for auditory warnings, but also for determining the appropriateness or otherwise of existing warnings. In Figure 1, the lower solid line shows the spectrum of level-flight noise in a BAC 1-11. The broken line above this shows auditory threshold, and the shaded band above this shows the appropriate level for auditory warning components for this noise environment. The vertical lines show the individual components of a firebell used on this aircraft. From the diagram, it can be seen that eight of the ten components are insufficiently loud to be heard given the noise spectrum of that environment. Only one component lies within the appropriate band, and one component is too loud, which will cause startle and annoyance especially as its frequency is also high. This situation could be remedied by boosting those components which are too low and reducing the high one so that all of the components fit within the shaded band.

A second approach, by Laroche et al [9], is based on Zwicker & Scharf's auditory filter model [10] , which has been validated for a larger range of frequencies than Patterson's model (63Hz to 12.5 kHz in the case of Zwicker & Scharf) and has been adopted as a general standard. Laroche et al's approach also incorporates other filter models. The approach taken is to generate an excitation pattern from 1/3 octave band measurements of noise, warnings, and other sounds in the environment, and then to generate excitation patterns for each of these sound sources. The excitation patterns can then be superimposed on one another, and if one pattern completely covers another, then the covered sound will be inaudible. The approach also takes into account some kinds of hearing loss as well as modifications caused by hearing protectors, which can be taken account of as the excitation pattern is produced. Laroche et al's model is very useful for making predictions about audibility in general work areas such as factories and hospitals. A study by Momtahan et al [11] using 'Detectsound' (the name of Laroche et al's model and computer program suite) demonstrated that many of the alarms and other sounds typically heard and used within a hospital's operating room and recovery room were masked by a number of significant sounds in this environment. In particular, an orthopedic drill masked at least a dozen other alarm sounds, so if any of these were to sound when the drill was being used, they would go undetected. The solution to this problem is not necessarily to increase the loudness of the quieter alarms, as this would only serve to increase the general noise levels in the hospital, which is no good either for staff or for patients. Rather, the ways alarms are used within such environments needs to be reassessed, in much the same way that dealing with a noisy environment is often dealt with more efficiently by introducing noise reduction policies than through finding more and more complex and elaborate methods of reducing the impact of noise on the hearer (such as the use of hearing protection devices).

Momtahan's study also demonstrated another practical shortcoming with the alarms under consideration, namely that of the forty-nine (in total) alarms typically used in the operating theater and recovery room being investigated, trained medical staff could identify just less than half on average. Further details of the work described above can be seen elsewhere [12]. This evidence adds to the argument that the way alarms are used in this (and most similar) environments needs to be reassessed.

Other acoustic issues

Other important issues in the acoustic stage of warning implementation in noisy environments include those of localizability and the use of hearing protectors.

Localizability of warning sounds, as with any sounds, will be improved if many, rather than a few, components are present, and particularly if these are in the range 500-5000Hz. Single, continuous sinusoids, so typical of hospital equipment alarms, are amongst the hardest sounds to localise (and are hard to discriminate between because of the way we encode pitch information at a cognitive level).

The wearing of hearing protectors typically reduces the overall noise level at the ear, but does not generally improve signal-to-noise levels (although there are certain regions in which the perception of speech can be improved, see Jones and Broadbent [13]). Ear plugs can also be beneficial, and can interact favorably with hearing protectors. Although hearing protectors can have occupational benefits, there are some potential drawbacks in the detection of warnings signals specifically, particularly speech, which is why it is recommended that noise reduction policies are a better answer to occupational noise problems than the ubiquitous use of hearing protection devices [13]. Hearing protectors can also affect localizability of sound, including alarm sounds [14]. It needs also to be borne in mind that some users of hearing protectors may already be suffering some hearing loss, which will make the prediction of their ability to hear warning sounds a further issue for consideration [15]. Both areas, localizability and the use of hearing protection devices, are highly technical and theoretical fields for which appropriate theory and modelling exist.

4. DESIGN OF AUDITORY WARNINGS

For a complex, fluctuating, and high-level noise environment it is probably easier to design nonspeech warnings than it is to design adequate speech warnings. This is not to say, however, that ways of reducing and simplifying the noise environment should not be sought, thereby making the implementation of either speech or nonspeech warnings a possibility. Furthermore, for some environments a mixture of the two might be the most appropriate design approach as for example a single nonspeech warning amid a set of speech warnings will have particular salience in the same way that a single speech warning will have added salience amid a set of nonspeech warnings.

Nonverbal warnings of the traditional type have generally consisted of devices such as horns, bells, buzzers, klaxons and the like. With the advent of digital technology, it is now possible to make almost any kind of sound for use as a warning sound. This itself introduce both new concepts and problems. One issue revolves around the number of warnings that can be produced. For example, a single piece of medical equipment can be armed with many different alarms which can signal changes in patient condition, equipment malfunction, changes in electricity supply, whether or not the machine has just been switched on and so on. A single patient in an intensive therapy unit could have several such pieces of equipment attached to them, meaning that the potential number of alarms which can sound even for a single patient can amount to thirty or forty. This is clearly unergonomic. A second major issue which is brought to bear is that just about any sound can now be constructed for use as an alarm sound. The question as to which (probably small) subset of possible sounds are actually suitable for warning purposes is one to which little research effort has as yet been directed. In the second part of this paper I wish therefore to look in some detail at the ways different types of sound are, and could be, used for alarm purposes.

Listening to sound

Once a sound is detected, it is necessary to interpret that sound in some way. This is just as true for alarm sounds as for other sounds, and indeed there are specific acoustic requirements of an alarm sound over and above that of simply being detected which may help it to stand out over other, more usual, sounds in that environment. This has traditionally been the approach which centred around the use of such sounds as sirens, horns, bells and klaxons which are generally firmly entrenched in the psyche of most listeners and are understood to be warning sounds, even if it is not always the case that the meanings of the sounds are specifically understood [16]. Indeed, there is some evidence which suggests that they way in which we listen to warning sounds is different to the way in which we listen to other sounds [17]. The interpretation of a sound as an alarm sound does not just depend on the structure of the sound itself, though; it also depends on what sounds mean to the listener. For example, if the flood alert on a submarine is known to be the nursery rhyme 'Baa Baa Black Sheep', not typically known for its alerting and attention-getting qualities, then hearing that tune will have a considerable impact on a submariner, especially if they are currently on board a submarine. Furthermore, the sounds of objects and events themselves, at least at a general level, can be thought of as 'warnings' as they tell us of actual and impending events. For example, the noise outside my window can tell me that an aircraft is currently flying over my house. I can tell not only what the object is, I can also tell how close it is (too close) and the speed at which it is approaching (too fast) by the overall level of the noise, and by the rate at which the level, and to some extent the spectrum, is changing. I am not consciously carrying out an acoustic analysis, but at some perceptual and cognitive level I am interpreting this information on the basis of both the acoustic information provided and my past experience with it. Thus in a sense I am being warned through the noise of the object or event itself.

The philosophical discussion as to whether everyday sounds telling us of events which we might like to avoid are actually warning sounds is one which requires some consideration, although it is probably most parsimonious to think of warnings as sounds, words, or symbols which 'stand for' an event or object rather than being those events themselves (and the sounds that these events and objects make [12]). But the ecological approach to acoustics and psychoacoustics [18], which takes as one of its central premises that one of the main purposes of the auditory system is to identify and enumerate the sound-making objects within the immediate environment, can help in both thinking about the design of warnings sounds and in understanding how people listen to and interpret those sounds. For example, using real, everyday sounds as warnings may be effective as a design protocol; and if sounds possess affordances [19] then it might be as well to find out what these are, as this can also inform warning design as it will shed light on the interaction between sound structure, knowledge of sound and action. In the following section, some modern approaches to warning design will be reviewed.

Warning design protocols

Many alternatives to traditional warning design, sometimes quite radical, have been proposed over the last few years. A few of these are highlighted below.

Patterson's approach. Probably the most influential new approach to auditory warning design was proposed by Patterson in support of his guidelines [5]. Warning sounds are constructed from a small unit of sound, only a few hundred milliseconds in length, called a pulse of sound. The pulse is harmonically complex, to aid in localisation and to reduce the possibility of masking as the noise level fluctuates and varies. The pulse also has a shaped onset envelope in order to avoid startle. The pulse of sound is then repeated several times, possibly at different levels and at different frequencies, to form a burst lasting one or two seconds in length. The burst can be made to have a distinctive temporal pattern, which will aid in identification and discrimination. The burst then forms the basis of the complete warning, whereby the bursts are played singly, or in pairs, or some other format which is then followed by silence. The purpose of the silence is to allow communication to take place, one thing that is essential when warnings are heard. The bursts can be played at different speeds, pitches and loudness levels in order to vary in urgency as the event progresses [20], [21].

This design protocol has many advantages over traditional warnings aside from potentially being tailored correctly to the noise environment, as described earlier. They allow communication to take place, and the can be varied in their urgency both as a single warning progresses, and across warnings. This design protocol has been adopted in the deign of warning sets for military helicopters as well as hospitals [22], [23].

Stanford & McIntyre's approach. A series of studies by Stanford, McIntyre and others [24], [25], [26] showed that a set of anaesthesia alarms contained many sources of confusion both in terms of localisation of the warning sounds and the identification of them. They proposed a set of warning sounds to replace these warnings, and the basic building block of the warning sounds was again a small unit of sound, like Patterson. However, in this particular example the researchers constructed vowel-like segments which were put together in different ways to signify different events. Each of the resultant warning sounds lasted from a half to one second. The individual segments consisted of low and high values of the vowels 'i', 'a', and 'u' each with a rich harmonic content and with frequency modulation, and the complete sounds consisted of several segments. For example one of the signals consisted of the sequence low 'a', high 'i', low 'a', high 'i', low 'a' and high 'i' with each of the segments lasting 100ms except for the first and last. On testing, the researchers found that each of the newly-designed sounds were highly detectable even at a signal-to-noise ratio of -24dB, which was far better than that which was achievable with more traditional sounds.

Aesthetic responses to the sounds were also collected and again the new set of warnings compared very favorably with those currently is use, gaining far fewer negative responses than traditional warnings. Positively liking a warning set is not important, but disliking a warning is important as it is more likely to be turned off if it is disliked. As in the Patterson set, time would need to be taken to learn these new sounds as the association between the warning and its meaning is not necessarily immediately intuitive or obvious.

Using auditory images. The study of ecological acoustics tells us that people do not necessarily carry out an acoustic analysis of the sounds that they hear, but use sound as a way of identifying which, and how many, objects are in our immediate environment. Given information over time, we can also infer what is happening to those objects. For example, when we hear a sound our first naturally occurring response to the sound is the name of the object or event making that sound, if it can be identified [27]. It seems reasonable to infer then that if we can provide auditory images and real environmental sounds as warnings, then our responses to them will be intuitively obvious. We should not need to learn what the sounds mean, and we should not be restricted in the number of sounds that we can have in a warning set because in our everyday environment we are able to identify literally hundreds of different sounds. Using everyday sounds as background feedback to ongoing events can therefore be quite effective, especially if the tasks themselves are being done remotely, for example from a computer screen [28], [29]. Whether using everyday sounds as warning sounds can be effective has yet to be determined. This rather depends on the way we listen to sounds in general and warning sounds in particular, which, as Ballas says, may be different [17]. The role of traditional warnings sounds here has an interesting position in the theory. While traditional sounds are generally abstract in nature, unlike everyday concrete sounds, they do have the advantage of being generally understood as warning sounds [16] and do, to that extent, have meaning and affordance. Thus while they may not stand for specific events or objects, they do stand for 'danger' in more abstract way and so could be quite effective under some circumstances. Of course traditional warnings do have many drawbacks (they are too loud, intrusive, insistent and so on) but it is possible to resynthesize sounds so that they contain the essence of the sound while removing other parts. Thus it may be possible to resynthesize a sound so that it retains the essence of the traditional sound (and thus retain any meaning already associated with it) while reducing its adverse qualities. For example, a horn spectrum could be tailored appropriately to the noise environment in which it was intended for use, possibly in a Patterson-style format. In this way, we might have the best of both worlds.

In terms of using environmental sounds as warnings there are many issues, both theoretical and practical, which require further investigation before recommendations can be made. A recent study [30] has shown that although it might be easier to learn real, concrete sounds than it is to learn abstract sounds, this advantage only occurs if people are told how to encode the sounds. If they are left to generate their own methods of encoding, this advantage disappears. It is important too to develop ways of finding out from people what they understand about sound, and particularly those sorts of sounds which might be used as warning sounds. A methodology has been developed but has only currently been minimally tested [31], [32].

5. RESPONDING TO WARNINGS

Within the auditory warnings field in particular, the main focus of research interest has been the issues surrounding detectability and design. It is true to say that the way in which auditory warnings are responded to has been less well investigated, although this is at least as important as those other issues. Some studies have compared responses to speech and nonspeech warnings, showing some advantage for speech over nonspeech warnings, although the nonspeech warnings used in these studies were no more than alerting tones, certainly not of the more advanced, and potentially more information-rich, warnings which have been developed more recently [33].

There are approaches and models which would allow the whole sphere of activity surrounding auditory warnings to be studied. For example, Woods' approach [34] of looking at dynamic fault management and directed attention within the context of alarms and Stanton's 'alarm-initiated activities' [35] both provide a broad context in which to look beyond the issues of detection and design, considering the way in which alarms, responses to them, and the context in which alarms are heard and seen all interact in occupational and other settings.

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NOISE AND COMMUNICATION: THE PRESENT STATE

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Interpersonal communication by means of speech is one of the most natural of human needs. The disturbance of such communication by noise, either directly in the form of interference or indirectly in the form of hearing damage or even other parameters, has also been the subject of research over the past few years.

Mainly three areas are addressed here: speech communication, signal recognition and hearing protection. In all these areas recent studies have been concerned with the influence of hearing impairment on the process of communication.

Signal Recognition

Malter & Guski (1999) simulate the various models for estimating signal recognition, a comparison being made either between the sound level in third-octaves or octaves (ISO 7731, Quoc & Hetu 1996) and the loudness according to Zwicker (Lazarus et al. 1983, Liedtke 1997) or the spectral components of the signal and the masked threshold (Patterson). In accordance with these models hearing protection and hearing impairment reduce the recognition of signals (Liedtke 1997, Coleman 1998). The perceived urgency and the response time were investigated for three warning signals (Haas & Casali 1995). Edworthy (1994), using Stevens' Power Law, derived urgency exponents for four auditory warning parameters. Stevens Power Law states that subjective value given by a stimulus = $K \cdot M^m$ (M = value, K = constant). The exponent (m), revealed when subjective and objective values are plotted against one another and the result is fitted by a power function. The higher the exponent, the stronger the parameter in producing changes in perceived urgency. With Edworthy (1994) the main parameters for urgency are speed ($m = 1.35$) (measured by pulse-to-pulse interval), number of repetitions (0.5), pitch (0.38) and degree of inharmonicity (0.12).

Audibility problems were observed with alarms in apartment buildings (Proulx et al. 1995)

Factors That Affect Direct Speech Communication

Speech communication involves a speaker and a listener who exchange roles constantly. The conversation is influenced by several factors, the physical properties of which are widely known. The speaker varies the loudness of his voice. The speech sound propagates through the room, is disturbed by noise as well as reverberation, and then reaches the listener.

The Speaker

Depending on his purpose or the type of communication, the speaker uses different vocal efforts, i.e., he whispers, uses normal voice or shouts. If a speaker must speak in noisy surroundings (L_{NA}), he will automatically speak louder than in quiet surroundings. This effect was named the Lombard effect.

The influence of further parameters on the rise in speech level is repeatedly the subject of research: The influence of the spectrum of the noise, the variability of the level rise, the influence of the sex of the individuals, the distance of the interlocutor, the kind of spoken text and the intelligibility of loud speech.

In an extensive study (Junqua 1993) the Lombard effect was examined. 10 speakers (male, female) spoke 6 different linguistic items quietly and at 85 dB (under headphones). The rise in speech level was 4 to 24 dB. The experiments show (1) when using additive white noise, and when the perceptual tests were performed on the complete vocabulary studied, confinable vocabularies (except the subset {m, n}) are less intelligible when produced in noise that when produced in quiet; (2) there is a strong interaction between the type of noise used and the intelligibility scores obtained; (3) in the presence of multitalker noise, female speakers are more intelligible than male speakers. This result may be related to a decrease of the breathiness of female speakers for Lombard speech; (4) when speech is produced in noise, there is a decrease of the consonant-to-vowel energy ratio for some of the speakers; and (5) the vocabulary size influences the judgements of intelligibility by the listeners.

The vocal response of speakers to change of distance from a listener is under discussion. The results of a new study by Michael et al. (1995) are in contrast to others, which found that speakers obeyed the inverse square law when compensating for distance changes. Speakers in this present study changed their vocal intensity to compensate for changes in doubling distance but by a maximum of 2.5 dB. There are four groups: normal ascending and descending and two correspondent "barely" groups. The ascending and descending groups, where the microphone for the listener was moved to the speaker or away, showed no differences. The reasons for different results may be different vocabularies used and various acoustic characteristics of test rooms.

The influence of the effects of variation in Talker characteristics was investigated (Sommers 1997). There are two stimulus conditions: single-talker and multiple-talker condition. The ten talkers produce monosyllabic words in carrier sentences. In the multiple-talker condition the ten talkers were randomly distributed. The influence of this effect on speech intelligibility was observed for three listener groups. Age and age-related hearing loss both reduce listeners' ability to compensate for variations in talker characteristics. Word-recognition performance measured under conditions where the talker varied from trial to trial was better correlated with self-reports of listening ability than was performance in a single-talker condition where variability was constrained (Kirk et al. 1997). The effect articulating clearly on speech intelligibility is analysed for ten normal-hearing and two hearing-impaired listeners in noisy, reverberant, and combined environments (Payton et al. 1994).

The most accurate objective method of measuring the level of speech with regard to loudness is still undecided. Objective measurements were made of subjectively determined loudness of words and sentences (Tschopp et al. 1992). Percentile loudness and L_{Aeq} showed the lowest standard deviation.

Masked Threshold

The masked threshold were studied for broad band noise and low-frequency noise especially for hearing impaired subjects. An important question is, whether there is a significant difference for the speech reception threshold (SRT) in noise between normal and hearing impaired persons, and how can it be predicted. Plomp's model, in which the quiet speech threshold (SRT_O) and a masked threshold in the super-threshold range (SRT_N) determine the speech intelligibility, has only been partially confirmed to date (Lee & Humes 1993). Nilsson et al. 1994 confirms this concept for evaluating various perception situations. The SRT increased with a limitation of the band width of the low-pass filter from 1.4 kHz to 10 dB in relation to the SRT with the unlimited band width.

The SRT was determined for various groups of hearing-impaired individuals with noises with temporal fluctuation of single talker and speech-shaped noise with spectral dips (Peters et al. 1998). The SRT for normal-hearing persons was - 2 to - 23 dB and for hearing-impaired persons (HL 10 to 80 dB) 2.5 to 8.5 dB. Although there was a high correlation between the values for the SRT and the hearing losses ($r = 0.52$ to 0.85), it was not possible to determine the SRT separately for the quiet speech threshold and the super-threshold range (SRT_N) - on account of the low noise level of 65 (75) dB.

The influence of distorted speech with four time-compression ratios (30 to 60 %) and four reverberation times (0.2 to 0.6 s) yields a difference between normal hearing persons and mild-to-moderate hearing loss, given as an equivalent S/N ratio, from 4 to 8 dB (Gordon-Salant & Fitzgibbons 1995).

Hearing Protection

Two studies have been conducted on the influence of hearing protection on speech intelligibility (Nakladal & Listner 1997) and on the location of signals (Nakladal & Hennig 1996). In the situation where the speech intelligibility was tested, 2 test subjects sat in each case opposite one another as speaker and listener (without visual contact). Both wore 4 selected hearing protection or no hearing protection. The operational noises were between 85 and 93 dB(A). The speech material consisted of monosyllables and command-like speech. The speech intelligibility in the situation without hearing protection (5) and with level-dependent hearing protection (4) is higher than for common ear plugs (1, 2) and muffs (3). The subjective evaluation of the hearing protection with respect to their speech intelligibility displays a similar pattern.

In a further experiment location in various hearing protection situations was tested. The test subjects had to recognise the specified directions (0°, 45°, 90° ... 315°) from which the signal sounded and the signal itself. The 5 noises had a level of 85 to 93 dB(A), the 5 warning signals had a level of 80 to 113 dB(A). Both in the case of the portion of correctly located warning signals and of the subjective evaluation as to with which hearing protection location was most accurate, the level-dependent hearing protection was poorest and the situation without hearing protection and with plugs was best.

Second Language

To determine how age of acquisition influences perception of second-language speech (Mayo et al. 1997), the speech intelligibility test (SPIN) was administered to native Mexican-Spanish-speaking listeners who learned English before age 6 (early bilinguals) or after age 14 (late bilinguals) and monolingual American-English speakers (monolinguals). Results show that the levels of noise at which the speech was intelligible were significantly higher and the benefit from context was significantly greater for monolinguals and early bilinguals than for late bilinguals.

The Articulation Index

Measures for predicting and assessing speech intelligibility are indices (AI, STI) which range from 0 to 1. These indices (AI, STI) are calculated from the physical parameters of the communication situation and, if measurable, human parameters are also taken into consideration (Kryter 1962; Lazarus 1990; Pavlovic 1987).

Over the past few years the Speech Intelligibility Index SII used in the American National Standard (ANSI S. 3.5 1997) and, in the ISO Draft (ISO 9921-2 1995) the modified Articulations Index (MAI) have been prepared. Both methods correspond to the concept of the AI as described. They both have in common that they include the whole communication from the speaker to the listener and take account of both hearing protection and hearing impairment. The level range of the speech (30 dB) in the case of the SII, however, is divided into ranges above and below the average value of the spectrum (i) of the speech level (L_{Sieq}) as in the case of the STI (15/15) and not as in the case of the AI and again in the case of the MAI (12/18). This means that with the SII the noise level is 3 dB higher for the AI and MAI respectively with the same value, i.e. with the same speech intelligibility a higher noise level is admissible in the case of the SII.

The MAI contains for the speaker a correction for the wearing of hearing protection and a correction for the reduction of speech intelligibility with loud speech (Lazarus 1990). The SII takes account of different spectra for four different vocal efforts. The hearing loss of a group is included in a similar way both by the SII and by the MAI. The hearing threshold, like the noise, is referred to as the lower threshold in each frequency band for the calculation of the AI. The MAI, however, also takes account of the loss of speech intelligibility in the super-threshold range.

When determining the SRT (50 % SI) for various hearing situations with hearing-impaired persons, the AI should yield the same value in each case (Peters et al. 1998). The hearing impairment threshold was used as the lower limit in accordance with the interfering noise. In fact the AI for normal-hearing persons was 0.75 - 0.92 (± 0.05) and for hearing-impaired persons 0.31 - 0.42 (± 0.16), i.e. the hearing impairment is not adequately taken into account in this way. This supports the introduction of a super-threshold SRT_N.

Interior Noises

In order to ensure a certain speech intelligibility in rooms, limit values are derived for the noise level and possibly also for the reverberation time. The speech intelligibility, however, is given largely by the signal-to-noise ratio, e.g. with 70 % intelligibility for monosyllables there must be an S/N ratio of at least $L_{SNA} = 2$ dB (or AI = 0.5). But this can be achieved by various vocal efforts according to distance, and so a noise level can hardly be fixed in this way. For very loud speech the speech level at the ear (with 1 m distance between speaker and listener) would be 78 dB(A), a maximum noise level would then be 76 dB(A). This is certainly a value which is generally unacceptably high for adequate speech intelligibility. This description makes clear that not a certain speech intelligibility, but only a certain speech communication which includes the speaker, the listener and their environment can be the basis for limit values.

The quality of communication is essentially linked with the strain on the communication partners under given conditions.

Therefore an attempt is made to present the speaker's strain in relation to his vocal effort or speech level and the listener's hindrance in relation to the signal-to-noise ratio. Table 1 presents the attempt to evaluate the effort of the speaker according to his kind of speaking, i.e., speech level, and the hindrance of the listener according to the existing signal-to-noise ratio (ISO 9921-1).

Table 1: Permissible sound pressure level (L_{NA}) in workplaces

Vocal effort			Permissible sound pressure level L_{NA} in dB											
		score ass.	1 perfect			2 very good			3 good			4 sufficient		
	$L_{SA,1m}$	L_{SNA}	16 dB			12 dB			8 dB			2 dB		
score	in dB	r	1m	2m	4m	1m	2m	4m	1m	2m	4m	1m	2m	4m
1	54	relaxed	38	32	30	42	36	30	46	40	34	52	46	40
2	60	normal	44	38	32	48	42	36	52	46	40	58	52	46
3	66	raised	50	44	38	54	48	42	58	52	46	64	58	52
4	72	loud	56	50	44	60	54	48	64	58	52	70	64	58

If an adequate communication is to be ensured, then the effort for the speaker and the hindrance of the hearer must be balanced. This simple model allows the estimation of the relationship between the permissible noise level, the distance between the speaker and listener, and certain assessment scale values concerning the strain on the speaker and listener.

RASTI and STI

Several intelligibility direct measurement results are compared to intelligibility evaluations via RASTI or STI measurements in various rooms (Tisseyre et al. 1998). Both methods are described and the measurement conditions specified (in particular, absence of any noise) as well as the comparison conditions (every intelligibility score is expressed as a phonemic score). The volumes of the halls under study range between 1,000 and 800,000 m^3 and are all, except for one, designed for speech listening. It was observed that for some highly reverberant halls, the RASTI index does not seem to provide a reliable approach to the speech listening quality.

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ADAPTING THE SPEECH TRANSMISSION INDEX (STI) FOR THE USE IN VERY NOISY ENVIRONMENTS

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1.INTRODUCTION

To protect the hearing against noisy environments, there are exposure limits which are based on A-weighted equivalent noise levels. In France and Germany, no one shall be exposed to a noise dose exceeding an equivalent noise level of 85 dBA for 8 hours. If hearing protection is worn, the insertion loss (IL) of the protection is taken into account, when the equivalent noise level is determined.

In some professions (e.g. crew members in helicopters, propeller airplanes or tanks) the people are not only submitted to very high noise levels, they also need to communicate by means of the communication system, being usually a part of the protecting ear muff. Especially in these cases, we have seen, that the noise level under the protection device during communication, may be as high or even exceeding the noise level of the unprotected ear. Figure 1 shows, that for the commander of a tank, the level that has been measured under the protection device is 110 dBA during a communication sequence, while it is 6 dB lower when the communication is halted.

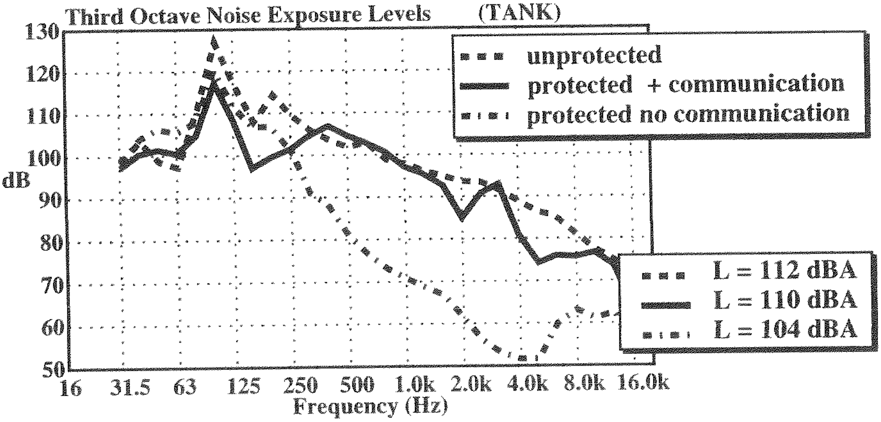


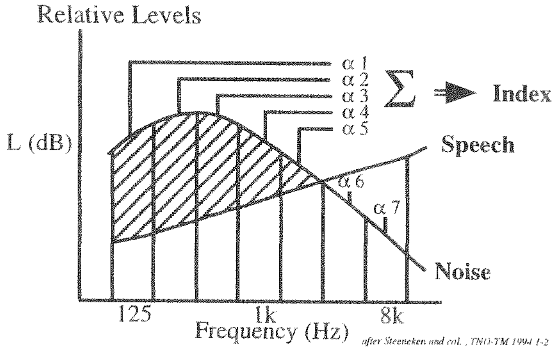
Figure (1). Noise exposure of a crew member in a tank

These measurements showed us, that it is important to have the possibility to predict the levels of the communication signals underneath the protection device. One method that seemed to allow this types of measurements, was the Speech Transmission Index proposed by Steeneken [1].

2.THE SPEECH TRANSMISSION INDEX (STI)

Principle of the STI

The calculation of this index, described in a TNO-Report (Steeneken [2]), is based (fig.2) on the determination of the signal to noise ratio between the background noise and the speech signal in seven octave bands, ranging from 125 Hz to 8 kHz. These 7 ratios are weighted by appropriate weighting factors (α n) and summed to express the STI. This index is related with the CVC test score (Consonant-Vowel-Consonant test) as it is shown in the table 1.



after Steeneken and col., TNO-TM 1994 I-2

Figure (2). Basic principle of the determination of the STI

Subjective quality Test type	very bad	bad	mediocre	good	excellent
STI	<0.3	0.3 - 0.45	0.45 - 0.6	0.6-0.75	>0.75
CVC (%)	<30	30 - 50	50 - 70	70 - 80	>80

Table (1). Relationship between STI measurements and CVC tests

Problems of the STI

For the determination of the STI only the physical signal to noise ratios are used, the psychoacoustical excitation levels of noise and speech are not taken into account. This means that the varying relative bandwidth of the critical bands as described by Zwicker [3] and the psychoacoustical masking is not included in the calculation. This approach shows good results if the noise doesn't show very high levels and if its spectra are more or less flat; this is probably true for most cases.

In noise environments like it is shown in figure 1, the standard STI procedure seems not to be adequate. Using the standard STI evaluation procedure, for the protected ear in this figure (dashed dotted line) a speech level of about 90 dB should already give a speech intelligibility (CVC) of about 80% and this means an excellent subjective rating (table 1). However, as the speech level used by the tank commander is 20 dB higher, we think, that this is a indication, that the predicted excellent speech intelligibility is not reached.

3.MODIFICATIONS TO THE STI CALCULATION

In our understanding the problems that have been shown above are due to the effects of masking. As the standard STI calculation takes into account a masking slope of 35 dB/oct, independent of the level of the masker, this masking paradigm may seriously underestimate the influence of masking for high level noise. In figure 3 the differences between the two masking paradigms for a narrow band noise at 250 hz and different levels is represented. It shows clearly, that for levels higher than 80 dB, the masking in the frequency range higher than 800 Hz is underestimated by more than 10 dB.

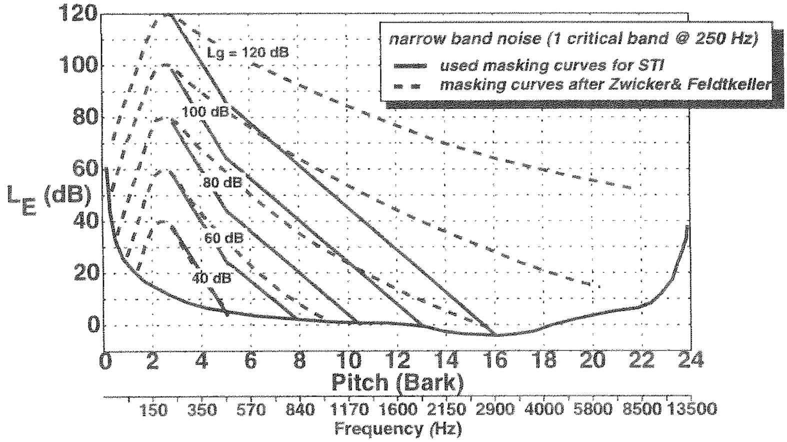


Figure (3). Masking paradigm used in the standard STI calculations (solid), compared to masking curves after Zwicker & Feldtkeller [3] (dashed)

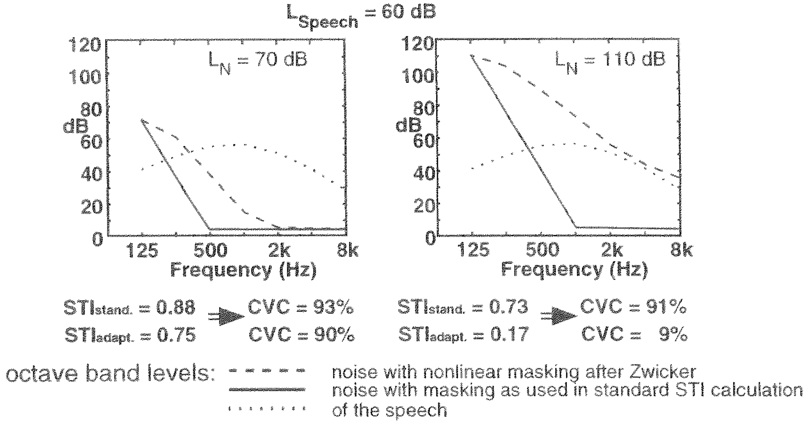


Figure (4). Differences between the standard and the adapted calculation method of the STI

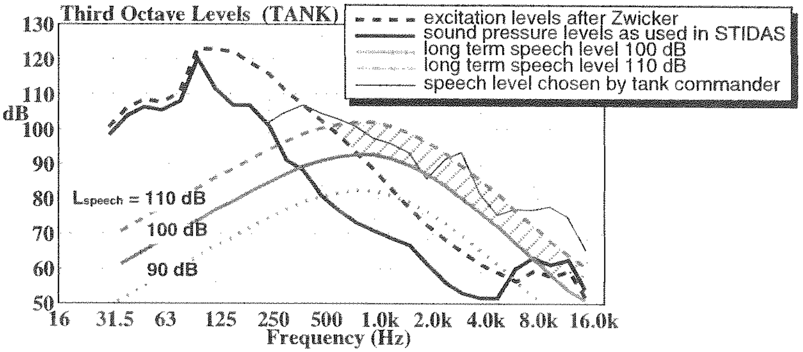
As the STI calculations are based on the signal to noise ratio in different octave bands, it is possible to use the excitation levels instead of noise levels, because the ratio is independent from the absolute level. This seems more adequate, as it takes into account the level dependence of masking and the frequency dependence of integration bandwidth (critical bands).

In figure 4 the different estimations for the STI are shown for a speech level of 60 dB disturbed by low frequency noise (f = 125 Hz) with two different levels (70 and 110 dB). In the case of the moderate disturbance, the masking does not play a major role, the ratings for both methods of calculation are close. For the high level disturbance, however, the standard calculation still predicts a CVC-rating of 91%, whereas the adapted method shows, due to the almost complete masking of the speech, no intelligibility at all (CVC = 9%). This masking is due to the nonlinarity of the increase of the masking curve as it has been described by Zwicker and Feldtkeller [3].

This example shows, that the use of excitation levels instead of sound pressure levels for the evaluation of the STI, seems to give more adequate results in extreme noise situations where hearing protection has to be worn. The exact formulation of the adapted algorithm has been described by Wessling [4]

4.APPLICATION TO TANK NOISE

In figure 5 we apply the modified STI calculation scheme to the noise to which is exposed a tank commander (figure 1). The thick solid line represents the third octave pressure levels of the tank noise underneath the hearing protector. These levels are taken into account for the standard STI calculations. The thick broken line represents the psychoacoustical excitation levels that are used for the calculations of the modified STI. The gray lines represent the long term speech spectra as they are used for the calculation of the STI for three different levels (broken gray line: 110 dB; solid gray line: 100 dB; dotted gray line 90 dB). We can see, that the effective (psychoacoustic) signal to noise ratios, in the relevant spectral areas for speech, are, due to masking, 10 dB worse, as they are predicted by the physical signal to noise ratio.



speech level / intelligibility	90 dB	100 dB	110 dB
STIstand /CVC	0.71 / 78.0% good-excellent	0.834/ 86.1% excellent	0.899/ 89.7% excellent
STIadapted /CVC	0.378/ 43,1% bad	0.629/ 71.5% mediocre-good	0.788/ 83.3% excellent

Figure (5). Application of the modified STI calculations, to the noise exposure of a tank commander. The table shows the related STI and CVC calculations

At a speech level of 100 dB CVC ratings are 86% (excellent intelligibility) for the standard STI calculation, but only 71.5% (lower limit for good intelligibility) for the modified STI calculation. Using a speech level of 110 dB, the rating increases by 3.6% for the standard calculation (excellent intelligibility) and by 11.8% for the modified calculation (excellent).

Considering that a tank commander who depends on good communication, will increase the speech level to a point, where the intelligibility is between good and excellent. Whereas this level of intelligibility is already reached for 90 dB speech level when evaluating with the standard STI (figure 5), the modified STI evaluation predicts, that the speech level should be higher than 100 dB, and not exceed 110 dB. The level for the speech that has been chosen by the tank commander (fine black line in figure 5) shows clearly, that this prediction is very close to reality.

5.CONCLUSION

We have seen that the evaluation of combined communication and protection devices (Headsets), that are used for communicating in noise environments with very strong low frequency components (armored vehicles, helicopters, propeller airplanes...), should not be done with methods that are simply based on the physical signal to noise ratios like STIDAS. These methods tend to underestimate the "psychacoustical noise" due to masking in the mid-frequency range (2 - 8 kHz) where the insertion loss of the protecting devices is best, and so tend to underestimate the level of the speech that is needed for sufficient communication. However, it seems possible to adapt this algorithms (at least for the calculation of the STI) in calculating excitation levels from the measured sound pressure levels and then applying the standard calculation procedures.

The prediction of required speech levels with this type of evaluation procedures seems very close to those used in the real world.

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EFFECT OF NOISE AND REVERBERATION ON THE INTELLIGIBILITY OF SENTENCES FOR LISTENERS WITH NORMAL HEARING AND PRESBYCUSIS

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1. INTRODUCTION

It is important to design sound environments for speech intelligibility considering listeners with hearing impaired because of the increasing number of elderly people. Hearing-impaired listeners are especially handicapped by noise and reverberations (e.g. Duquensnoy and Plomp [1]). The combined effects are greater than the effect of reverberation and noise measured separately (e.g., Nabelek and Mason [2], K.L.Payton et.al. [3]).

This study was proposed to measure the effects of both noise and reverberation on sentence recognition and to determine the difference between hearing ability of young listeners with normal hearing and that of elderly listeners with impaired hearing. In this study, both types of listeners were tested on sentences presented with background noise, reverberation and combination of the two in an anechoic chamber.

2. EXPERIMENTS

Stimulus Materials

The speech materials used as stimuli were arranged lists of easy Japanese questions and commands, consisting of 50 sentences, described by Toida [4]. The lists were phonetic balanced and were spoken by a male voice. The average duration time and number of syllables per sentence was 2.97s and 24.6 respectively. The mean rate of pronunciation was 8.28 syllables/s. To eliminate the effects of training, subjects were exposure to one list only once. The word order in Japanese questions is different from that in English. For example "What color are petals of dandelion?" is ordered " dandelion, petals, what, color?" in Japanese. To avoid any unexpected influence of background noise on the first word, a useless word was added at the first like " flower, dandelion, petals, what, color?". In this case, the word "flower" has no effect to recognize the sentence, because "dandelion" is always thought of as a flower and the color of petals cannot be decided without the word "dandelion".

Sound Fields

The reverberation times (*T*) used were 0, 1, 2, 3 and 4s. The noise levels (*L*) had the Hoth spectrums as shown in Figure 1 with dBA levels of 60, 62.5, 65 67.5 for young subjects and 57.5, 60, 62.5, 65 for elderly subjects. The combined conditions consisted of *T*=1, 2s and *L*=60, 62.5, 65dBA. The impulse responses of reverberatory fields are illustrated in figure 2. Noise and reverberation sound were presented from two loud speakers at both sides of the speaker presenting speech. The peak level of speech at the listening point without reverberation was set for 70dBA (long time average level:65dBA). Reverberation sounds were added by digital reverberator (YAMAHA SPX-900).

Subjects

56 young people with normal hearing (20 to 28 years old) and 15 elderly people with presbycusis (60 to 70 years old) were used as subjects. The mean hearing level and its standard deviation of both group were shown in Figure 3.

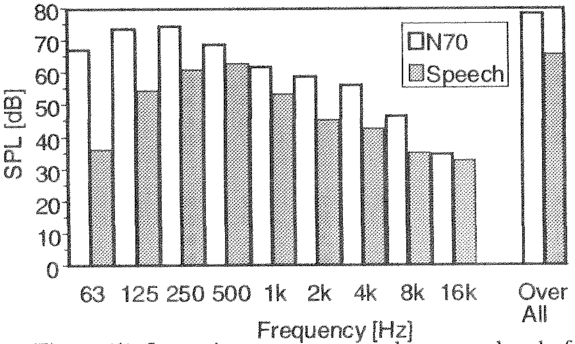

Figure (1). Long time average sound pressure level of back ground noise (*L*=70) and speech at 1/1 oct. band

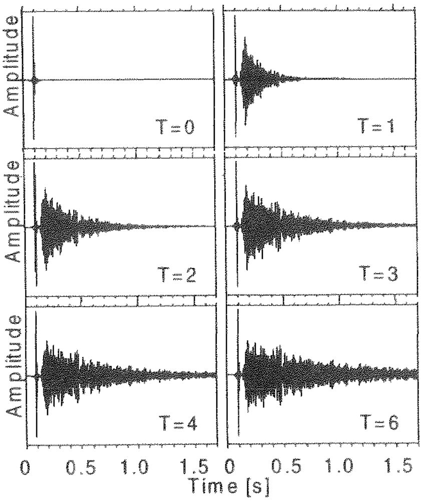

Figure (2). Impulse response of reverberatory fields at 2 oct.band of 0.5 to 1kHz

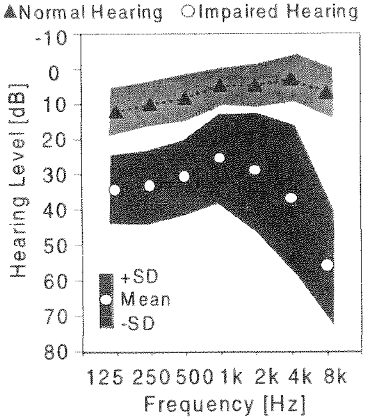

Figure (3). Mean hearing level and its standard deviation of both normal-hearing (occupied triangle) and impaired-hearing (unoccupied circle) subjects

Table (1). The condition of experimental sound fields, their STI and results of sentence recognition tests of both the normal-hearing and impaired-hearing subjects

Condition			Results							
Reverberation Time [s]	Noise Level [dBA]	STI	Number of Samples	% Correct	SD	Max.	Min.	Decided Response *1	% Correct (Modified) *2	SD (Modified) *2
Normal Hearing										
0	Quiet	0.98	33	94.3	4.3	100	82	94.5	99.7	1.0
0	60	0.41	23	93.0	4.7	100	82	94.8	98.2	2.8
0	62.5	0.33	20	87.9	7.4	98	70	92.3	95.3	4.4
0	65	0.24	28	77.1	11.5	98	42	92.4	83.3	10.4
0	67.5	0.17	16	49.5	9.9	70	36	92.8	53.4	10.7
0	70	0.10	17	13.8	7.0	30	4	97.8	14.2	7.4
1	Quiet	0.58	18	81.3	11.6	92	56	95.2	85.2	10.7
2	Quiet	0.47	22	62.8	13.7	84	36	91.9	68.2	13.9
3	Quiet	0.42	20	41.7	14.0	70	20	91.0	45.8	14.8
4	Quiet	0.38	20	33.0	11.9	62	16	93.1	35.5	12.6
1	60	0.36	21	58.6	11.9	82	38	93.1	62.6	10.9
1	62.5	0.29	21	51.9	16.8	80	14	93.3	55.5	17.3
1	65	0.21	21	40.4	9.8	62	24	92.4	43.9	11.5
1	67.5	0.14	16	32.3	10.5	56	16	92.4	34.9	11.0
1	70	0.07	16	8.1	6.8	20	0	96.8	8.4	7.1
2	60	0.32	20	42.3	14.2	70	14	95.0	44.7	15.7
2	62.5	0.25	18	33.2	15.3	62	10	93.9	35.6	16.6
2	65	0.17	20	19.1	10.0	38	2	95.3	20.1	10.8
2	67.5	0.11	16	21.9	9.5	44	10	92.3	23.9	10.4
2	70	0.05	17	6.5	4.7	16	0	98.6	6.6	4.7
Impaired Hearing										
0	Quiet	0.98	44	79.3	17.2	98	40	87.1	92.2	10.8
0	57.5	0.49	21	78.5	17.7	96	42	88.5	88.4	13.6
0	60	0.41	15	70.4	17.1	90	42	87.1	80.6	16.8
0	62.5	0.33	15	49.9	22.5	80	14	85.2	57.9	22.1
0	65	0.24	15	30.3	18.7	66	4	94.8	32.3	20.6
1	Quiet	0.58	15	48.1	21.9	78	6	88.0	55.1	23.9
2	Quiet	0.47	15	25.1	17.3	62	2	94.0	27.0	18.6
3	Quiet	0.42	15	13.7	8.3	24	0	94.9	14.5	8.5
4	Quiet	0.38	15	8.7	7.7	30	0	97.3	9.0	8.1
1	60	0.36	15	36.1	20.4	66	4	87.2	43.7	25.6
1	62.5	0.29	15	25.1	19.9	64	0	86.3	29.0	21.5
1	65	0.21	15	22.7	17.5	64	0	94.7	24.2	18.5
2	60	0.32	15	22.8	16.5	60	0	88.9	24.9	16.1
2	62.5	0.25	15	16.1	13.7	46	0	93.2	17.9	15.0
2	65	0.17	15	14.0	11.7	44	0	94.0	15.1	12.2

*1 Percentage of decided response which were judged correct or incorrect absolutely. The cases where subjects could recognize the question but could not decide on the answer were not counted.

*2 Values obtained from the decided responses

3. RESULTS & DISCUSSIONS

Table 1 shows the experimental conditions, their STI (Speech Transmission Index, Houtgast and Steeneken [5]) and the results. The subjects were instructed to write the answer to the question only if they could decide the answer, to keep the answer space blank if they could not recognize the question and to write a question mark if they could recognize the question but could not decide on the answer. Because the last case couldn't be counted both as recognized and unrecognized, such answers were removed from the data. The 2nd to 5th columns of the results in Table 1 were obtained including the question marked cases. The 6th column of the results is the mean percentage of the decided responses in total 50 questions. The last two modified values were calculated without the question marked cases. The modified values are used in the discussion.

In the condition without noise and reverberation, the average percent correct of young subjects was 99.7% (Standard Deviation : SD=1.0) and that of elderly was 92.2% (SD=10.8). The difference of the scores was small, but SD of elderly subjects was much larger than that of the young because of the elderly group's fragmentary character shown in Figure 3.

Figure 4 shows the mean value of percent correct of both normal hearing and impaired hearing subjects in reverberatory fields. The scores of the young without noise decreased as *T* increased up to 4s. In contrast the score of the elderly decreased more rapidly at short reverberation times and seemed to reach a bottom (14.5%) at *T*=3s. The difficults of these impaired hearing listeners to recognize speech in reverberatory fields is as Duquensnoy and Plomp [1] noted.

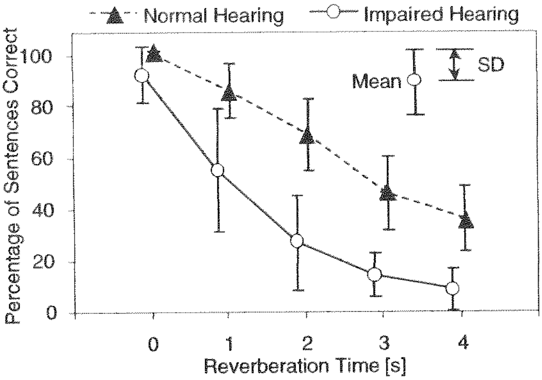

Figure (4). Mean value of percent correct of both normal-hearing (occupied triangle) and impaired-hearing (unoccupied circle) subjects in reverberatory fields. Error bar shows ± SD.

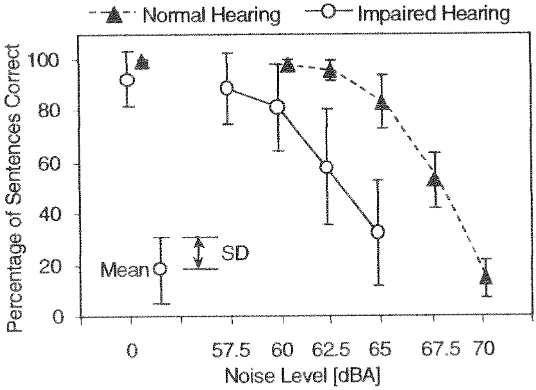

Figure (5). Mean value of percent correct of both normal-hearing (occupied triangle) and impaired-hearing (unoccupied circle) subjects in noise. Error bar shows ± SD.

Figure 5 shows the mean value of percent correct of both normal hearing and impaired hearing subjects in noise. When noise was presented without reverberation (*T*=0s), the scores of the young started to decrease at *L*=65dBA (S/N=0dB), and those of the elderly started at *L*=60dBA (S/N=-5dB). After this point, the scores of both groups decreased with the same tendency as *L* increased. In background noise, The effect of hearing loss could be described as adding noise.

The results in reverberatory fields and in background noise shows the difference between noise and reverberation on speech intelligibility. Noise obscures the less intense of speech described before, whereas reverberation is a more complex distortion than noise because it causes not only masking from reflected energy, but also smears elements in the time domain and smooths the temporal envelope.

Figure 6 shows the mean score of both normal hearing and impaired hearing subjects in both noise and reverberation. In the case of the normal hearing subjects, the scores decreased as *L* increased up to 67.5dBA with reverberation. There was no difference between the score with and without reverberation at *L*=70dBA. In the condition of *T*=2s, the score of the normal hearing subjects decreased when noise was presented (68% in quiet to 45% at *L*=60dBA). On the other hand, the score of the impaired hearing subjects did not change (27% in quiet to 25% at *L*=60dBA)

Nabelek and Mason [2] noted that the combined effect of noise and reverberation on intelligibility scores is greater than the individual contributions. This study shows both that the combined effect is greater and not greater than the individual contributions. The result of normal hearing subjects supports Nabelek and Mason [2] except for *L*=70dBA and the results of impaired hearing listener always shows the opposite result. This phenomenon depends on the range of degradations in environments especially for elderly listeners.

Comparing the scores of the elderly and young, Figure 7 shows that the normal hearing subjects can tolerate 5dBA more noise than hearing impaired subjects. The correlation coefficient of elderly scores to those of normal hearing subjects with more 5dBA noise is 0.93.

The average difference of the scores of both groups is 25% (Max:51%, Min:5%) and should be considered when evaluating and designing aural environments.

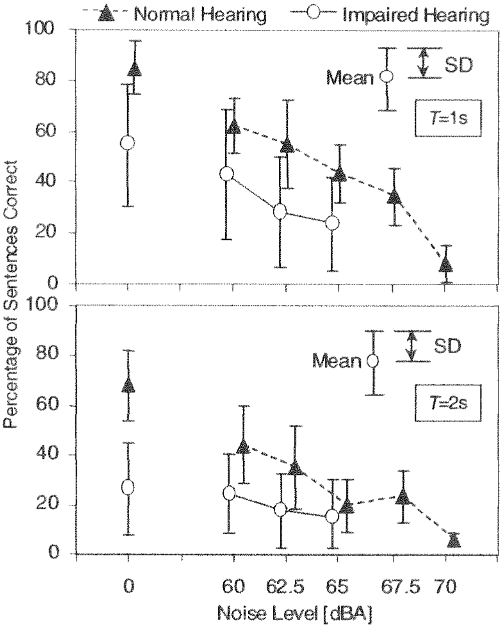

Figure (6). Mean value of percent correct of both normal-hearing (occupied triangle) and impaired-hearing (unoccupied circle) subjects in the combined condition both reverberation and noise. Error bar shows ± SD.

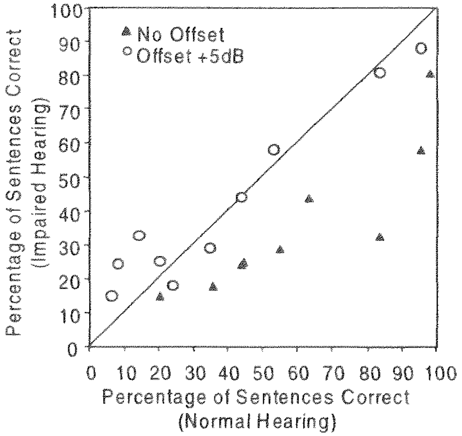

Figure (7). Relation between mean score normal-hearing and impaired-hearing subjects. Occupied triangles shows simply comparison, and unoccupied circle shows the relation between impaired hearing and the score of normal hearing subjects at added +5dB noise condition (R=0.93).

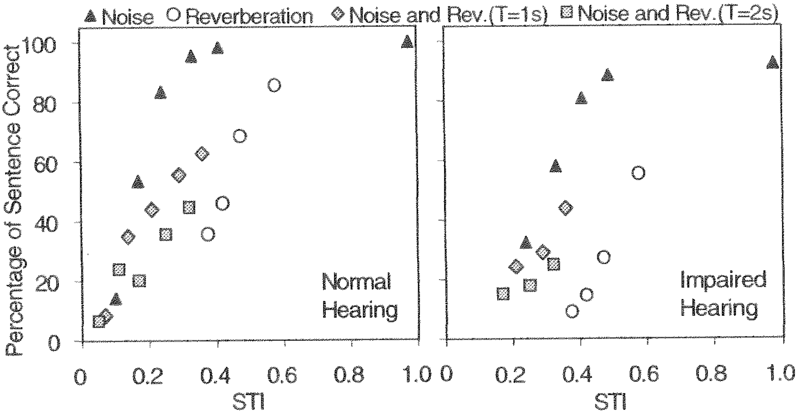

Figure (8). Relation between Speech Transmission Index and mean score of speech recognition tests of normal hearing (on the left) and impaired hearing (on the right) subjects.

Figure 8 shows the relation between STI and mean score of the speech recognition test. This data indicates that STI underestimates intelligibility loss in noise fields for normal hearing listeners and overestimates it in reverberatory fields for impaired hearing listeners. STI performs differently in noise, in reverberation and in both for both normal hearing and impaired hearing subjects. STI was presented as an appropriate measure for describing the combined effects of noise and reverberation on speech intelligibility [5], but STI perform less reliability in this case. This fact shows the possibility of existing factors which STI cannot consider.

ACKNOWLEDGMENTS

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ENHANCED COMMUNICATIONS IN NOISE FOR MODERATELY HEARING IMPAIRED WITH CUSTOMIZED ACTIVE NOISE REDUCTION HEADSETS

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1. INTRODUCTION

Conventional active noise reduction (ANR) headsets designed to reduce levels of noise at the ears also provide improvements in speech intelligibility, perception of auditory signals, personal comfort, and user acceptability. There are many applications of ANR headset technology for normal hearing listeners. They range from the control of low-level background noises in relatively quiet environments to the reduction of the high levels of noise in aviation, construction, mining, manufacturing, and military environments. The primary goal is the reduction of noise-induced hearing loss with its associated benefits. Laboratory and field studies demonstrate significant improvements in noise reduction and voice communications. Users of ANR headsets also report the additional beneficial effects of increased comfort, enhanced performance, and reduced fatigue. The potential is excellent for these benefits to provide similar and even greater advantages when used by persons with hearing deficits.

An ANR headset was modified to allow a young female with profound binaural hearing loss to communicate in an aviation noise environment. She was unable to communicate without her dual hearing aids except for face-to-face situations where she used excellent lip-reading skills. The ANR headset optimized her residual hearing and enabled her to hear all audio communications while she experienced a demonstration flight in the noisy cockpit of a high-performance tactical aircraft.

The customized ANR headset was demonstrated in a very noisy flight environment. It is fully applicable to the many occupational noise environments experienced daily by employees with partial hearing loss. The sound attenuation and speech communications performance of customized ANR headset technology are described for persons with normal hearing and those with deficient hearing. The limitations and advantages are discussed as well as what can be expected from conventional and customized types of ANR headset systems. The customized ANR headset concept was fully demonstrated only once. It is very promising, relatively easy to fabricate, and cost effective, particularly in relation to the exciting potential benefits for the user. This paper describes the customization procedure, cites limitations and advantages, and relates details of the successful experience with the profoundly deaf individual.

2. BACKGROUND

Auditory signals convey information that ranges from the exchange of small talk and whispers at a party to notifications of imminent threats and danger in recreational and occupational environments. In the military, particularly in military aviation and heavy tracked vehicles, crewmembers must work with a variety of auditory signals. These signals continually inform the crewmembers of operational conditions, status of the vehicle, onboard systems, navigation, and other information vital to mission success. The most critical of the audio signals is effective voice communications that are indispensable for performance, safety and survival. Similar situations exist in noisy nonmilitary occupations where accidents and personal injury have been attributed to inadequate voice and audio signals.

The ear is a remarkable mechanism. Its sensitivity enables us to hear a pin drop and its robustness to withstand the intense noise of jet aircraft engines, at least for a time. Military noise environments are equally as or more intense than almost all other noise sources. These environments can degrade voice communications and task performance as well as induce temporary and permanent noise-induced hearing loss. Temporary noise-induced hearing losses occur during noise exposures and may interfere with the perception of speech and other audio signals. The temporary hearing loss gradually disappears and the pre-exposure hearing ability returns after the noise ends. Permanent noise-induced hearing loss does not recover to pre-exposure threshold levels and is not responsive to medical treatment.

Persons with hearing loss from noise exposure, or other means, have substantial difficulty with speech recognition in noise. Recognition is impaired by the individual's hearing loss and by the masking effect of the noise on the residual hearing. Communications are formidable for persons with hearing loss who wear conventional passive hearing protection devices as well as those using electronically-aided communications systems. The restricted ability of hearing impaired individuals to hear and understand audio signals poses a continuous threat to performance and safety. Job performance is reduced by errors attributed to the inability to hear routine audio signals in the occupational environment. Personal accidents and fatalities are attributed to the employee's inability to hear the sounds or warnings associated with the threat or to determine their locations in sufficient time to avert the consequences. Hearing loss can constitute a threat to the safety of the employee. ANR headset technology reduces and prevents noise-induced hearing loss and overcomes the auditory inadequacies caused by the loss.

3. OBJECTIVES

The objective of this paper is to introduce and describe the concept of customizing ANR headsets for individuals with moderate hearing deficits. The approach is to tune the performance of the headset to compensate for the specific characteristics of the individual hearing loss.

The objective for the flight demonstration was to illustrate the customization concept. A helmet version of a conventional active noise reduction headset was modified to compensate for the hearing deficits of an individual with a profound binaural hearing loss. The headset provided sufficient noise reduction, speech level, and quality to satisfy the needs of the individual. It was mandatory that the individual's ability to fully understand voice commands in the aircraft noises be demonstrated. Compliance with this requirement assured the pilot and the flight safety officer that voice communications would be no problem.

4. SITUATION

Wright-Patterson Air Force Base, Dayton, Ohio, U.S.A., sponsored an on-base conference and workshop on personal disabilities. It targeted the application of current Air Force Research Laboratory technologies to enable persons with physical disabilities to maximize their talents and abilities. Emphasis was on abilities and was clearly expressed in the conference title, "Wright Focus On Abilities." The special conference was accomplished in seminars, tutorials, and workshops as well as relevant scientific and technical exhibits and demonstrations. The theme was to emphasize and optimize the abilities and skills possessed by each and to demonstrate the potential of new technologies to mitigate the effects of various disabilities. One of the workshop areas focused on the abilities of individuals with non-normal hearing and deafness.

The celebrity guest and spokesperson for this event was Miss Heather Whitestone, Miss America 1995. Miss Whitestone has a severe hearing loss in both ears and has virtually no hearing without dual hearing aids. During coordination of arrangements for her participation in the Wright Focus On Abilities event, she was invited to take a celebrity ride in a high performance tactical aircraft, the F-16D.

As noted earlier, it was necessary for Miss Whitestone to demonstrate her ability to hear and understand voice commands from the pilot in the noisy cockpit to be permitted to fly in the two-seat F-16D. The flight helmet worn by Miss Whitestone interfered with the operation of her hearing aids, causing them to be unusable for the flight. The standard flight helmet was inadequate and a special helmet was needed to provide her with the capability to communicate in the F-16D cockpit noise in spite of her severe hearing loss.

5. PROCEDURE

A multi-fold approach was launched to provide the level of speech intelligibility required for compliance with flight safety standards. Hearing threshold data, speech reception scores, maximum comfortable loudness values, and other performance data were obtained from Miss Whitestone. Passive and active noise reduction technologies were applied to a conventional ANR headset to provide additional attenuation of noise levels at the ears. The headset was altered to enhance perception of speech by raising the overall gain of the speech signal. The band-pass of the speech was modified to optimize Miss Whitestone's residual hearing. A variable gain control was added for her convenience. Communications for normal and hearing impaired subjects with and without the ANR headset were measured with a standard speech intelligibility test. A highly descriminable, closed set vocabulary of 30 words was developed for the flight. Miss Whitestone was required to demonstrate effective communications wearing the modified headset under in-flight noise conditions emulated on the ground prior to flight.

The active noise reduction headset was modified by the Bose Corporation to provide gain and band-pass characteristics that utilized Miss Whitestone's residual hearing and speech recognition. The effectiveness of her communications ability with the F-16D pilot was evaluated with a series of operationally valid speech tests in the Biocommunications Laboratory and in the cockpit of the aircraft while on the ground. Measurements of speech perception performance were made with Miss Whitestone in the different levels of the F-16D aircraft cockpit noise that would be experienced during the flight. Both the F-16D pilot and Miss Whitestone were trained with the special 30-item, highly-descriminable vocabulary in the F-16D noise environments. Random words and phrases spoken by the pilot were presented to her via the customized ANR headset. She repeated the words and phrases she believed she heard. Her responses to the stimuli were scored and evaluated.

6. DATA

The entire 30-item vocabulary was presented to Miss Whitestone three times in the F-16D noise at an overall level of 105 dB. She correctly responded to 100 percent of the stimuli presented. These and other communications performance data in noise in the laboratory authenticated her ability to correctly understand voice commands from the pilot in the F-16D cockpit noise environment. This capability to understand the commands was, again, confirmed in the aircraft cockpit immediately prior to the demonstration flight. Her performance with these stimuli was the final factor in obtaining permission for the flight.

The demonstration flight was very successful, with Miss Whitestone perceiving a reported 100 percent of the voice communications. The special ANR headset reduced the level of noise by about 15 dB. The increased gain improved the speech signal by approximately 10 dB. Overall, the special ANR headset improved the speech-to-noise ratio at the ears of the subject by about 25 decibels. This ratio was obtained from a decrease in noise level at the ear of about 15 dB combined with an increase in level of the speech signal of about 10 dB. The quality/fidelity of the high-level speech was also improved by the active noise reduction circuitry.

7. DISCUSSION

The customized helmet/active noise reduction headset system enabled Miss Whitestone to experience a one-hour flight in the F-16D aircraft, after which she reported hearing "perfectly" everything that was said during the flight. The customized helmet concept was demonstrated this one time in flight in a high-level cockpit noise by an individual with a severe hearing loss. The auspicious, worst-case experience clearly established that ANR headsets can be customized to significantly enhance the voice communications capabilities of individuals with impaired hearing. Customizing the ANR system for less severe and moderate hearing losses and for moderate-level noise environments will be less of a challenge.

Hearing loss is common among pilots and aircrew members as well as other personnel who work in high levels of noise. One targeted area to benefit from customized ANR headsets is aviation where individuals with hearing and communications deficiencies can be removed from their occupational environments.

Military aviators must periodically pass a pure tone audiometric criterion test for retention on flight status. Those who fail the pure tone test because of the magnitude of the hearing loss are grounded. These grounded aviators may request a waiver to fly with the hearing loss, claiming no communications difficulties in-flight in spite of their failure with the pure tone test. The aviator must verify the claim of good in-flight communications for the waiver to be favorably considered. Many of those who continue to fly have moderate hearing losses that could negatively affect their ability to discriminate speech and recognize other audio signals in noise environs.

Aviators are highly-specialized, experienced, and skilled professionals with very expensive investments by themselves and their organizations in the extensive training required over the years. Organizational efforts are very strong to retain these individuals with moderate hearing loss and to keep them flying. Current regulations can keep aviators with moderate hearing loss on the ground. The customized helmet/ANR system should enable a significant number of these highly-trained experts to continue to fly and many of the grounded aviators to return to flight status. Most users of customized ANR headset/helmets will experience and demonstrate much-improved voice communications and flight safety.

Similar hearing loss situations exist in many occupations outside the field of aviation. Occupations in mining, construction, manufacturing, and others also have environments where the levels of the noises are high and personnel could benefit from the customized active noise reduction units. Most of these professions do not have practices that remove those with hearing loss from their jobs. Consequently, individuals with hearing deficits continue to work and, depending upon the situation, can be a safety risk to others as well as themselves because of their limited hearing ability. Hearing deficits often continue to increase under these conditions. Accidents in the occupational situation are often attributed to failure of personnel to hear some announcement, system failure, or warning signal. However, information reporting or describing such mishaps or accidents is not routinely available in the literature. One publication reported several accidents over several years resulting in the deaths of employees attributed to the inability of the victims to hear sounds that should have warned them of the event and enabled the tragedies to be avoided.

Some basic information about the hearing function of an individual is needed in customizing the ANR headset. Pure tone audiograms and speech reception thresholds are needed, both aided and unaided. Information on most comfortable and uncomfortable listening level thresholds as well as word recognition scores is also important, preferably for the noise environments in which the headset will be used. Other information, such as hyperacusis, recruitment, etc., depending on the situation, is also useful in the customizing process.

The performance or effectiveness of conventional active noise reduction headsets can vary substantially from one manufacturer to another. It is important, in terms of cost as well as performance, that the purchaser verify that the ANR system under consideration provides the required performance features. ANR headsets are most effective in environments with substantial low-frequency energy below 1000 Hz with the peak level often occurring around 250 Hz. Measurements of six different ANR headsets showed maximum active attenuation values at 250 Hz ranging from 8 dB to 22 dB. Some ANR systems cease to operate and create a loud discrete tonal noise when the acoustic seal of an earcup is broken, resulting in an air leak. ANR systems overload and cease to operate at some high noise level. A sample of three different units showed that active attenuation decreased with increasing levels of noise from 120 dB to 130 dB, with two units providing only 5 dB and 0 dB at 135 dB. The third headset ceased to function above 130 dB. Thus, current ANR headset systems operate poorly or not at all at sound pressure levels of about 125 dB and above. Also, the ANR unit must generate a signal equal in amplitude to the unwanted noise at the ear to effectively cancel and reduce the overall level under the earcup. One limit of ANR headset performance may be the inability of some systems to generate the maximum levels of noise inside the earcup required for cancellation. Another is simply the very brief but finite time delay required for the system to process the noise cancellation signal.

The customized ANR system brings those with moderate hearing loss up to communication performance at normal levels. Noise levels at the ear are reduced. Speech intelligibility is increased with improved speech-to-noise ratios. The quality of the communication signal is elevated. Subjective increases in comfort and reductions in fatigue are also reported.

8. LABORATORY STUDIES

The successful flight demonstration of the customized ANR headset concept has been followed by initiation of a series of laboratory experiments to further develop the headset for occupational use. Subjects with moderate hearing loss are being evaluated to systematically determine the amount of improvement in communications that is achievable and the features that are essential to ensure individual success. Experiments will investigate the speech intelligibility obtained by normal hearing and non-normal hearing subjects while wearing the conventional ANR headset, the customized ANR headset, and the customized headset with and without additional speech gain.

9. SUMMARY

The customized ANR headset concept was fully demonstrated only once with an almost deaf subject in intense aircraft cockpit noise. The subject reported after the flight that "The lab put a special hearing aid in my helmet"... and "I could hear everything perfectly." The customized unit reduced the level of the noise by approximately 15 dB. The gain, configured to enhance the residual hearing of the subject, improved the speech signal by approximately 10 dB. This combination provided a speech-to-noise ratio improvement of about 25 dB. This concept of customized or personalized units is very promising, relatively easy to fabricate, and cost effective, particularly in terms of the exciting potential benefits. Initial indications are that the specialized ANR headset can improve the speech communications capabilities of many aircrew members, and others, with moderate hearing loss. This customized system enables highly experienced personnel with moderate hearing loss to communicate effectively in their various occupational noise environments. It appears appropriate for applications for aiding the hearing impaired in areas such as music, communications, training, and education.

Richard McKinley has been a biomedical engineer at the Bioacoustics and Biocommunications Branch of the Air Force's Armstrong Laboratory located at Wright-Patterson Air Force Base near Dayton, Ohio. His research has focused on physiological effects of high intensity sound, development and application of active noise reduction and active noise cancellation technology, speech communication in noise, and development and application of virtual or 3-D audio displays. He was elected to "Fellow" in the Acoustical Society of America in 1996. Currently, he is technical advisor for the Audio Interfaces and Acoustics Branch at the Air Force Research Laboratory.

OPPORTUNITIES FOR ACTIVE NOISE CONTROL IN PORTABLE COMMUNICATION DEVICES

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1. INTRODUCTION

Active noise reduction (ANR) is a well-established technique for controlling sound and vibration that commonly finds application in the control of environmental noise.[1] It has been applied to one portable communication device, the headset, for almost a decade,[2] and holds potential for application to devices as disparate as telephone handsets,[3] and hearing aids.[4] The opportunities for ANR would appear to be to: 1) control environmental noise when the communication signal originates elsewhere (e.g., headset, telephone); 2) isolate speech in a noisy environment (e.g., hearing aid), and; 3) control the acoustic impedance at the ear. The first of these opportunities for ANR has received most attention in the literature, and will serve here to exemplify the potential of this technology.

Effective application of ANR to control environmental noise at the ear requires an understanding of the limitations imposed by physical acoustics, control theory, signal processing, and electronics. Almost all commercial ANR devices employ feedback control systems with preset filters and analogue signal processing. This combination provides, at best, a conditionally stable device. Good performance can be obtained at the lower speech frequencies, with some headsets reducing environmental noise at the ear at frequencies of up to 1 kHz.[2,5] There are documented improvements in speech intelligibility in some noise environments.[2] Inconsistent, and degraded, performance occurs in circumstances in which the acoustic impedance experienced by the secondary source producing the corrective sound field changes. This occurs, for example, when air leaks are introduced around the cushion forming the seal between a circumaural earmuff and the skin.[6]

The variation in acoustic coupling between the ear and the secondary source when a communication device is brought to the ear suggests a control system is required that is capable of optimising its performance each time the device is used. Adaptive control of the sound field can be expected to accommodate such variations, and research on *adaptive controllers* is proceeding on several fronts. One focuses on combining the fixed-filter analogue feedback control system with an adaptive digital control system, to produce an "adaptable" feedback system.[7] This approach apparently attempts to use adaptation to

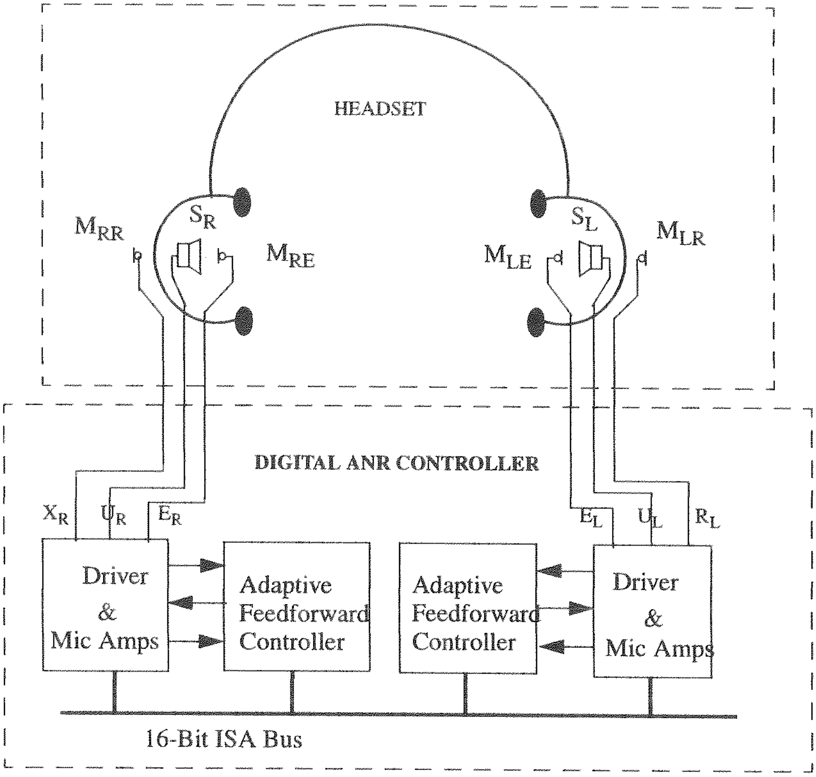

Figure 1: Adaptive feedforward ANR headset

decrease the need for "de-tuning" the feedback loop gain: its use for speech reproduction has not been reported. Another approach is to employ an adaptive feedforward controller, which requires sensing the sound field before it reaches the secondary source, as well as at the entrance to the ear canal.[8]

For situations in which speech is separable from environmental noise, an adaptive feedforward ANR system, operating in real time, offers the possibility for establishing specific performance targets, in addition to reducing the sensitivity of the secondary source to the acoustic load. The extent to which such a control system can provide the user with the potential for improving speech intelligibility will now be considered.

2. ADAPTIVE FEEDFORWARD ANR DEVICE

The only adaptive feedforward communication device operating in real time known to the authors is the ANR headset described by Pan et al.[8,9] The device contains two identical, independent ANR systems, one for each ear, with separate analogue interfaces and digital signal processors (DSP), as shown in Fig. 1. The headset consists of two earmuffs, with circumaural cushions that seal the muffs to the head, connected by a sprung headband.

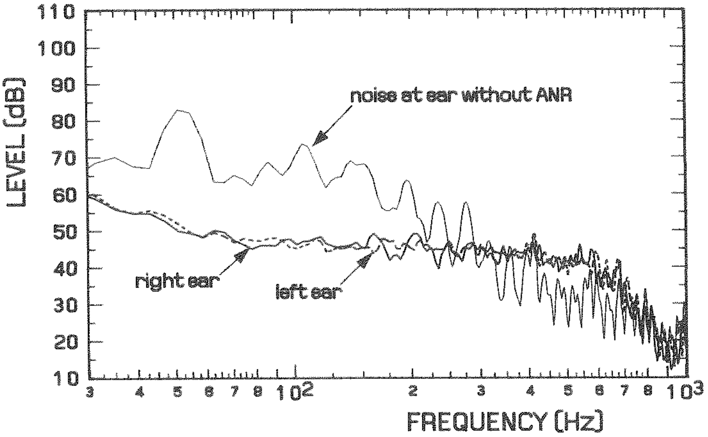

Figure 2: Effect of speech reproduction on ANR

Microphones are attached to the outside of each muff, labelled M_{RR} and M_{LR} in Fig. 1, to sense the environmental noise near each ear, and provide the "reference" input signals to the digital controllers (labelled X_R and X_L). Miniature loudspeakers are used to generate the secondary sound fields in the volumes enclosed by the earmuffs (S_R and S_L), and are driven by signals derived from inputs X_R and X_L. Additional microphones, located close to the entrance of the right and left ear canals (M_{RE} and M_{LE}, respectively), provide the "error" signals used by the DSP to optimize the control signals driving the secondary sources. The process of optimization employs the well-known filtered-X LMS algorithm to produce adaptive (digital) control filters that provide the appropriate signals, U_R and U_L, to drive the secondary sources.[1]

3. SPEECH REPRODUCTION

For a device configured as in Fig. 1, the signals fed to the secondary sources are derived from the noise at the reference microphones, which are outside the earmuffs. Hence, the reproduction of a communication signal by the miniature loudspeaker within the muff at the same time as the system is controlling environmental noise would not be expected to influence significantly ANR performance. In contrast, with feedback control, the control signal is derived from the sound within the volume enclosed by the earmuff, which contains both the environmental noise and the communication signal.

The extent to which this expectation is realized in practice has been demonstrated for the device shown in Fig.1 using the noise spectrum of a Leopard tank, with a subject wearing the headset and seated in an anechoic chamber. The ANR systems were configured to control low-frequency noise (i.e., below 400 Hz), with input/output signals digitized at a frequency of 33 kHz, and the algorithm implementing the adaptive control filter operating at 3.0 kHz.[9] The control filters contained 400 coefficients.

While the ANR systems were operating, a pre-recorded speech signal was fed into the loudspeaker at the right ear, and replayed at a level that could be clearly understood by the subject. The speech signal was not fed to the loudspeaker at the left ear, which consequently continued to function as an unperturbed active noise control system. The speech consisted of a male voice repeating sentences with a brief pause between each sentence. The pause was not of sufficient duration for the active control system to re-adapt to the acoustic signal without speech, but was long enough for the ANR to be measured.

The spectra recorded close to the ear canal entrance under these conditions are shown in Fig.2. The noise at microphones M_{LE} and M_{RE} in the absence of active control is shown by the thin continuous line, and represents the environmental noise reduced by the passive attenuation of the earmuff. The sound pressures at these microphones when the control systems are operating are shown by the continuous line (right ear) and dashed line (left ear). It is evident by comparing these spectra that the control system is unaffected by the presence of a speech signal at the right ear. There is an indication of a variation in ANR for the control system with the speech signal at frequencies around 200 Hz, but the overall effect on the ANR can be seen to be small. Thus, the anticipated lack of dependence of the performance of the adaptive feedforward controller on the presence, or absence, of a communication signal is confirmed. In addition, the speech remained intelligible to the subject when the control system was operating. Confirmation of these aspects of performance is an essential prerequisite to more complex signal processing.

4. SPEECH INTELLIGIBILITY AND PRESERVATION OF HEARING

It is well known that the risk of noise-induced hearing loss is related to the sound level at the ear, when expressed in terms of the A–weighted sound pressure level. It is also possible to relate speech intelligibility to the speech signal to noise ratio, when both are expressed as A–weighted sound pressure levels. The latter relationship, while initially proposed for environmental noise with spectrum similar to that of speech,[10] can also be expected to apply approximately to other broadband environmental noise spectra.[11] In view of these considerations, the possibility of operating an adaptive feedforward ANR controller with a frequency-dependent target convergence function has been explored. It should be noted that the performance of feedback controllers tends to be degraded by the introduction of additional phase shifts within the feedback loop.

The potential for actively controlling environmental noise so as to produce an A-weighted sound level at the ear has been demonstrated by introducing an analogue filter in the error signal path (i.e., between the error microphone and the analogue interface in Fig.1), with frequency response approximately that of the A-weighting network. The experiment used one ear muff of the device in Fig. 1 held by spring pressure against a flat-plate coupler, which formed the base of a small enclosure designed for experiments involving high sound pressure levels. The control system employed an input-output/control frequency ratio of four, and the control filter contained 200 coefficients.

When operated in white noise, band-limited to from 150 to 700 Hz, the difference between the ANR spectra recorded at the error microphone is shown in Fig. 3. In this diagram, the ordinate is the ratio of the ANRs obtained with, versus without, a frequency-selective target convergence function. It is evident from this result that, overall, the ANR is not greatly compromised by selecting a frequency-selective network as the target convergence function, though there is a tendency for the noise reduction at low frequencies

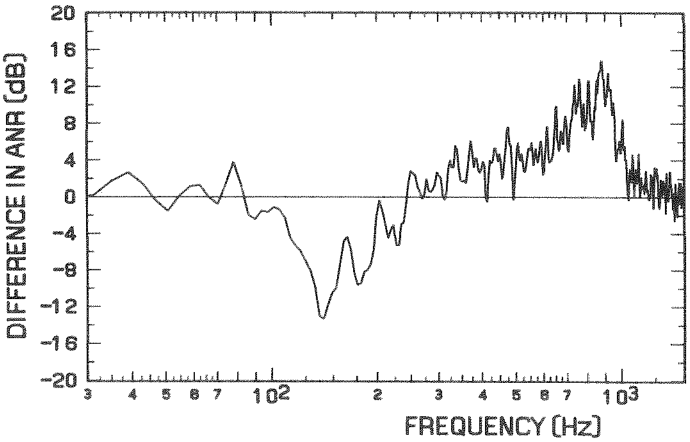

Figure 3: Difference in ANR with two different target convergence functions

to be decreased (i.e., a negative difference), and at high frequencies to be increased (i.e., a positive difference), by as much as 14 dB. Note, however, that these excursions appear to be associated with the limiting frequencies of the environmental noise. Thus an adaptive feedforward ANR headset may be designed to operate with a frequency-dependent target convergence function for improving speech intelligibility and preserving hearing, at least for broadband noise at frequencies above 150 Hz.

5. DISCUSSION AND CONCLUSIONS

In contrast to feedback control, a feedforward approach does not derive the control signal directly from the sound at the ear (i.e., the error microphone), which contains both the undesired environmental noise and speech. In the former approach, the speech component sensed by the microphone close to the ear (M_{RE} or M_{LE}) must be removed before being fed back to the controller, which can be an imprecise process and introduce spectral or harmonic distortion. In consequence, improvements in intelligibility will not necessarily be obtained unless the treatment of both speech and environmental noise is carefully integrated.[12] A feedforward control structure provides the opportunity for higher fidelity communications, with the consequent maintenance of intelligibility.

The development of feedforward controllers that can operate in real time, as discussed here, permits the introduction of additional phase delays in the error path. In this way the control structure permits the residual noise spectrum to be adjusted towards that providing optimum speech signal-to-noise ratio for intelligibility. In principle, different spectral shaping could be applied to the environmental noise and speech when the two signals are separable, based on the articulation index or the spread of masking. Spectral shaping also appears to be beneficial for improving intelligibility for speech reception in noise.[13]

The introduction of adaptation in the control system can provide more active attenuation than that obtained by a comparable fixed-filter controller, as there is no "de-tuning" of the filter gain necessary to maintain stability. If the modelling of the acoustical system is continually being updated, the controller will automatically make adjustments for changes in the acoustic load experienced by the secondary source that occur on a time scale comparable with, or greater than, the convergence time for the algorithm.

These considerations will influence the control strategies selected for many applications of ANR to portable communication devices. For the enhancement of speech in noise, a two-stage, feedforward adaptive noise canceller has been successfully demonstrated for a hearing aid, based on the use of directional microphones and the presumed incidence of speech from the frontal direction.[4] The potential benefits of adaptive frequency-gain characteristics have also been demonstrated for this application.[13]

6. ACKNOWLEDGMENT

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ATTENUATION AND PROTECTION: WE CAN ACHIEVE BOTH

G BERG

DALLOZ SAFETY PTY LIMITED

1. INTRODUCTION

This presentation will outline some new design efforts that have taken place in the field of hearing protection. Contrary to traditional development, the direction of research should now be towards moderate attenuation hearing protection devices (hpds) that can be designed to provide sufficient protection but with improved communication capabilities.

2. WHAT IS PROTECTION?

Comprehensive protection is not defined as maximum attenuation. On the contrary, attenuation is only one element of an effective hearing protection management program. Communication requirements are arguably as important as attenuation requirements in hearing protector selection.

Impaired communication can lead to disastrous situations. Many hearing conservationists are convinced that they are providing the best protection by selecting the hpds with the highest ratings for their employees. This selection criterion alone makes no allowances for communication requirements. Most industries will have individuals with varying degrees of hearing loss. Fitting these individuals with maximum attenuation hpds will completely isolate many of them from voice communication and inhibit the perception of warning signals.

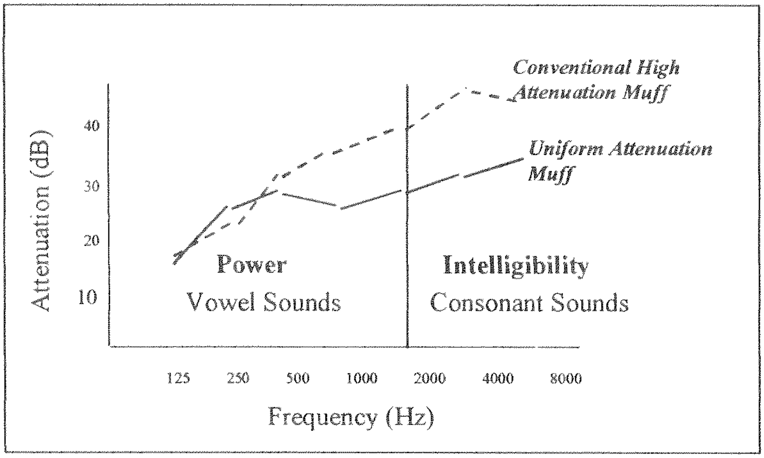
Comfort should also be a primary consideration in the selection criteria. The hpd must be comfortable enough to allow the employee to wear it for the entire duration of the noise exposure.

Our concerns regarding communication and comfort are echoed by workers in industry all over the world.

3. EFFECTS OF HPDS ON SPEECH PERCEPTION

The power of speech, or the sounds that create the volume, are primarily low frequency vowel sounds. The frequency range of these sounds is typically below 1800 Hz. However, the intelligibility of speech is primarily located in the frequency region at about, or above, 1800 Hz. These sounds are the consonant sounds and they can be voiced or unvoiced sounds. An example of this situation is presented in Figure 1:

Fig 1. Effects of HPDs on Speech Perception



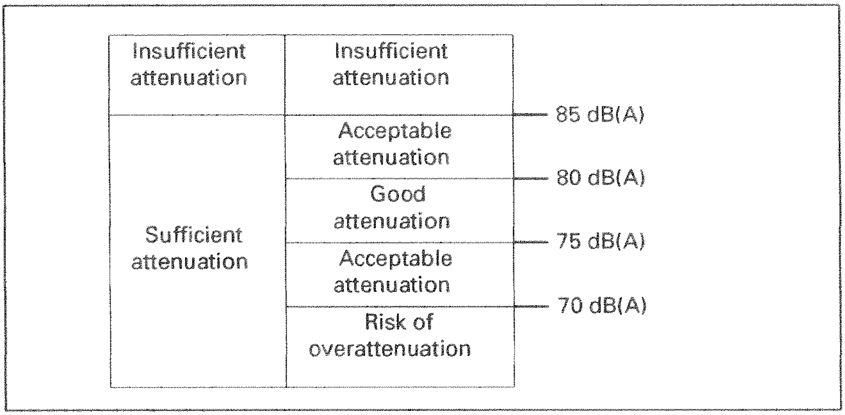
The solution to this problem of communication while wearing hpds is, therefore, increased low frequency attenuation and decreased mid-to-high frequency attenuation. While this sounds simple, in reality it is quite difficult to achieve. Conventional passive hearing protectors are simply barriers to sound. So, the hpd that we seek cannot just be a simple barrier.

4. HOW MUCH ATTENUATION IS REQUIRED?

There is a European guidance document, EN 458, titled "Hearing Protectors: Recommendations for Selection, Use, Care and Maintenance". It is currently the only standards-type document in the world that provides guidance in the selection of hearing protection with the goal of maximizing the ability to communicate in noise. The EN 458 guidelines suggest that the hpds be selected on the basis that they reduce the level of the exposure at the ear to between 70 and 85 dB(A) - and that attenuating the noise below 70 dB(A) can be considered overprotection. Overprotection is defined as too much attenuation in a specific noise.

Individuals who are overprotected experience degraded communication and feelings of isolation. Basically the idea is not to have more attenuation than necessary. Overprotection also leads to difficulties in the administration of a hearing conservation program, because overprotected individuals are more likely to remove their hpds during the noise exposure, or to intentionally disable their hpds to lower attenuation and enhance communication. Many studies, including those by Sharon Abel and Peter Alberti[1,2], have demonstrated this.

Figure 2 . From EN 458 Guidance Document



Overprotection is most prevalent for individuals with sensori-neural hearing loss. This type of loss is common for industrial workers as it occurs with noise exposure and aging. For these people, the hearing loss usually starts in the higher frequency range where many consonant sounds are located. These consonant sounds are critical to speech intelligibility. Unfortunately, this is also the frequency range where traditional hearing protectors are most effective. These conventional hpds can attenuate important speech sounds below the wearer's hearing threshold leading to major communication problems.

5. MAXIMUM WEARING TIME

Wearing time is often overlooked by buyers who select hpds based on maximum ratings without giving enough attention to comfort.

Why is communication so important? Because, wearing time is often overlooked by employees who remove their hpds for communication.

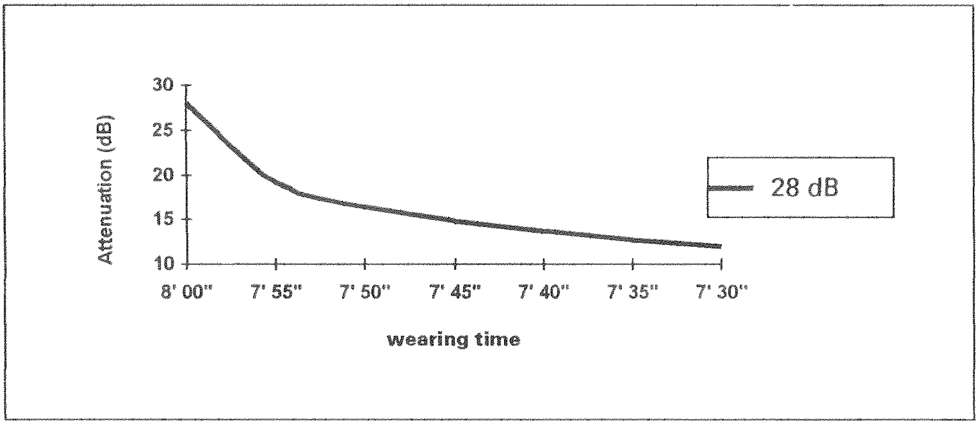
From surveys conducted in a Danish shipyard by Dalloz Safety[3] on wearing time, it was revealed that almost half of the workers had more than 5 conversations per hour and in almost 80% of these conversations the hpds were taken off. We cannot, and should not, prevent workers from talking during the workday.

We can, however, design hpds that enhance the ability to communicate in noise. The workers must then be educated in the effects of removing their hpds for even short periods, and motivated to wear their hpds at all times, even during conversations.

6. WEARING TIME VS PROTECTION

One hundred percent wearing time is vital for effective protection. Without 100% wearing time, there is little difference between protectors: none is effective in this situation. Consider this graph taken from the new AS/NZS 1269:

Figure 3. Effects of Non-wear Time



As you can see, there is a rapid degradation of performance due to the logarithmic accumulation of hearing damage. This will become one of only two standards in the world dealing with this issue which is so critical to hearing conservation. One hundred percent wearing time is absolutely essential if the attenuation provided is to be even close to the labelled value.

7. PREDICTABLE PERFORMANCE

If one is not using a hpd with uniform attenuation, the actual exposure at the ear will be highly dependent on the specific noise situation. In fact, the protection provided may vary by as much as ±12 dB. Comparing a database of 100 different noises collected by NIOSH (National Institute of Occupational Safety and Health) with the attenuation provided by the conventional hpd, wide variations in protection are seen. On the other hand, the uniform attenuation hpd provides consistent protection in all noise environments.

8. CONCLUSIONS

When selecting hearing protectors as part of a noise management program, the hearing conservationist should strive for:

1) sufficient attenuation
2) maximum comfort
3) maximum communication.

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NEED AND ISSUES FOR AMERICAN STANDARDS AND GUIDELINES FOR CLASSROOM ACOUSTICS

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1. INTRODUCTION

Good acoustics is central to verbal learning in classrooms and therefore vital to every knowledged-based society. Many countries, including Great Britain, Germany, Portugal and Sweden have already taken steps to establish standards or guidelines for classroom acoustics. No such standards or guidelines for classroom acoustics exist in national design or building codes in the United States and exist only for the State of Washington thanks to the energetic commitment of the late Robin (Buzz) Towne. Motivation to develop such standards or guidelines in the United States includes the following.

a) A recent survey by the U.S. General Accounting Office, a fact-finding agency for the U.S. Congress, found that "acoustics for noise control" was the most unsatisfactory environmental condition in their classrooms [1]. Based on the survey, an average of 28% of the nation's schools claimed this condition; affecting an estimated 21,900 schools and 11 million students - a strong suggestion that a substantial portion of students in U.S schools are faced with acoustic barriers to learning in their classrooms.
b) About 40% of the U.S. 4th grade students cannot read as well as required for academic standards [2]. This lowered development of verbal learning skills in school equates to reduced capability to hold solid jobs in the future workplace.
c) $12.8 billion was planned for school construction in the U.S. in 1997, 6% more than in 1996 and more than in any other single year in our nation's history [3]. More than 50% of this total was for entirely new school buildings - the balance is for adding to, and upgrading, existing buildings. This upward trend is expected to continue for several years as school enrollment increases and aging school buildings are replaced or upgraded.

2. EXISTING STANDARDS OR GUIDELINES FOR CLASSROOM ACOUSTICS

Some of the existing standards and guidelines used or proposed by other countries or organizations for classroom acoustics are summarized in an abbreviated form in the following table. Similar values for ambient noise levels and reverberation time are found in many architectural acoustics books.

COUNTRY	Standard or Guideline	Ambient Level, dB(A)	RT60 sec.	STC (or R'w)	Comments
USA (ASHA)[a]	Guideline	30	0.4	-	SNR ≥ 15 dB
,, (ASHRAE)[b]	Guideline	45	-	-	Normal Children
,, ,,	, ,	35	-	-	For HOH [c]
ENGLAND [d]	Guideline	40	0.5-0.8	38	General Classroom
,,	,,	35	0.5-0.8	48	Language ,,
GERMANY [e]	Standard	30	-	47 [f]	Between Classrooms
,,	,,	-	-	42	Classroom-Corridor
,,	,,	-	-	55	Classroom-Shop/Sport
,,	,,	-	-	32	Door to Classroom
,,	,,	-	-	Leq-30[g]	Exterior walls
PORTUGAL [h]	Standard	35	1.0 (125-250Hz)		Normal Children
,,	,,	,,	0.6-0.8(500-4Khz)		,, ,,
,,	,,	30	0.4-0.6(125-4Khz)		HOH Children
,,	,,	30	0.4(125-4Khz)		Speech Therapy
,,	,,	40	-	-	Noisy Rooms (HOH)
,,	,,	45	-	-	Very Noisy Rooms
SWEDEN [i]	Standard	30 [j]	-	48	Classroom, In/Ext Walls
,,	,,	35	-	-	Staff,Office,Library
,,	,,	40	-	-	Dining,Gyms,Shops
SWEDEN [k]	Design Guide		90% [l]	44 [m]	Classroom to Classrooms
,,	,,		60%		Corridors, stairs
,,	,,		40%		Office, Conf. Rooms
,,	,,		100%		Swim'ng Pools, Gyms

Notes
a) ASHA Position Statement & Guidelines, Acoustics in Educational Settings, 11/94.
b) Recommendations by members of ASHRAE TC 2.6 Sound and Vibration Committee.
c) Signifies Hard-of Hearing children or anyone who is acoustically challenged.
d) Guidelines for Environmental Design in Schools, Bldg Bulletin 87, Dept. of Education and Employment, U.K., 1997 [R'w values 7-10 dB higher for HOH cases]
e) German Performance/Design Standard, DIN 4109, 1989.
f) R'w (Apparent weighted sound reduction Index) ≈ FSTC, (Field Value.)
g) R'w for Exterior walls = Leq(Outside) - 30 dB where Leq.(inside)-10Lg(S/A)-C = 30 dB, C=0-3 for rail noise; 6-8 dB for A/C noise.
h) "Regulamento Geral Sobre o Ruido" Decreto-Lei n. 251/87, June 24, 1987.
i) "Swedish Building Regulation BBR 94", 1995
j) The Swedish Guidelines include controls for low frequency noise levels.
k) Swedish Council for Building Research, "Acoustic Guide-Selection of Acoustic Quality in Buildings", 1996.
l) % ceiling coverage by ISO Class B Acoustic Tile (NRC (0.75), Mounting depth to be defined.
m) One cell of a matrix of R'w values between a classroom and other spaces.

3. ASA ACTIVITY SUPPORTING DEVELOPMENT OF U.S. STANDARD

Prior to the establishment in June, 1998 of an ANSI S12 Working Group on Classroom Acoustics, the ASA, including the authors, carried out several preliminary related supporting activities including: a) a special session on classroom acoustics at the spring, 1997 ASA meeting, b) a short Seminar in July, 1997 on the topic for the Los Angeles Unified School District Architectural Design staff, c) a multidisciplinary Workshop in Dec., 1997 on Overcoming Acoustic Barriers to Learning with 90 attendees at the House Ear Institute in Los Angeles and d) presentations on Classroom Acoustics in June 1998 at a Universal Design Conference and at an annual meeting of SHHH, (Self Help for Hard of Hearing People). Since June, 1998, the Society and a Coalition of supporting organizations formed at the Dec. 1997 workshop have been very active preparing responses to a Request for Information published in the Federal Register by the U.S. Access Board. This Federal agency is currently responsible for issuing, and monitoring compliance with, federal regulations or guidelines to eliminate barriers to handicapped persons in public facilities. It is considering expanding this role to encompass the problem of acoustic barriers to learning for acoustically-challenged students. A key element of any such action would be the existence of nationally-recognized standards or guidelines for classroom acoustics - hence another reason for the urgent need for development of such standards or guidelines in the U.S.

4. CONCEPTS BEING CONSIDERED FOR A U.S. STANDARD OR GUIDELINE

As suggested by the entries in the preceding table, there are several obvious minimum elements of an effective standard or guideline for classroom acoustics. In a highly simplified form, these include, at least: a) - upper limits for the ambient noise level from interior and exterior sources, b) suitable values for the reverberation time in the classroom.

However, there are other parameters that require consideration. These include: c) the maximum "signal to noise" ratio in the classroom, especially when electronic amplification is required, d) a suitable means of actually measuring this parameter - (Just what is the "signal" in question and what is the "noise" - does it include the self-noise of a classroom of active children?), e) a measure of low frequency noise not provided by A-weighted levels to prevent upward spreading of speech masking by low frequency noise, f) consideration of practical tolerances and g) built-in features which help to motivate potential users to make effective application of the standards or guidelines. For point e), the low frequency problem, two methods may be considered - for simplicity, the preferred method would be to limit the difference between C-and A-weighted noise levels, possibly requiring lower differences as A-weighted levels increase. An alternative approach, like a Type 1 versus a Type 2 sound level meter, may allow use of octave band measurements and associated criterion curves, such as RC curves, when greater precision is required.

5. SOCIETAL COST/BENEFIT OF GOOD ACOUSTICS FOR CLASSROOMS

The unit cost per square foot for the building of new or renovated schools in the U.S. mentioned at the beginning of this paper is about $98 (in 1997 USD) for the median elementary school or about $ 20,000/student for a typical elementary classroom with a typical classroom (600 ft^2 and 30 students)[3]. The average cost of providing a good acoustic environment in a typical elementary school classroom is estimated to range from about $2,000 (when air conditioning is not required) to $8,000 when a quiet wall or window-mounted air conditioning system is required (the cost including a central fullyducted system may be somewhat greater but such a system is certainly able to provide lower ambient noise levels in a classroom). Costs can't be readily generalized due to the wide range of interior and exterior noise isolation requirements. That is, different STC values will be required for interior and exterior walls depending on the school design (i.e. - the arrangement of acoustically-conflicting learning and administrative or building operating spaces) and the exterior acoustic environment at the school location. Clearly, good acoustic environment planning at the beginning in this regard can be very cost effective. For the sake of illustration, however, assume a average cost of $5,000 per classroom to achieve good acoustic design for a new classroom. That would represent, for the average 600 ft^2 elementary classroom, an added cost of about 25%, according to the previously cited figure of about $100/$ft^2$ for the basic cost. This added cost is probably on the high side.

Accepting this figure for illustration, the cost for providing a good acoustic environment, amortized over a facility life span of, say, 30 years, would be of the order of $200/year/classroom (assuming some fiscal costs are involved in raising the initial moneys). When this is compared to the basic amortized cost over the same life span of about $600/year/classroom for the new classroom and estimated costs for teaching and administrative staff to provide the education to the children of, say 40,000/year/classroom, the incremental cost for providing the acoustic treatment is indeed small.

However, it becomes even smaller, in perspective, when compared to the cost to society of a lowered level of achievement upon graduation due to the presence of acoustic barriers to learning. This would be expected to be reflected in a reduction in their earnings throughout their lifetime. Valid quantitative figures can not be readily estimated but just a 3% decrease in average lifetime earnings of a classroom of 30 students can be roughly estimated to correspond to more than 100 times the cost of providing a proper acoustic environment in the classroom for these students throughout their school career. Even allowing for an order of magnitude error in such an estimate, can there be any doubt as to the cost benefit to society of providing good acoustics in classrooms.

Unfortunately , as stated in the school construction study in Ref. [3]:

> "... we are nowhere near keeping up with the need to remodel, retrofit and renovate our existing school buildings. America says it cares about its children and wants them to do better in school, but it still doesn't appear to have the will to spend the money to make sure that every child has a proper seat in a proper room with the proper equipment to make that learning possible."

6. SUMMARY

This basic economic hurdle for new and upgraded schools does not include the modest increment for better acoustics presented here. The acoustical community must face this major challenge with fortitude, dedication and application of ingenuity. As one among us has so well stated it: "Let the Word be Heard" - indeed, the need for better classroom acoustics must be a persistent and clear message to all concerned with education facility funding, design and construction until its significance and economic sense "sinks in".

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"CAN YOU HEAR ME AT THE BACK?" EFFECTIVE COMMUNICATION IN CLASSROOMS

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1. INTRODUCTION

"A good acoustic environment may be defined as that situation in which noise that is irrelevant ...is suppressed as far as possible, while the useful sounds are easily distinguishable"[1]. In schools, the relevant sounds, which are usually the teachers' or perhaps the pupils' speech, have much competition. Noise is produced by the children talking and moving around, other classes nearby, corridors and halls in use, plus, in some situations, external noise from traffic, trains or even aeroplanes. If this noise cannot be adequately suppressed to allow full attention to be paid to the important sounds, children will find attention hard to maintain and learning may well be hindered. Previous studies have also shown that children subjected to substantial levels of noise throughout the day in the classroom have an increased chance of suffering from high blood pressure and increased heart rate[2]. Teachers forced to work in noisy rooms often become stressed and suffer headaches or fatigue. Noise also causes annoyance to teachers, restricts teaching options and often results in loss of teaching time[3]. In one study, 61% of teachers found "uncomfortable" noise levels in their classrooms and 77% of teachers complained about noise in gymnasia[4].

Most teachers will control noise to a certain extent, by asking children to be quieter, closing doors, and sometimes shutting windows, often sacrificing ventilation for quietness. But what about those factors beyond a teacher's control, such as a busy main road outside, regular PE classes in the hall next door, or an extremely reverberant classroom? This paper reports on a survey of UK classrooms and examines a way of controlling noise levels and improving the classroom listening environment.

2. LEVELS OF NOISE EXPERIENCED IN CLASSROOMS

As children spend up to 75% of the school day listening and speaking, it seems obvious that classrooms should have good acoustical environments. The UK Department for Education recently issued guidelines for noise levels in schools[5]. The recommended background noise levels are 40dBA for normally hearing pupils and 30dBA for hearing impaired. Although not stated in the bulletin, it is assumed that these figures are for empty rooms, while the present research was carried out under realistic conditions in occupied classrooms. However, these guidelines do not take into account the fact that many classrooms may contain both hearing impaired and hearing children, and the levels are only suggestions, not enforceable regulations with advice on how to achieve them.

Table 1 illustrates the high levels of background noise measured in primary school classrooms around the UK. The classrooms have been divided into groups depending on their design. Open plan and cellular classrooms have been considered independently, and a separate group includes only classrooms which have specific acoustical treatment (all of which were cellular). A wide variety of schools were studied, including urban and rural schools, and old and modern buildings. The levels stated are the mean of a number of noise samples taken in approximately 60 classrooms under two different conditions; a) children silent, and b) children working and talking under normal conditions.

	OPEN-PLAN CLASSROOMS	CELLULAR CLASSROOMS	ACOUSTICALLY TREATED CLASSROOMS
PUPILS SILENT	56.6 dBA (min 49.1 / max 70.3)	55.5 dBA (min 31.4 / 67.8)	46.5 dBA (min 33.9 / max 55.0)
PUPILS WORKING	72.1 dBA (min 59.8 / max 84.3)	77.3 dBA (min 51.9/max 101.1)	70.1 dBA (min 58.9 / max 79.0)

Table (1). Average Measured Background Noise Levels dBA

It can be seen that open-plan classrooms experience slightly higher levels of background noise when the pupils in the tested classroom are silent, caused by noise entering from surrounding areas, but are quieter during active lessons This is usually due to higher reverberation times in cellular classrooms and because teachers in open plan rooms tend to restrict their lessons to quieter activities to avoid disturbing other classes. Around the world, research has reported similar noise levels in classrooms with particular problems caused by aircraft and traffic noise[7,8,12,], whilst the majority of noise in this study tended to be generated from within the school buildings themselves.

Classrooms with acoustical treatment, usually in the form of acoustical suspended ceilings, experienced lower levels of background noise throughout the day. It must be remembered that a decrease of 9dBA[6] is perceived as a halving of noise and would make a large difference in a classroom. The lower levels of background noise in the treated classrooms are due to the increased levels of absorbency which lower the reverberation times and, to a certain extent, protect the room from intruding noise.

3. IMPLICATIONS OF FINDINGS

A substantial amount of work on classroom acoustics and the effects of noise has been conducted world-wide. Most research, such as that conducted by Blake et al[7], found that "the acoustical conditions in the majority of classrooms were unacceptable". The effect this situation may have upon children was highlighted by Finitzo-Heiber et al[8], who concluded that if children are placed in learning environments that are not conducive to listening, they may well fall behind in their schoolwork and perform less well than their peers in more appropriate learning environments. Because children's listening skills are not yet fully developed, they are more easily distracted by background noise than adults. In particular, children with hearing aids and temporary hearing loss find it difficult to filter out unwanted noise and pay attention to the meaningful sounds. A large number of primary school children suffer middle ear disease, so most classes will contain several children with some kind of hearing impairment, whether temporary or permanent.

Speech will be clearer in quieter rooms because the signal to noise ratio, where the signal is usually the teacher's voice, will be much higher. An average teacher's voice level[9] is approximately 57dBA. It is recommended[5] that in order for children to perceive speech clearly, the signal to noise ratio should be +15-20dB. It can be gleaned from Table 1 that, whilst it would be possible for a teacher to make her or himself heard when the children are quiet, it would be virtually impossible for the teacher's voice to be clearly perceived once the children begin talking and working. It is often assumed that a teacher will ensure a class is silent before speaking, but in today's busy classroom, a teacher often talks with one group whilst the rest of the class is working around them. Even though the speaker to listener distance would probably be reduced in this situation, the high level of background noise will still be detrimental to those children trying to hear. It must also be considered that when children are working and not listening to speech, levels of background noise such as those measured will not be conducive to concentrating and performing tasks requiring memory skills.

4. IMPROVING CLASSROOM ENVIRONMENTS

The usual perception of classrooms is that they are noisy places, and all too often teachers believe classroom noise is just an 'occupational hazard' and something over which they have no control. Teachers who suffer regular sore throats or loss of voice accept this as normal, but it does not have to be. There have already been cases in the UK where teachers have taken their local education authority to court, claiming compensation for 'industrial injury' caused by noisy working conditions. Rather than tackling the, often expensive, result of poor acoustics, whether measured in monetary terms or by low academic achievement, it is possible to correct or prevent noisy and reverberant classrooms.

An important development of this research was to carry out subjective tests to determine how children are affected by classroom noise. Objective measurements using the Speech Transmission Index (STI) have shown that classrooms with higher levels of background noise and reverberation times(10) had poor levels of speech intelligibility. If this is true and children do not perceive speech as well in noisy classrooms as in quiet, then their performance on listening tasks will be impaired. The Modified WIPI test is a subjective test of speech intelligibility based on an original test designed to assess hearing impairment in children(11). A list of phonetically balanced words were presented to groups of children in two occupied classrooms before and after installation of an acoustical ceiling. The tests were administered under three conditions; a) in silence, b) in typical classroom noise and c) control, with lists presented through headphones to eliminate all noise. Measures were taken to rule out any learning effects and different children were selected for each test from groups of equal ability.

From Table 2, it can be seen that there is a reduction in the percentage of words being understood when the pupils are subjected to levels of background noise. The rooms with acoustical treatment result in higher pupil scores in the word recognition task in noise, which suggests that due to a quieter working environment the children are less distracted and can perceive speech more clearly.

	ROOM UNTREATED	ROOM TREATED
CONTROL	96.7%	97.5%
QUIET CLASSROOM	94.2%	97.5%
NOISY CLASSROOM	57.2%	67.0%

Table (2). Average correct word recognition by pupils in quiet and noise

To draw statistically significant conclusions from this type of study, a larger number of tests need to be applied and the varying levels of background noise monitored. However, it has been shown that the memory, concentration and reading skills of pupils decrease in noisy environments(12). The results of this study, and of previous work by other researchers, suggest by lowering background noise levels in schools, teachers and pupils will not only communicate more easily, but will perform better. The problem of noise entering into, and being generated within schools, needs careful consideration by school designers in the early planning stages, and by users of existing school buildings.

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COMPARISON OF OCCUPATIONAL NOISE EXPOSURE RESULTS ACQUIRED FROM AN IN-EAR PROBE TUBE AND AN ARTIFICIAL EAR, FOR USERS OF TELE-COMMUNICATION HEADSETS

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ABSTRACT

A major tele-communications company in Australia initiated a study into the noise exposure levels amongst their telephone headset users. To conduct this study, two test techniques were trialed: an In-Ear Probe Tube and an Artificial Ear technique. These techniques are most suited to the measurement of noise exposure of people wearing tele-communication headsets or headphones, as they measure noise within the ear canal, rather than outside the ear of a person. The two methods enable the measurement of both the headset signal level and the surrounding ambient noise entering the ear, giving an accurate overall noise exposure level.

This paper presents and compares the occupational noise exposure results acquired in the field using both techniques on 20 subjects wearing tele-communication headsets, and it highlights the limitations and practical difficulties associated with each technique.

1. INTRODUCTION

The current maximum allowable standard in Australia for a exposure to occupational noise is an eight hour equivalent continuous A-weighted sound pressure level ($L_{Aeq,8h}$) of 85dB(A), and an unweighted or linear peak sound pressure level (L_{peak}) of 140dB. This applies to measurements of occupational noise exposure outside the ear of employees, in a relatively diffuse sound field. Some employees however, such as telephonists, use headsets or headphones as part of their daily work. For such employees, special testing techniques are required to measure and assess their exposure to occupational noise.

A major tele-communications company in Australia initiated a study into workplace noise exposure levels amongst their telephone headset users. Two test methods were selected and used to conduct this study: namely a 'direct' method for measuring noise within user ear canals using a probe-tube device, and an 'in-direct' method where sound generated by a user's headset is measured using an artificial ear via a second headset connected in parallel to the user's headset.

Both methods are often used to measure in-ear sound levels of hearing aid wearers and are sometimes used in the assessment of hearing protection devices. In this case, these methods were selected as they provide the opportunity of measuring the sound which actually enters the ear canal from which the sound pressure level at the eardrum can be estimated. Both methods allow the measurement of total sound experienced in the eardrum, as opposed to the measurement of only the sound occurring outside the ear with conventional methods. Standard transfer functions established by researchers in this field, were used to convert the sound pressure levels at the eardrum to those outside the ear in a diffuse sound field, enabling the results to be assessed against conventional noise standards.

2. TEST EQUIPMENT & PROCEDURES

2.1 In-Ear Probe Tube & Headset

The in-ear probe tube instrumentation used in this study was purposely designed and built by RTA Technology Pty Ltd for this project. The instrumentation consisted of a thin and flexible silicone tube, which was fitted through a hole in the ear-piece of a standard tele-communication headset that can be used on the left or right ear. The silicone tube positioned on the headset was inserted into the wearer's ear canal. The inserted tube was used to carry the sound signal from within the ear canal to a 6mm diameter microphone. After pre-amplifying the signal (CEL-231), the signal was then fed into an integrating-averaging sound analyser (Norwegian Electronics-Norsonic SA 110) to enable a third-octave band frequency analysis to be conducted on the measured levels.

This custom-built test system was calibrated by fitting the in-ear probe tube and headset on to a Knowles DB-100 artificial ear, feeding pink noise over a range of amplitudes through the tele-communication headset, and comparing the output of the in-ear probe tube system to the output of the reference artificial ear in third-octave frequency bands. By repeating the above calibration tests several times and averaging the results, correction values in third-octave band frequencies were established (see column 3, Table 1) and then applied to the measurement results (see result in column 4, Table 1). The system's calibration was re-checked in the field before and after each set of noise tests using a field sound level calibrator (Brüel & Kjær Type 4230).

To make the in-ear probe tube method easier and safer to use in the field, the silicone probe tube was inserted to a point only slightly past the entrance of the ear canal, instead of placing it near the eardrum.

2.2 Artificial Ear

An artificial ear (Knowles DB-100) fitted with a latex pinna, a 12.5mm diameter condenser microphone (Brüel & Kjær Type 4134) and a precision integrating-averaging sound level meter (Brüel & Kjær Type 2231), was used to measure the sound signal emitted through a second headset connected in parallel to the user's headset. The second headset was identical to the user's headset and the impedance of both headsets also matched.

The size of the artificial ear unit is that of the average adult human and the soft pinna allowed the tele-communication headset to be positioned in a manner similar to the way it would fit on a human ear. The Knowles DB-100 unit and microphone combination possesses the acoustic response of the average human ear(4).

The system calibration was checked in the field before and after each set of noise measurements using a field sound level calibrator (Brüel & Kjær Type 4231). Once calibrated, the amplifier gain setting for the second headset fitted to the artificial ear, was fixed so that each individual subject's main control settings could be monitored.

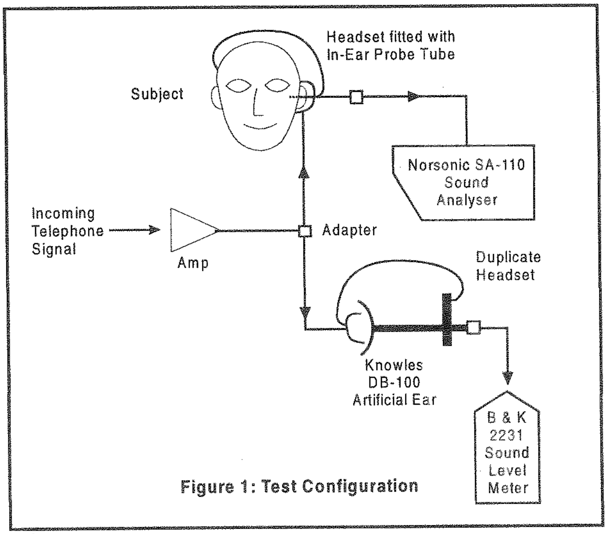

Figure 1: Test Configuration

2.3 Test Procedures

In the field, a total of twenty subjects wearing tele-communication headsets were tested: ten subjects (9 female and 1 male) were tested at Site A, and ten subjects (all 10 female) were tested at Site B. Each subject was tested using both test systems concurrently over a minimum of 15 minutes while conducting their normal daily work which involved answering incoming telephone enquiries from the general public.

A workstation in the open plan office of each site was selected and once fitted with the equipment of both test systems, employees were randomly selected to work at the instrumented workstation and participate as test subjects for the study. Subjects were assisted with the fitting of the instrumented headset ensuring that the silicone tube was properly inserted into their ear canal. Once fitted with the headset, subjects were allowed time to adjust themselves and were permitted to adjust the amplifier gain to a comfortable level of their choice. During each test session, each subject responded to approx. 5-10 phone call enquiries, which is considered representative for typical work periods.

3. RESULTS

3.1 In-Ear Probe Tube & Headset System Results

Table 1 presents the mean of all L_{Aeq} sound levels measured in third-octave frequency bands at each of the two sites (see column 2). The table also includes the calibration correction values applied to the measured data, as discussed earlier (see column 3). Furthermore, as the human external ear amplifies incoming sound, and the amount of amplification varies as a function of frequency, a suitable transfer function(3,7) (see column 5) describing the relationship between the eardrum and outside the ear was necessarily applied to convert the measured values into equivalent diffuse field values (see column 6). Sound levels in the third-octave band frequency range 200Hz to 6300Hz were analysed as human speech on a telephone line is generally limited to within this range.

The resultant overall diffuse field L_{Aeq} levels shown in Table 1 for Sites A and B are therefore 71.6dB(A) and 69.8dB(A), respectively. Both levels are clearly below $L_{Aeq,8h}$ of 85dB(A) and are therefore compliant with the national standard.

The entire range of diffuse field L_{Aeq} overall levels were 63-76dB(A) for Site A and 67-74dB(A) for Site B. Similarly, these levels are below $L_{Aeq,8h}$ of 85dB(A) and are compliant with the national standard.

The L_{peak} sound levels measured inside the ear canals of subjects were typically in the range of 96-111dB(lin) at Site A and 100-114dB(lin) at Site B. After determining the mean results for each site and converting the measured values to equivalent diffuse field values, the resultant overall L_{peak} levels are approx. 101dB(lin) and 103dB(lin) for Sites A and B, respectively. The L_{peak} levels measured are therefore all clearly below the national maximum limit of 140dB(lin).

Table 1 – Mean L_{Aeq} Sound Level Data in Third-Octave Band Frequencies and Overall Levels for Site A & Site B

1. Third-Octave Centre Frequency Hz	**2. In-Ear Probe Tube Sound Levels, dB(A)**		**3. Calibration Correction Values, dB**	**4. Corrected In-Ear Sound Levels, dB(A)**		**5. Transfer Function: In-Ear to Diffuse Field**	**6. Resultant Diffuse Field Sound Levels, dB(A)**	
	Site A	**Site B**		**Site A**	**Site B**		**Site A**	**Site B**
200	69.9	68.6	-16.1	53.8	52.5	-0.4	53.4	52.1
250	69.4	68.0	-12.7	56.7	55.3	-0.5	56.2	54.8
315	65.5	64.7	-8.7	56.8	56.0	-1.0	55.8	55.0
400	69.6	65.3	-4.9	64.7	60.4	-1.3	63.4	59.1
500	66.5	63.4	-1.5	65.0	61.9	-1.7	63.3	60.2
630	64.6	60.0	1.4	66.0	61.4	-2.2	63.8	59.2
800	63.7	60.8	2.9	66.6	63.7	-2.9	63.7	60.8
1000	63.9	64.9	1.6	65.5	66.5	-3.8	61.7	62.7
1250	64.5	65.1	0.7	65.2	65.8	-5.3	59.9	60.5
1600	58.8	58.3	8.8	67.6	67.1	-7.2	60.4	59.9
2000	53.7	54.2	13.6	67.3	67.8	-10.2	57.1	57.6
2500	52.6	54.1	11.8	64.4	65.9	-14.9	49.5	51.0
3150	46.4	48.2	17.8	64.2	66.0	-14.4	49.8	51.6
4000	40.1	41.5	19.8	59.9	61.3	-12.9	47.0	48.4
5000	40.1	40.3	18.9	59.0	59.2	-10.8	48.2	48.4
6300	39.9	39.4	9.8	49.7	49.2	-8.7	41.0	40.5
Overall	**76.8**	**75.0**		**76.1**	**75.6**		**71.6**	**69.8**

The last row in Table 1 presents the overall results as dB(A) sound levels. Comparison of results in columns 4 and 6 show that the corrected in-ear sound levels are higher than the resultant diffuse field sound levels by 4.5dB(A) for Site A and 5.8dB(A) for Site B. This difference is to be compared with the 5dB correction recommended by AS/NZS 1269-1998(1).

3.2 Artificial Ear Results

To convert the L_{Aeq} levels measured via the artificial ear into equivalent diffuse field sound levels, necessarily a single value correction of –5dB(1,3) was applied. Table 2 presents a summary of the measured and resultant mean L_{Aeq} levels for each site.

All levels presented in Table 2 are clearly below $L_{Aeq,8h}$ of 85dB(A) and are therefore compliant with the national standard.

Table 2 – Mean L_{Aeq} Overall Sound Levels for Site A & Site B

	Artificial Ear Sound Levels, dB(A)		**Correction: Artificial Ear to Diffuse Field**	**Resultant Diffuse Field Sound Levels, dB(A)**	
	Site A	**Site B**		**Site A**	**Site B**
Mean	75	76	-5	70	71
Range	72-77	72-79	-5	67-72	67-74

The L_{peak} sound levels measured by the artificial ear were in the range of 101-107dB(lin) [mean 102.6dB(lin)] at Site A and 101-103dB(lin) [mean 101.9dB(lin)] at Site B. After applying a -3dB correction(1,3), which is appropriate for converting peak sound levels from in-ear to diffuse field values, the resultant overall mean L_{peak} levels are approx. 100dB(lin) and 99dB(lin) for Sites A and B, respectively. The L_{peak} levels measured are therefore all clearly below the national maximum limit of 140dB(lin).

Although there is the potential for significant errors associated with the use of generic corrections based on the average human ear and an everyday noise spectrum(3), the corrections are well established by researchers in this field and are deemed suitable for the purpose of this study.

3.3 Comparison: In-Ear Probe Tube -V- Artificial Ear Results

To enable a direct comparison of both techniques, a summary of the mean results of all 20 subjects are presented below in Figure 2.

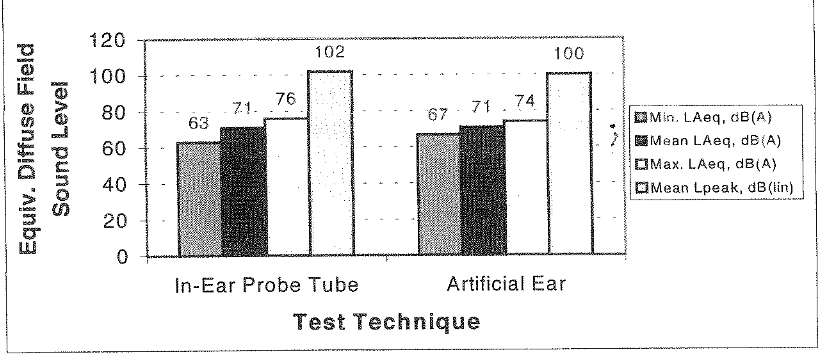

Figure 2: Comparison of Results

The differences between each respective results acquired by the two techniques were generally found to be within the range 0.2 - 4dB. The In-Ear Probe Tube technique generally measured conservatively higher levels than the Artificial Ear technique. The differences in results between the two techniques did not affect the occupational noise assessment conclusions.

4. CONCLUSION

A study was conducted into the assessment of occupational noise exposure of tele-communication headset wearers. Twenty subjects, wearing tele-communication headsets as part of their normal work, were tested in the field using two different techniques. The test results were compared to relevant national standards and an appraisal of the two test techniques was also provided.

The test results show that under typical conditions, the headset users were not exposed to levels which exceed national occupational noise limits.

The results acquired from the two test techniques are similar. However, in terms of conducting the tests, it was found that the use of the In-Ear Probe Tube technique was more cumbersome and slower to execute than the Artificial Ear technique. Other advantages in using the Artificial Ear over the In-Ear Probe Tube technique are that testing can occur without the discomfort of subjects, tests can be conducted over longer periods which improves the statistical accuracy of results, and importantly, there are no risks associated with inserting a probe into a subject's ear canal.

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The Effects of Hearing Protectors on Reaction Times in Audio-Visual Target Acquisition

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1. INTRODUCTION

Over the last three decades, a great deal of research has been conducted on hearing conservation programs and the design and evaluation of hearing protection devices (HPDs). Contemporary hearing protectors effectively reduce the amount of ambient noise that reaches the auditory system, and as such are used effectively in occupational environments to prevent noise-induced hearing loss and to enhance task performance and personal safety. Surprisingly, very little attention has been paid to the potential safety hazard inherent in the disruption of auditory localization by hearing protectors, in spite of the fact that it is well-known that the physical properties of the individual HPDs result in modification of the monaural and binaural spectral cues important for localization [1]. The issue of mislocalization of routine sounds and warning signals in the workplace is recognized in some occupational health arenas. Workplace accidents, and even fatalities, have been attributed to the inability to hear and/or localize critical audio cues in the immediate environment [2]. Hearing protector designers appear to be moving slowly toward ameliorating this situation.

Only a few researchers have examined the effects of conventional hearing protectors on localization acuity. Atherley and Noble [3] had listeners localize a 1000 Hz pure tone in the horizontal plane with and without a circumaural HPD, and found that while wearing the HPD: 1) more errors were made; and 2) listeners more frequently perceived the source as coming from the hemifield contralateral to its actual position. In a study by Abel and Hay [4], a similar effect was found with a stimulus frequency of 4000 Hz but not with a 500 Hz stimulus, suggesting that interaural differences in *intensity* rather than *time* are disrupted.

In a later study, Noble and Russell [5] examined the combined effects of different stimuli and different types of hearing protection on localization acuity. Participants localized a broadband noise or a 1000 Hz pure tone while wearing either circumaural earmuffs or earplugs. Listeners made more errors when the stimulus was broadband, suggesting disruptions of the spectral cue. They performed better with earplugs than with earmuffs, but not as well as in the unoccluded condition, a difference that the authors attribute to an increase in the number of front-back confusions in the earmuff condition. Finally, listeners in this study made no more contralateral errors with earplugs than they did without hearing protection. Later research [6] demonstrated that, when free head movements are permitted, listeners localize as accurately in azimuth with either earplugs or earmuffs as they do without occlusion. However, reaction times (RT) are slower when hearing protection is worn, and the addition of the dynamic head motion cue does not restore proficient localization in the vertical plane.

One problem with drawing conclusions about real-world phenomena from such experiments is that they reflect neither the complexity of real-world tasks nor the abundance of non-auditory sensory cues available in any occupational context. The objective of the present study was to evaluate the effects of hearing protection on a more ecologically valid task: aurally-aided visual search [7]. In this case, it is not localization acuity which is being investigated, but rather how degradations in localization acuity contribute to the time required for a listener to locate and identify an audio-visual target among a background of visual distractors.

2. METHOD

Three males between the ages of 21 and 35 participated in the experiment. All subjects had pure tone thresholds of less than 15 dB above audiometric zero and uncorrected 20/20 vision.

All testing was conducted in the Air Force Research Laboratory's Auditory Localization Facility (ALF) at Wright-Patterson Air Force Base, Ohio, consisting of a geodesic sphere of radius 2.3 m, centered within a cubic anechoic chamber of side 6.7 m. Located at each of the sphere's 277 vertices, spaced approximately 15° apart, was a Bose 4.5" Helical Voice Coil full-range loudspeaker (Model 118038), facing the center of the sphere. Mounted 5 cm above the anterior surface of each loudspeaker was a square array of light-emitting diodes (LEDs), each of which emitted a 620 nm wavelength light at a luminance of about 200 mL [7].

At the beginning of each session, the subject was seated at the center of the ALF, with the room darkened and all of the LEDs extinguished. Before testing began in the occluded conditions, the subject donned earmuffs or inserted earplugs. At the inception of each trial, an even number of LEDs was energized at the fixation point (0° azimuth, 0° elevation). Before the subject was permitted to continue, he/she was required to correctly indicate, via a two-button response switch, the number of LEDs energized (*i.e.*, 2 or 4). Once this was accomplished, the target and distractor LED clusters were energized simultaneously, and the subject began his/her search. The clusters at the distractor locations contained an odd number of LEDs. The target cluster always contained an even number of energized LEDs, and the search task involved finding the target and indicating the number of LEDs which were energized using a two-button switch. All targets fell within ±180° in azimuth, and between -70° and +90° in elevation. In the auditory conditions, a continuous acoustic stimulus (pink noise, 40 dB SL) emanated from the same location as the target. RT and correctness of response were stored for each trial.

Four sensory conditions of non-audio, unoccluded, earplugs, or earmuffs were combined factorially with three set sizes of 5, 10, or 25 distractors. In the non-audio condition, participants completed a simple visual search task. In the unoccluded audio condition, participants performed the same task, augmented by an audio cue co-located with the visual target. The two occluded conditions were identical to the unoccluded with the exception that participants wore either earplugs (EAR Classic) or earmuffs (Tasco Sound Shield).

Participants were given 60 practice trials on each of the conditions prior to testing. Subsequent to training, each of the subjects completed 5 blocks of 266 trials (one trial per target location) for each of the 4 (sensory conditions) X 3 (set sizes) = 12 possible treatments. The order in which the conditions were run was randomized session by session to minimize the effects of additional learning.

3. RESULTS

Reaction Time

Mean RTs for all of the experimental conditions were analyzed using a 4 (sensory condition) X 3 (set size) repeated measures analysis of variance, which revealed significant main effects of sensory condition ($F(3, 6) = 1763.56$; $p < .01$) and set size ($F(2, 4) = 1473.40$; $p < .01$), and a significant sensory condition X set size interaction ($F(6, 12) = 826.44$; $p < .01$). The interaction is illustrated in Figure 1, in which RT is plotted as a function of set size for each of the four sensory conditions.

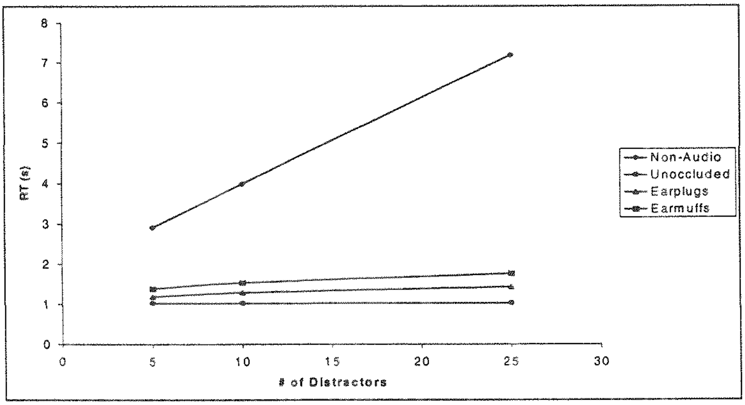

Figure (1). Reaction time as a function of set size for each of the four sensory conditions.

The interaction was further investigated by tests of simple main effects of the sensory conditions as a function of set size, and of the set sizes as a function of sensory condition. All simple main effects were statistically significant ($p < .01$), excepting the unoccluded and hearing protector conditions analyzed as functions of set size. Post hoc *t*-tests were performed to compare pairwise the mean RTs for all of the set sizes within each sensory condition for which simple main effects were significant, and for all sensory conditions within each set size. Furthermore, simple linear regression analyses were performed on RT as a function of set size for each sensory condition. For the non-audio and the two hearing protector conditions, the RT *vs.* set size functions did not differ significantly from linearity ($p < .05$). For the unoccluded condition, this difference was marginal ($p = .08$).

Within the non-audio condition, all effects of set size were significant ($p < .01$). As Figure 1 illustrates, RTs in this condition increased linearly with set size. The regression analysis revealed a rate of increase of 214 ms per distractor.

Under the unoccluded and hearing protector conditions, none of the effects of set size reached statistical significance at the .01 level, implying that, regardless of the complexity of the target+distractor array, RT was approximately constant. This interpretation is supported by the regression analyses, which yielded RT *vs.* set size functions with slopes of 0, 11, and 18 ms per distractor for each of the unoccluded, earplug, and earmuff conditions, respectively.

Within each set size, RTs in the non-audio condition were significantly slower than in all of the other conditions ($p < .01$). Within *no* set size did RTs in the earplug condition differ from those in the earmuff condition at the .01 level of significance. Performance in the unoccluded condition differed significantly from that in the earplug condition only in the 10 and 25 distractor cases. Differences between the unoccluded and earmuff conditions were significant for each set size ($p < .01$).

Percent Correct

Mean percentages of correct responses were analyzed using a 4 X 3 repeated measures analysis of variance similar to that used in the analysis of the reaction time data. Neither the main effects nor the interaction were found to be statistically significant ($p > .05$). Percent correct varied from 94-99% for each of the conditions tested.

4. DISCUSSION

Most of the studies on the effects of hearing protection on auditory localization have reported gross disturbances in the ability of listeners to determine the location of a sound source. These studies have typically been done under conditions of less than optimal audio cues (e.g., pure tones), restricted or no head movements, and lack of visual feedback. In an occupational environment, many sounds are broadband and/or are associated with objects which are either immediately visible or which can be brought easily into an operator's field of view by a brief head movement. The results of the present investigation indicate that, while RTs in a task requiring accurate localization are significantly slower when the operator is wearing hearing protection, this difference is negligible when compared to the performance advantage obtained in any of the audio conditions over the non-audio control.

This research suggests that hearing protection should not occasion mislocalization of sounds in an occupational environment, provided that they are of sufficiently long duration and are spectrally complex. While these criteria are met by many occupational sounds, they are certainly not definitive. More work needs to be undertaken to determine how listeners perform when the sounds they are required to localize are of shorter duration, potentially eliminating the dynamic cue afforded by head motion, or more limited bandwidth, diminishing the spectral cues necessary to localize sounds outside of the horizontal plane. Furthermore, research is needed in the area of localization in noisy environments, and in the effects of ambient noise on localization by listeners wearing hearing protectors. Finally, all of the studies conducted up to this point have involved normal hearing listeners. It is not known whether these results generalize to hearing-impaired populations.

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SEMANTIC REACTIONS TO DYNAMIC ACOUSTIC STIMULI

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1. INTRODUCTION

There is an increasing tendency to use sound monitoring as feedback for ongoing and unfolding events both in noisy and in quiet environments. This is a process by which an object, a process, or some physical parameter is monitored via a computer or other equipment. Examples might be changes in patient temperature or heart rate in a hospital ward, or variation in rotor speed in a helicopter. A range of different types of sounds can be used to convey such messages, varying from speech, through sound images which might actually be the sounds of those events themselves as they unfold (or sounds which can convey a similar imagery), to more abstract, or semi-abstract sounds which do not necessarily convey the nature of the process itself being portrayed but do have the advantage that they can convey the changing importance or urgency of the process or parameter being monitored.

Warren and Verbrugge [1] showed that different subsets of acoustic parameters convey firstly the nature of the object itself making the sound, and secondly what is happening to that object over time; a series of experiments by Solomon ([2], [3], [4]) showed that sonarmen interpret sonar signals along several dimensions according to their acoustic structure. These studies demonstrate that it is possible to retain the essence of a sound without fully reproducing it. Studies on auditory warning design (Edworthy et al, [5], Hellier et al, [6]) also suggest that the dimensions of pitch, rhythm, speed and harmonic structure are among the most salient aspect of abstract sounds, and are therefore likely to figure importantly in conveying changes in meaning in a sound as they themselves are changed.

In the series of studies briefly described here, we explore the relationship between semantic meaning and these four acoustic parameters (pitch, speed, rhythm and inharmonicity). The results of these studies have allowed us to create sounds which can be used to monitor ongoing trends, for application in the complex noise environment of the helicopter.

2. THE STUDIES

Participants

Sixteen participants took part in the study. There were 12 females and four males, aged from 23 to 45 years. All were undergraduate students from the University of Plymouth, paid for volunteering to be in the experiment. Participants were screened for normal hearing using a Peters 250 Audiometer, and all were shown to have normal hearing.

Stimuli

Four sets of 7 stimuli were generated. Within each set of 7 stimuli, only one acoustic parameter varied across the set, and this did so systematically. Each of the 28 stimuli used in the study consisted of a unit of sound lasting usually (except in the 'speed' condition) 1200ms in length, made up from 6 200ms pulses of sound with a 20ms onset envelope. For the 'speed' stimuli, it was necessary to change the number of pulses in the sound in order to vary the speed within a fixed stimulus length of 1200ms.The four sets of stimuli were designed as follows:

Pitch stimuli. The fundamental frequency of the 7 stimuli varied from 100Hz to 1000Hz in 150Hz units.

Rhythm stimuli. The rhythm of the 7 stimuli varied systematically in their interpulse interval so that some stimuli became faster as they proceeded, one was regular in temporal pattern, and some slowed down. The rate at which the stimuli speeded up or slowed down was systematically increased or decreased by 25ms units.

Inharmonicity stimuli. The number of extra harmonics between the first and second partials of the pulse was systematically increased from 0 to 6.

Speed stimuli. The interpulse interval of the stimuli was systematically decreased from 950ms to 0ms.

Rating scales

On the basis of previous research (Solomon [2], Solomon [3], Solomon [4], Lazarus and Hoge [7], Loxley [8]) a set of 42 adjectives were selected for use. They were presented as unipolar 7-point Likert-type scales, in booklets containing one example of each of the 42 adjectives.

Procedure

The 28 stimuli were presented in a different random order for each of the participants, and 7 stimuli were listened to in each of 4 half-hour sessions. The seven stimuli in each session ranged across the four sets of stimuli. During a single trial participants were required to listen to a single sound and to rate it on each of the 42 adjectives. The sound was played continually while the participant carried out the task for that sound.

3. RESULTS AND DISCUSSION

This study generated a large amount of data, and further detail can be seen elsewhere (Edworthy et al [9]). Adjectives were deemed irrelevant for each of the four stimuli if they were selected as 'irrelevant' (on the adjective sheet) for more than 15% of the time. Using this criterion, 15 adjectives remained associated with the pitch stimuli, 13 with the speed stimuli, 12 with the inharmonicity stimuli and 5 with the rhythm stimuli. These associations were then subjected to further analysis.

Firstly, a value for Kendall's W' was derived for each set of stimuli (pitch, speed, inharmonicity and rhythm) and its association with each of the remaining adjectives. This showed how consistent participants had been in making their judgements. However, it does not actually address the nature of the relationship between the stimuli and the adjectives, it simply shows that participants were consistent in making their judgements (if Kendall's W' is significant). Thus a regression was also carried out between the mean adjective ratings assigned to each of the individual stimulus levels and the 7 levels for each set of acoustic stimuli. On the basis of both methods of analysis, the following significant associations were found:

Pitch stimuli

This was significantly associated with the adjectives 'dangerous', 'urgent', 'high', 'low', 'rising', 'safe', and 'straining'. This means that there was both significant agreement between participants and a significant linear trend showing that as the levels of the pitch went up (or down), so there were significant changes in the rating assigned to those adjectives. In some cases the ratings went up as the pitch went up (as in the cases of 'dangerous', 'urgent' and 'high', for example) and sometimes they went down as the pitch went up (as in the case of 'low', for example).

Speed stimuli

A significant value for Kendall's W' and significant linear trends were found for the adjectives 'dangerous', 'urgent' and 'fast'. In all three cases, ratings for those adjectives increased as the speed of the stimuli increased.

Inharmonicity stimuli

A significant value for Kendall's W' and significant linear trends were found for the adjectives 'powerful' and 'urgent'. In both cases the ratings went down as the degree of inharmonicity increased.

Rhythm stimuli

The stimuli were divided into two subsets of four stimuli for analysis, as three speeded up and three slowed down. The metrically regular stimulus was retained in both subsets. Only one significant regression was found here, between the slowing down stimuli and the adjective 'jerky'.

4. DESIGN APPLICATIONS

On the basis of this and other associated work, a set of trend monitoring sounds have been designed. One example, for rotor overspeed in helicopters, is given here. Previous work (Edworthy et al [10]) established a design protocol for trend monitoring sounds with 5 levels. A trend monitoring sound designed to convey that the rotors are speeding up should be least urgent and least indicative of a fault at level 1, and most indicative at level 5. A design based on an increasing pitch through levels 1 to 5, together with an increasing speed and also an increasingly regular rhythm, was selected. Increasing speed can convey that the situation is becoming more urgent, dangerous, urgent and so on, and increasing pitch can convey similar changes, as well as the meaning 'straining'. Increasing the regularity of the rhythm of the stimulus also helps to convey increasing jerkiness.

A trend monitoring sound designed in this way is therefore likely to convey an increasingly urgent, dangerous, straining, fast situation and thus is likely to convey its designated meaning. It also has the benefit that the resultant sound mimics some of the things the rotors are actually doing in reality, in particular that they are speeding up. In other examples of trend monitoring sound design, things are not as quite straightforward as sometimes different meanings contradict each other. For example, rotor underspeed can also be a problem requiring signaling and this presents the problem that the most obvious design (a sound which slows down systematically) may not also convey that the situation is becoming more urgent (which would not be indicated by designing a sound which slowed down in this way). Thus further research in this area is necessary.

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NON-AUDITORY HEALTH EFFECTS OF NOISE: REVIEW OF THE 1993-1998 PERIOD.

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1. INTRODUCTION

This review addresses the current evidence of population based research efforts (period 1993-1998) concerning adverse physiological health effects of occupational and community exposures to noise. Overall, 30 studies are reviewed. Some studies were excluded because the quality of information concerning noise or data analysis was not adequate for evaluation. The majority of the studies deal with cardiovascular health (19) followed by neuroendocrine (5) and reproductive (4) health outcomes. During the reporting period several full, partial or conceptual reviews have dealt in more detail with selected aspects and it is recommend to consult these as well (Passchier-Vermeer (1993), Lercher (1994, 1996, 1998), Berglund & Lindvall (1995), Nurminen (1995), Job (1996), Thompson (1993, 1996, 1997), Stansfeld & Haines (1997), Vallet (1997), Ising & Günther (1997), Babisch (1998), Evans (1993, 1998). As has been pointed out earlier by Thompson (1993) a quantitative meta-analysis seems not to be adequate for the diverse outcomes, analysis strategies, settings and backgrounds of the various studies. Therefore, studies are discussed followed by a summary of improvements needed in future research.

2. REVIEW OF STUDIES

Cardiovascular Health in Children

Wu et al. (1993) report a comparison of 309 deaf mute children with 583 normal hearing children both exposed to heavy traffic noise at school (60-75 dBA). Both systolic and diastolic blood pressure were lower in the deaf mute children than in the normal hearing children after adjusting for age and body mass index. However, caution is needed to attribute this lower blood pressure simply to less noise exposure; the cause of the deafness (e.g. rubella) may influence lifestyle and the nature of school task performance, which in turn may influence blood pressure.

Regecova & Kellerova (1995) carried out a cross-sectional study of 1542, 3-7 year old children in kindergartens exposed to three noise conditions (quiet ≤ 60 dBA, noisy 61-69dBA, very noisy ≥ 70 dBA). They found significantly higher systolic and diastolic blood pressure in noisy or very noisy environments (both kindergarten and home noise) compared to quiet environments. These findings were not affected by age, height or weight. This is a carefully designed study although it is difficult to tell whether social class might have confounded the association of noise exposure and blood pressure.

In the cross-sectional part of the Munich airport study there was a marginally significant relationship between noise exposure and baseline systolic blood pressure and lower reactivity in systolic blood pressure to a cognitive task presented under acute noise (Evans et al. 1995). Diastolic blood pressure and reactivity were unrelated to noise exposure. Children were matched on socio-economic characteristics. In the prospective part of this study (Evans et al. 1998), blood pressure increased in the noise impacted communities after the opening of the new airport. The MANOVA results revealed significant increases in systolic blood pressure ($p < 0.01$) and marginal significance for diastolic blood pressure ($p = 0.06$).

The "Munich airport move study" was the first study to examine neuroendocrine indices of chronic stress among well-matched children exposed to community noise. In the baseline cross-section of the Munich study overnight resting levels of urinary catecholamines (epinephrine and norepinephrine) were significantly higher in children chronically exposed to aircraft noise around the old Munich airport than in children in the control areas (Evans et al. 1995). There was no significant association between chronic aircraft noise exposure and cortisol level. After the move of the airport, overnight urinary catecholamines increased sharply among children living in the flight paths of the new airport. Urinary cortisol changes were not related to the changing noise conditions (Evans et al. 1998). The replication of the results in the prospective part of this study with audiometrically screened children adds credence to the existing cross-sectional evidence of increased psychophysiological stress among children with exposure to aircraft noise.

These studies increase the evidence for slight elevations of blood pressure in children residing or attending school or kindergarten near major noise sources (air, road). Although the degree of blood pressure increase is small on average from a clinical perspective, these increases need to be tracked into adulthood. The accompanying elevations in neuroendocrine markers of stress (catecholamines) give further credence to the idea of stress being a potential intermediate step between noise and increased blood pressure. A further refinement in these studies would be to concentrate on subgroups of children with a family history of hypertension or low birth weight, both of which are associated with a higher risk of developing hypertension. All studies would profit from repeated blood pressure measurements.

Cardiovascular effects in adults: acute effects

A study on 68 cardiac patients in a rehabilitation clinic on continuous cardiac monitoring exposed to noise from low altitude military flights (300 m) did not see clinically relevant changes in heart rate or number of ventricular extrasystoles (Brenner et al. 1993). Sound levels were measured at the flat roof (peaks >95 dBA) and individual exposure may have been much lower. Furthermore, the possibly mitigating effect of ongoing medications is difficult to estimate and the chosen clinical parameters may not have been sensitive enough.

In an experimental study with 89 hypertensives and 150 normotensives Griefahn (1994) found no differences in the reaction of treated hypertensives (Beta-blockers) to noise (62-80 dBA Leq) compared with normotensives. This is in contrast to earlier findings (Andren et al 1981), however, noise levels were higher (100 dB) and exposure duration was longer (10 min) in the earlier study. Furthermore, Griefahn (1994) did not see any consistent effect of individual noise sensitivity (3 groups of 50 persons each) on the short-term reactions to noise on blood pressure, while the situative emotional reactions towards a specific noise exposure did parallel the measured cardiovascular reactions. This carefully conducted study shares the uncertainty of the external validity inherent to all laboratory studies.

Cardiovascular reactivity (heart rate and diastolic blood pressure) to noise was increased in workers in a heavy machinery workshop who were exposed to noise above 80 dB (Melamed et al. 1993). Likewise noise induced tension and Type-A-behaviour were related to both cardiovascular indicators, suggesting a possible mediator effect of both psychological variables.

In a Polish study (Novak 1996) blood pressure was measured three times during a normal workday in 2599 workers exposed to continuous or intermittent noise of over 90 dB and in 2454 controls. The rise of systolic and diastolic pressure during the day was significant for the noise exposed taking into account initial level, age, duration of employment. Blood pressure increase was strongest in workers with borderline hypertension, and increase was small in those with normal pressure. Workers with isolated systolic hypertension did show stronger increases in diastolic blood pressure and a reverse observation was made in workers with diastolic hypertension.

Cardiovascular effects in adults: chronic

Lercher et al. (1993) using reported annoyance to noise as a proxy for noise exposure, found that occupational noise annoyance in a community based cross-sectional study was linked with 2.1 mm Hg increase in systolic blood pressure and 3.5 mm Hg increase in diastolic blood pressure, after adjustment for age, BMI, sex, education, smoking and other occupational risk factors. However, the combined effect of noise annoyance and low work satisfaction was twice as large on blood pressure (systolic BP 7.5mm Hg, diastolic blood pressure 6.3 mm Hg). There was a similarly large effect for the combination of night shift work and noise annoyance. Currently it is not sufficiently clear whether noise annoyance is a good proxy measure of occupational noise exposure or whether it is also a proxy for other factors, such as socio-economic status or work satisfaction. On the other hand, results have been adjusted for education and other work related factors (shift work, work satisfaction). For clarification longitudinal studies are needed including dosimetric measurement of noise exposure

In a cross-sectional study of 8811 metallurgical workers, the high noise exposed groups (n=733; >80 dB) showed higher mean systolic blood pressure, in the overall sample and across 4 age groups. Prevalence of hypertension was also significantly higher (11.9 vs 7.5%) across the ages, and most prominent in the eldest age group. Stratification on BMI and family history of hypertension did not alter the results. But no differences were noted in mean diastolic blood pressure or heart rate (Fogari et al. 1994). An additional analysis of 242 carefully matched pairs revealed a slightly higher odds ratio (1.77) for hypertension in the noise exposed group (>80 dB) compared with the cross-sectional odds ratio (1.59). Furthermore, both mean systolic and diastolic blood pressure were significantly higher in the noise than in the reference group. However, work characteristics other than noise were not considered.

No significant associations between noise exposure and blood pressure were found in a retrospective cohort study of 2197 South African miners (Hessel & Sluis-Cremer, 1994). Change in noise level over time was not consistently related to change in blood pressure either. This study was an attempt to use routinely collected information from 3 yearly medical check-ups to assess the long term effects of mixed noise exposure. However, this approach does have methodological problems: blood pressure was not measured under standardised conditions and noise exposure was only indirectly measured by retrospective expert assessment. Smoking and job type were not taken into account and lots of missing data may have introduced unknown bias.

Ledesert et al. (1994) studied the relationship between blood pressure and work conditions in 17 poultry slaughterhouses and 6 canneries in two French regions (N = 1447). Data on blood pressure and other health related factors were collected in the course of an annual medical visit. Amongst the various working conditions studied, loud noise and the number of work breaks were found to be associated with heightened mean values of DBP or SBP in men only. Mental strain inducing work conditions were found to be related to lower mean blood pressure in both sexes. Type and size of the factory was also associated with elevated blood pressure for both sexes. The authors themselves stress the complexity of the relationships which exist between the physical and environmental factors and blood pressure of employees.

In the CORDIS study 2202 men and 904 women from 21 industrial plants across Israel (involving six different sectors: metalwork, textile, light industry, electronic, foodstuffs, plywood) underwent physical examination and blood pressure measurement (Kristal-Boneh et al. 1995). There was no association between noise and systolic blood pressure; diastolic blood pressure was only related to noise in women. Blood pressure did not increase with work noise exposure and no interaction with the source or type of noise (intermittent/continuous) was observed. No significant effects were found for use of ear protection or noise exposure at home. There was neither evidence that control over the noise source influenced blood pressure nor that noise at home influenced the association between work noise and blood pressure. The authors attribute their lack of a noise effect on blood pressure partly to low noise levels (<95 dBA) and possible selection factors that could not be ruled out. Another possible reason could have been masking by the opposite effect of ambient temperature which was negatively related to blood pressure in both sexes.

In a Chinese journal Wu (1992) reported the results of a matched case-control study of 218 pairs with essential hypertension. In the conditional logistic regression model hypertension (and borderline hypertension) was associated with heart rate, family history of hypertension, Quetelet Index and environmental noise. However, noise characterisation was ill-defined.

Talbott et al. (1996) used a nested-case control approach to compare the effect of wearing hearing protection most of the time ('case') in workers (N=46) with long duration of employment in noise (mean=23 years) with a group of age-matched workers (N=46) wearing rarely or no hearing protection ('control'). Average annual noise exposure was 98.3 dB in the 'case' and 95.5 dB in the 'control' group. As expected, workers wearing hearing protection showed significantly better hearing thresholds than controls for frequencies above 3 kHz. In the multivariate analysis calculated average noise exposure was significantly associated with both systolic blood pressure and diastolic blood pressure after adjustment for case/control status, BMI, alcohol, and hypertensive medication use.

Tomei et al. (1996) studied 416 pilots subdivided into two groups according to the different levels of chronic exposure to noise and compared the prevalence of several cardiovascular outcomes with a group of 150 control subjects not exposed to noise. They found a higher prevalence of hypertension, nearly always diastolic, and of ECG abnormalities in the group of pilots of turboprop aircraft compared to jet plane pilots and to controls. Hypertension was significantly associated with hearing deficit. Furthermore, a higher prevalence of orthostatic hypotension was observed in the two groups of pilots in comparison with the controls. Unfortunately, no direct adjustment of cardiovascular risk factors was employed.

In a small questionnaire study (N=366) on road traffic noise exposure and health along a main road in Tokyo prevalences for heart disease, hypercholesterolemia, gastro-enterological diseases and climacteric disturbances were found to increase at noise levels between 65 and 70 dB (Yoshida et al. 1997).

In further investigations by the CORDIS team (Melamed et al. 1997), the association between industrial noise exposure, noise annoyance, and serum lipid/lipoprotein levels was studied in male (n = 1455) and female (n = 624) blue-collar workers. While young men (< 45 yrs of age) exposed to high noise levels (> 80 dB[A]) exhibited higher total levels of cholesterol (p = .023) and triglycerides (p = .001) than men exposed to low noise levels, serum lipid/lipoprotein levels of women and older men (> 45 yrs) were not affected by the same amount of noise exposure. However, noise annoyance covaried independently with total cholesterol (p = .022) and high-density lipoprotein (p = .0039) levels in young men and with total cholesterol (p = .035), triglyceride (p = .035), and high-density lipoprotein levels (p = .048) in women (under high noise exposure conditions).

The relation between reported work noise exposure and the risk of myocardial infarction was assessed in a population based case-control study by Ising and colleagues (1997). Patients (395) with clinically verified myocardial infarction (MI) were compared with 2148 randomly selected population controls. A dose related increase in the relative risk for MI was found. The increase was largest in the younger group (aged 31-45, p=0.058). In the multivariate model adjustments were made for BMI, education, occupational status, marital status, shift work, residential area and smoking. Without concurrent noise measurements the validity of reported noise remains uncertain.

A large cross-sectional, community-based study of 20,216 residents was conducted in China (Harvard-Anhui-Study) to identify and characterise major environmental and occupational determinants of blood pressure in rural communities (Xu et al. 1997). Multiple linear regression analysis indicated that among a long list of other factors, self-reported exposure to noise was related to both increased systolic and diastolic blood pressure. This study demonstrated that in spite of a broad array of considered factors (demographic, ergonomic, nutritional, and environmental factors) self reported noise exposure remained as a significant determinant of blood pressure in this rural Chinese population. The validity of reported noise remains to be tested.

Stress hormones

In a study of middle-aged women living in inner city districts of Berlin, Babisch et al. (1996) found elevated levels of noradrenaline excretion in overnight urine samples of women whose bedroom faced a busy street (> 20000 vehicles/day). Likewise, noradrenaline excretion was significantly higher in women reporting high disturbance of communication and sleep under closed window conditions. No relationship was found between traffic volume and renal adrenaline excretion and the relationship with the subjective indicators was non-significant. By design it cannot be distinguished whether the observed effects on noradrenaline excretion reflect acute or chronic reactions. However, the fact that the relationship with the subjective indicators were seen only when disturbance was reported under closed window conditions supports the interpretation of noise induced stress reactions as occurring predominantly when the individual's coping strategies are no longer effective.

In a two-day study of textile workers in Hanoi urinary catecholamine levels were significantly higher in 50 randomly selected female workers exposed to machinery noise (93-100 dB(A)) compared to 25 female workers in quieter working environments (71-75dB(A)) (Sudo et al. 1996). Cortisol level shared the same trend. On the second day of testing when the noise exposed workers were advised to wear earplugs their catecholamine excretion decreased and they reported less fatigue.

In a similar quasi-experimental field study Melamed & Bruhis (1996) explored the effect of noise attenuation on urinary cortisol excretion among 35 healthy industrial workers chronically exposed to high ambient noise levels (> 85 dB [A]) without using ear protectors. At the end of the workshift the cortisol level was high, reached almost the morning level, and was accompanied by high levels of accumulated fatigue and postwork irritability. After fitting the same workers with earmuffs (attenuation of 30 to 33 dB) for a period of 7 working days, the cortisol level declined steadily during the workshift and approached the normal diurnal rhythm. There was also a concomitant reduction in reported fatigue ($P < .05$) and postwork irritability ($P < .01$).

Immunological effects

Research on stress hormone responses to noise needs to be linked with the area of immunological effects because cortisol elevations are involved in impaired immune functions. However, more research is necessary to determine suitable indices of immune function for field studies. Because learned helplessness is also associated with impaired immunity, the mediating effect of perceived control over the noise should be carefully evaluated. Likewise the potentially mediating effect of noise induced sleep loss has not yet sufficiently been studied.

Reproduction and development

Schell & Ando (1991) found a dose-response function relating airport noise levels and physical stature of 3 year old children in a large epidemiological study. However, the medical relevance of this finding is not yet clear and has to be investigated further.

Researchers from Finland (Hartikainen et al. 1994) have conducted a careful prospective investigation on the effect of occupational noise on the course and outcome of pregnancy. No differences in outcome measures were observed between women exposed to noise levels greater than 78 dB and a reference group of women with similar work conditions without noise exposure. With sound exposure above 90 dB an absolute and relative decline in birth weight was seen. No differences between the noise groups were found for maternal blood pressure. Due to the small number of observations in this high exposure group the confidence limits are wide. On the other hand the adequate use of hearing protectors in 39% of the sample may also have influenced the results.

In a case control study of 210 American mothers and 1260 controls preterm birth (<37 weeks pregnancy) was significantly related to self-report of high occupational noise exposure (Luke et al. 1995). However, noise exposure does not seem to have been included in the final model, the response rate was low, and the study was based wholly on retrospective report.

In a study of 200 Taiwanese women, noise exposure measured by 24 hour personal dosimetry (52.4 - 86.8dBA Leq) on three occasions in pregnancy, was not predictive of infant birth weight (Wu et al. 1996). Furthermore, occupational noise exposure, and road traffic noise exposure and listening to amplified music during pregnancy was not related to birth weight. This study improved on earlier studies by use of dosimetry and by adjusting for social class, smoking and alcohol use, maternal weight gain in pregnancy, infants' sex and gestational age.

Recently, Thompson (1996 and 1997) judged the evidence of fetal effects of noise as equivocal and asked for further studies. Future studies need to develop better measures of noise exposure during pregnancy (timing and dose, including control for wearing ear protectors), to consider other work stressors (shift work, lifting) and maternal risk factors which may confound the association between noise and low birth weight such as body build, parity, and smoking.

Accidents and sickness data

In a blue-collar worker subsample of the CORDIS Study (N=2368) the relationship of 3 exposure levels of occupational noise (<75dB, 75-84dB, >84dB) was examined with accident involvement and sickness absence (Melamed et al. 1992). Higher noise levels were associated with increases in accidents and sick leave in both sexes. The increase was evident already in the "moderate" exposure group. Noise annoyance did partially moderate the results, however the effect was stronger in male workers.

Barreto et al (1997) used a nested case-control design to study in detail the increased risk of mortality from motor-vehicle injury (SMR=209) found in a large cohort of steelworkers (N=21816). For each case four controls were selected at random from all cohort members employed at the plant at the time of the case's death and born in the same year as the case. Based on workplace and job title industrial hygienists estimated noise exposure as high (>95 dB,A), medium (90-94 dB,A), low (85-90 dB,A) or none. The final multivariate model revealed hearing deficit (OR = 2.3) and high and medium occupational noise exposure (OR = 2.0 resp 1.7) as independent significant risk factors. Among the possible limitations: Only current measures of noise exposure were available and the role of hearing protectors could not be evaluated, because the actual use (although required) was not recorded. This excellent study clearly demonstrates that the topic is highly relevant and deserves further study.

3. SUMMARY AND RESEARCH NEEDS

During the recent five year period the overall quality of research into non-auditory effects of noise has improved considerably both conceptually and methodologically. However, further improvement in the following main areas is needed:

Exposure characterisation and design

The simple characterisation of sound exposure by expert classification on the basis of job titles at work or exposure assignments based on static measurements at fixed locations in community studies does not suffice. Use of psychoacoustic techniques (loudness, roughness, sharpness) and personal dosimeters are necessary to appropriately describe sound and to distinguish sufficiently among sound environments (e.g. low frequencies). Furthermore, a concept of total noise exposure (based on time-activity pattern, including quiet and rest periods) is necessary to be applied. Personal dosimeter studies have shown surprisingly high noise exposures in non-occupational settings, when total exposure time is considered.

In community studies refinement of exposure estimates is often easy to accomplish by including residential room location.

The observed exposure range in many studies is not sufficient or is truncated, and group sizes at the various noise levels are too small to allow dose-response analysis.

Because traffic noise occurs jointly with other ambient exposures (vibrations, air pollution) it is necessary to characterise these as well.

Setting characterisation and selection

Most studies work with the hidden assumption that ambient environments are equal across studies. However, work and residential environments may differ substantially and need to be adequately described to allow proper interpretation when effect levels deviate.

Because - more than other pollutants - noise interacts with other daily stressors (density, work schedules and organisation, family stress, social support) it is necessary to measure the total amount of stress at a specific setting.

Not only in occupational studies but likewise in community studies selection processes may bias results due to self-selected or forced choices of residence and the clustering of urban black spots with low SES. This makes additional information on these factors and residential mobility essential to judge the validity of study results.

Confounding, mediating and moderating variables

(1) Concentration on vulnerable groups (noise sensitivity, and other traits (Type A, family history of hypertension) may be a promising approach.

(2) Coping activities/styles and coping resources (perception of control) available to escape from the noise should be studied more often in relation to behavioural and health outcomes.

(3) Behaviours such as alcohol, tobacco or drug use may also act as mediators between noise exposure and health outcomes. Conceptually it is not sufficient to only 'statistically control for' these factors. Likewise, this concerns potential biochemical mediating factors of cardiovascular outcomes such as magnesium deficiency, fibrinogen, and serum lipids. They should be at the center of noise epidemiology that touches on cardiovascular outcomes.

(4) Emotional responses: The most obvious potential mediator bundle – annoyance/affectedness or interference – has not yet sufficiently been studied. Babisch (1995) has dealt with it in a full article (in German) with mixed results.

Outcome characterisation and design

(1) Refinement in standardisation of health outcome measurements should be pursuit further. Specifically in occupational studies, standardisation of blood pressure measurements is an ultimate requirement and repeated measurements should be made in community studies. Follow-up of smaller groups of individuals with repeated measurement of blood pressure would be a favourable design.

(2) Exposure time: To study the appropriate time window is vital for establishing effects. There is still uncertainty about the time to onset of cardiovascular outcomes. Thompson (1997) mentioned a large range from 5 to 25 years. The lower estimate was derived from a study with exposures above 90 dB. However, the latency depends not only on the noise itself. Lifestyle, other working and living conditions may determine the total 'health risk' and 'timing' to a much larger degree than years exposed. Therefore, even prospective designs may fail. Effects may be masked or biased if this critical time window is missed. This may also explain inconsistent risk estimates.

(3) The whole range of potential non-auditory effects needs to be studied concurrently. The concurrent inquiry of physiological and psychological parameters in the Munich study is an excellent example of the gain of such an approach.

(4) Possible “after effects” (e.g. accidents), effects on the immune system and hypotension should be studied in further detail.

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EPIDEMIOLOGICAL STUDIES OF CARDIOVASCULAR EFFECTS OF TRAFFIC NOISE

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1. INTRODUCTION

The hypothesis of a relationship between exposure to traffic noise and cardiovascular diseases is based on the general stress model [1,2]. However, the epidemiological evidence of the long-term effects of environmental noise on health is limited [3]. Only a relatively small number of epidemiological studies are known in this area. In contrast to the noise effects observed at occupational noise levels, physiological effects of relatively low environmental noise levels primarily occur when the sound is experienced as noise, causing emotional reactions, or interferences with activities of the individual including sleep (indirect pathway). In this respect, it seems to be impossible to extrapolate the effects of environmental noise from results of occupational noise studies. For example, it may very well be that a truck driver reacts little to the sound of his engine, but shows much of an effect if disturbed by traffic noise at home although the exposure level is much lower. The two noise environments cannot be merged into one sound energy related dose-response model. Meta-analytic approaches comprising work noise and traffic noise studies as done, [4] appear to be questionable from this point of view.

This review focusses on hypertension and ischaemic heart disease (IHD) as a clinical outcome in the adult pupulation. The basic epidemiological approach to dealing with this issue looks 'simple'. Assuming the hypothesis is true, the proportion of subjects with cardiovascular problems is expected to be higher in more traffic noise exposed areas than in less exposed. However, methodological aspects - namely longer latency period of chronic effects, misclassification in the assessment of exposure, possible influence of confounding factors, small magnitude of effect - make this field of noise research appear rather complicated and the interpretation of findings in studies particularly difficult.

2. DATA BASE

Altogether 19 epidemiological traffic noise studies have been reviewed (carried out in 14 locations) and which provide quantitative information on hypertension or IHD as manifest clinical disease endpoints. Most of the available studies are of cross-sectional type; a few case-control or cohort studies are known.

Relative risks, estimated as odds (model-adjusted) or risk ratios of the prevalence or incidence of disease, were either obtained from the cited publication or recalculated for the purpose of this review on the basis of the data provided there in. If not explicitly given in the publication, test-based 95%-confidence intervals were estimated on the basis of the available information. The subjects were grouped according to the daytime (6-22 h) outdoor average A-weighted sound pressure level. Other noise level indicators used in the various studies were converted for this purpose on the basis of approximate formulas [5]. Not all studies allow dose-response reflections because some of them considered very broad exposure categories. Besides objective noise exposure measurements, subjective measurements of exposure have been used in some epidemiological noise studies. Type of road, disturbances or annoyance were rated by the study subjects on given scales. The results of these studies were grouped into four ordinal categories: 1 = "never or not at all or dead end street or not affected"; 2 = "seldom or a little or side street"; 3 = "sometimes or moderate or busy road"; 4 = "often + always or much + very much or major trunk road or affected", depending on the items in the questionnaires. Only relative risks for the extreme group comparisons of noise exposure are given in this paper. Full information including tables of the relative risk of subjects for all noise categories is given elsewhere [6]. To identify the studies considered (location/year of publication/certain study characteristics), abbreviations are used in the following figures which are explained in Table 1 and 2.

Table (1) Listing of studies used in the figures

Study	Location	Exposure levels compared
Amst77a	Amsterdam, The Netherlands	30-40 vs. 41-50 KE
Amst77b	Amsterdam, The Netherlands	30-40 vs. 41-50 KE
Amst84	Amsterdam, The Netherlands	≥65 vs. <65 dBA; Category 3+4 vs. 1+2
Berl92	Berlin, Germany	Category 4 vs. 1+2
Berl94a	Berlin, Germany	≥71 vs. ≤60 dBA
Berl94b	Berlin, Germany	≥71 vs. ≤60 dBA
Bonn81	Bonn, Germany	≥66 vs. ≤60 dBA
Bonn87	Bonn, Germany	>63 vs. <55 dBA
Caer90	Caerphilly, UK	≥66 vs. ≤55 dBA
Caer93	Caerphilly, UK (4 y follow-up)	≥66 vs. ≤55 dBA
Caer95	Caerphilly, UK (10 y follow-up)	≥66 vs. ≤55 dBA
Doet79	Doetinchem, The Netherlands	≥65 vs. ≤60 dBA
Erf83	Erfurt, Germany	70-75 vs. 61-65 dBAI
Erf90	Erfurt, Germany	71-75 vs 56-60 dBAI
Ger94	Population sample, Germany	Categories 3+4 vs. 1+2
Gron89	Groningen an others, The Netherlands	≥66 vs. ≤55 dBA; >50 vs. ≤40 KE
Lueb89	Luebeck, Germany	≥66 vs. ≤60 dBA; Categories 4+5 vs. 1+2
Speed90	Speedwell, UK	≥66 vs. ≤55 dBA
Speed93	Speedwell, UK (4 y follow-up)	≥66 vs. ≤55 dBA
Speed95	Speedwell, UK (10 y follow-up)	≥66 vs. ≤55 dBA
Tyr92	Tyrol, Austria	≥60 vs. <60 dBA; Categories 3,4 vs. 1,2
CS95	Caerphilly+Speedwell (reconstructed cohort - 6 y follow-up)	≥66 vs. ≤55 dBA; Category 4 vs. 1

Table (2) Abbreviations to describe study characteristics in the figures

Characteristic	Identifier	Meaning
Gender:	m	males
	f	females
Noise measurement:	o	objective (sound level)
	s	subjective (annoyance, type of road) *
Type of noise:	a	aircraft noise
	r	road traffic noise
Hypertension:	c	clinical measurement
	t	treatment
Ischaemic heart disease:	p	angina pectoris
	h	heart trouble
	e	ECG defined ischaemia
	y	myocardial infarction
	i	ischaemic heart disease
	v	cardiovascular

* Full-dot markers in the figures refer to subjective noise measurements

2. TRAFFIC NOISE STUDIES

Hypertension

Figure 1 gives the results of epidemiological traffic noise studies on the relationship between noise level and prevalence of hypertension. In fact, one study [7] refers to incidence of hypertension. Hypertension in these studies was either defined by WHO (or similar) criteria based on measurements of systolic and diastolic blood pressure, or was defined by antihypertensive treatment, information on which was obtained from a clinical interview or a social survey questionnaire. All studies except one which refers to aircraft noise [8] deal with road traffic noise. The subjects studied were the adult male and female population, sometimes restricted to certain age ranges.

The picture is heterogeneous. Some of the earlier studies carried out in Amsterdam, [8], Bonn [9], Erfurt [7] suggest an increased risk at noise levels above 60-70 dB(A) with significant relative risks of between 1.5 and 2.4 for subjects who live in areas where traffic noise levels are higher. The Erfurt study is difficult to conceptualize. When analysed in terms of a proportional morbidity ratio, a significant relative risk of 2.4 was found. No error terms can be calculated from the data provided in the reference. The study carried out in Doetinchem [10], and later studies from Amsterdam [11], Luebeck [12], Berlin [13], Tyrol [14] which may have a higher validity as far as statistical control of possible confounding is concerned, do not support the noise hypothesis, showing relative risks of between 0.5 and 1.0 for the group comparisons with regard to objective noise measurements. In the cross-sectional part of a before-after study carried out in a village near Erfurt [15], the relative risk of 2.4 for the period prevalence of hypertension was significant. However, little information was given about the control of possible confounding factors.

The full-dot markers in the figure refer to the results of studies on the relationship between subjective ratings of traffic noise exposure and prevalence of hypertension. The cross-sectional studies from Amsterdam [11] and Tyrol [14] give no indication of an

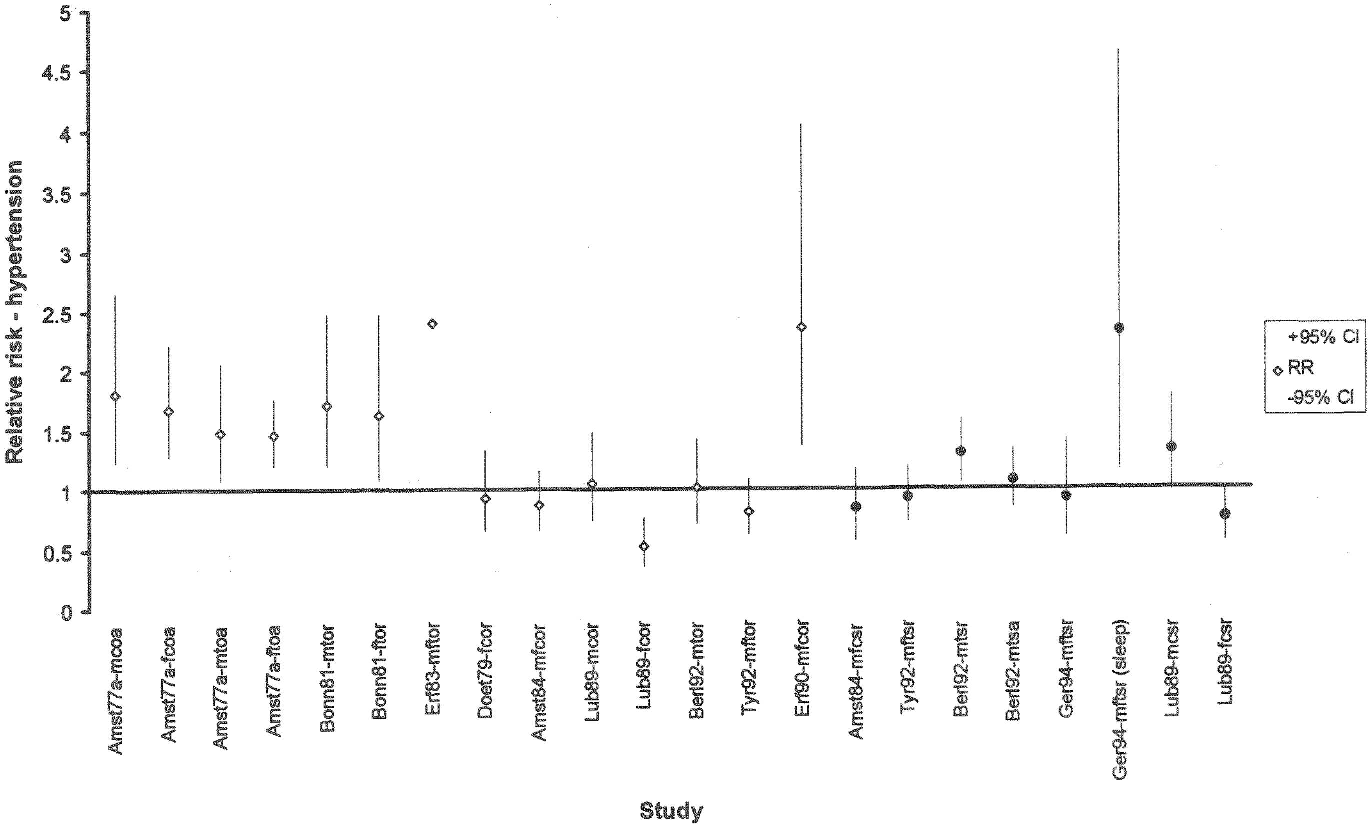

Figure (1) Epidemiological studies: traffic noise - hypertension increased risk of hypertension in subjects more annoyed/disturbed by traffic noise as compared to less annoyed/disturbed. A significant relative risk of 1.3 for self-reported prevalence of hypertension was found in high road traffic noise disturbed subjects in a cross-sectional study carried out in Berlin [16]. Since exposure and disease were assessed on a subjective basis, these results are susceptible to recall bias due to overreporting. This reservation is true for all cross-sectional studies where exposure and disease are assessed subjectively. A prospective study carried out on a random sample of the German population [17,18] must be viewed as cross-sectional with regard to traffic noise because exposure and disease were measured at the same point in time. A relative risk of hypertension of 0.9 (males: 1.2, females: 0.9) was found with regard to global annoyance. However, a relative risk of 2.3 was found with regard to reported sleep disturbances which was significant. In the Luebeck study [12] a borderline significant relative risk of 1.3 was found in male subjects who described the street in which they lived as busy as compared to those who described their residential streets as quiet.

Ischaemic heart disease

Figure 2 refers to the risk of ischaemic heart disease (IHD). In cross-sectional studies IHD prevalence was assessed by clinical symptoms of angina pectoris, myocardial infarction or ECG abnormalities as defined by WHO criteria. In longitudinal studies IHD incidence was assessed by clinical myocardial infarction as obtained from hospital records, ECG measurements or clinical interview. The Dutch studies carried out in Amsterdam [10,19] and partly the study carried out around the cities of Groningen, Twenthe, Leeuwarden and Amsterdam [20] refer to aircraft noise, all other studies to road traffic noise. Study subjects were the male and female population - in the longitudinal studies mostly males - sometimes restricted to certain age ranges.

Much information comes from the Amsterdam aircraft noise studies [10,19], showing significant prevalence ratios of between 1.0 and 1.9 - depending on the IHD endpoints looked at - in subjects who live in noise exposed areas of more than approx. 60 dB(A) outdoor noise level. The "general practice survey" [19] can be considered as an ecological study on disease specific contact rates with general practitioners; populations not individuals have been analysed statistcally. Multiple consultations were allowed. The study provides information on prevalence of cardiovascular disease which must be viewed as a combination of hypertension and ischaemic heart disease. No noise level related increase in IHD risk, as defined by clinical interview and ECG, was found in the study carried out in four Dutch towns [20] with regard to road traffic noise. With regard to air traffic noise, prevalence ratios greater than 1.0 were found at noise level categories greater than approx. 55 dB(A). However, no dose response relationship was found across the categories, and the relative risk to subjects in the highest noise category was 0.9. The non-significant road traffic noise studies carried out in Doetinchem [11], Bonn [21], Caerphilly [22], Speedwell [22] and Berlin [13], consistently suggest a risk of IHD-prevalence 1.1-1.4 higher for outdoor noise levels of more than 65-70 dB(A). The result of the Bonn study was not controlled for confounding factors because IHD was not the major outcome of interest. The study carried out in Tyrol [14] revealed a significant relative risk of 2.1 with regard to angina pectoris for subjects from areas of more than 60 dB(A) while a negative relationship - relative risk 0.8 - was found with regard to myocardial infarction.

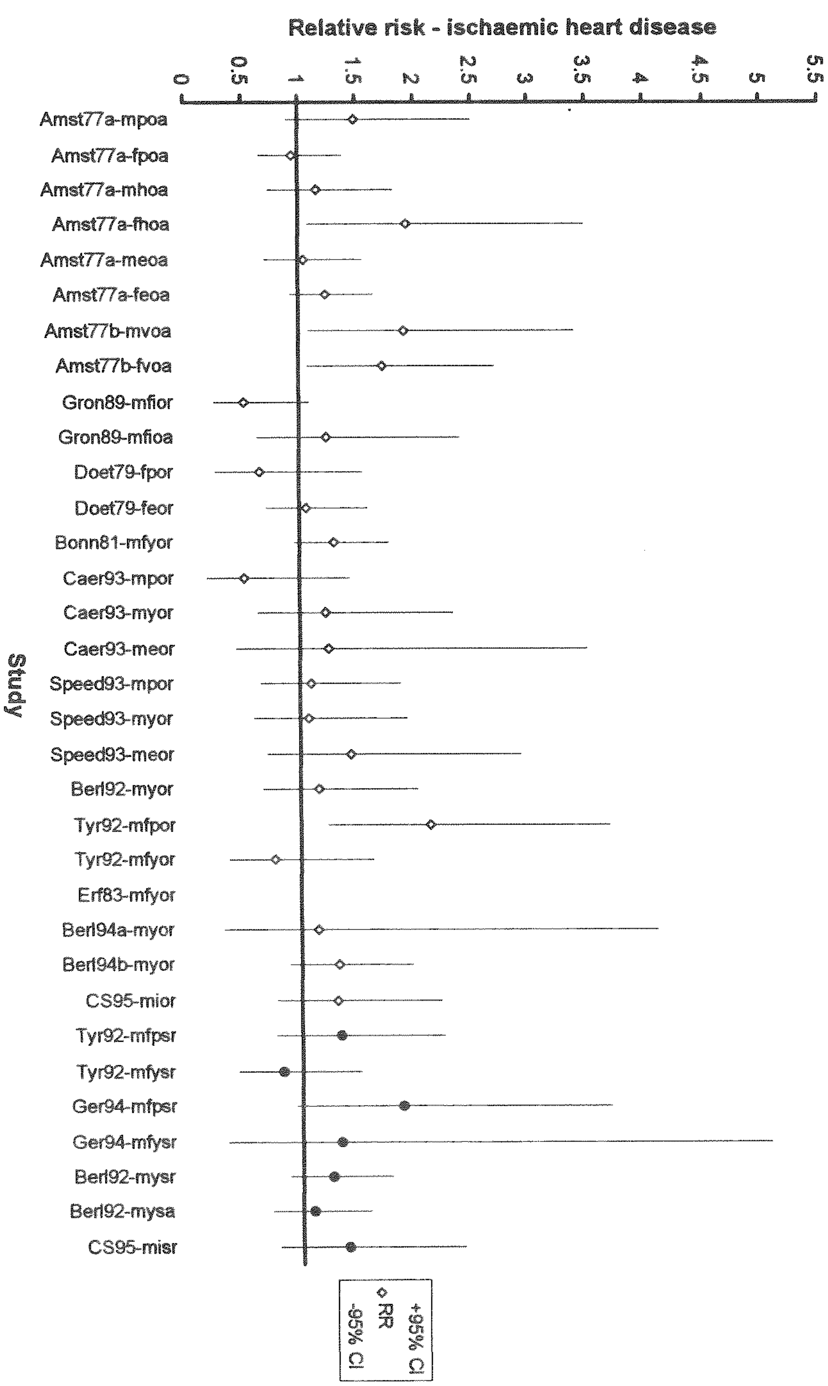

Figure (2) Epidemiological studies: traffic noise - ischaemic heart disease

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As far as the relationship between noise level and IHD-incidence is concerned, a high and significant proportional morbidity ratio of 4.4 was derived from the retrospective study carried out in Erfurt [7]. Some methodological issues concerning the validity of the results were raised earlier. In the Berlin case-control studies [23], non-significant relative risks of 1.1-2.1 were observed for outdoor noise levels of more than 70 dB(A), following a dose-response relationship. In the 10-year follow-up studies at Caerphilly and Speedwell [24,25,ibidem] no noise effects were detected with regard to the (address-related) outdoor traffic noise level. However, the follow-up analyses of the pooled reconstructed cohort, in which exposure assessment accounted for room orientation and window opening habits, revealed non-significant relative risks of between 1.2 and 1.3 for subjects in the highest 66-70 dB(A) category.

The results of studies on the relationship between subjective ratings of traffic noise exposure and prevalence or incidence of ischaemic heart diseases show a similar tendency. The cross-sectional study from Tyrol [14] and the cross-sectional noise related analyses carried out as part of a general population follow-up study of a random German population sample [18] revealed relative risks of between 0.8 and 1.9 in subjects greatly annoyed/disturbed by traffic noise in comparison with subjects who were not as annoyed/disturbed. Relative risks greater than 1 were found in particular with regard to angina pectoris. The prospective studies carried out in Berlin [16,23] and in Caerphilly and Speedwell [24,25] revealed relative IHD risks of between 1.0 and 1.4 only in subjects of the highest annoyance/disturbance category considered. A strong effect modifying impact of pre-existing diseases on the relationship was found. Relative risks were higher in healthy subjects, ranging from 1.7 to 2.7, which was significant in the case of some items of disturbance. As pointed out earlier, there is some concern about the subjective assessment of exposure with regard to recall bias.

3. CONCLUSIONS

With regard to hypertension, the relative risks found in three significant positive studies range between 1.5 and 2.4 for subjects who live in areas of more than 60-70 dB(A) as the daytime average sound pressure level. One study shows a significant negative association. Across all studies no consistent findings on the relationship between traffic noise level and prevalence of hypertension can be seen. Dose-response relationships which may support a causal interpretation of findings were rarely studied. The results look somewhat more consistent when subjective ratings of noise or disturbances due to traffic noise are considered for exposure instead of the noise level. The relative risks found here range from 0.8 to 2.3. These studies, however, are of lower validity due to methodological reasons. In conclusion, there is little epidemiological evidence of an increased risk of hypertension in traffic noise exposed subjects.

With regard to ischaemic heart disease there is not much indication of an increased IHD risk for subjects who live in areas of less than 60 dB(A) as the daytime average sound pressure level. At higher noise categories increases in IHD risk are relatively consistently found amongst the studies. Statistical significance was rarely achieved. Some studies permit reflections on dose-response relationships. These mostly prospective studies suggest an increase in IHD risk at noise levels above 65-70 dB(A), the relative risks ranging from 1.1 to 1.5 when the higher exposure categories are grouped together. The results appear as consistent when subjective responses of disturbances and annoyance are considered as exposure. However, these findings may be of lower validity due to methodological issues. In conclusion, there is some epidemiological evidence of an increased risk of ischaemic heart disease in traffic noise exposed subjects.

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THE CAERPHILLY AND SPEEDWELL STUDIES, 10 YEAR FOLLOW-UP

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1. INTRODUCTION

This paper refers to a series of articles relating to different follow-up phases of two cohort studies in which the effects of road traffic noise on the cardiovascular system were investigated [1,2,3]. The hypothesis was tested that prolonged exposure to traffic noise at home increases the risk for ischemic heart disease (IHD). Full information about the 10 yr follow-up results is given elsewhere [4,5].

2. METHODS

Two cohorts of 2512 (Caerphilly, South Wales) and 2348 (Speedwell, England) middle aged men, aged 45-59 yr and 45-63 yr, respectively, were recruited in the United Kingdom to study the predictive power of already known and new risk factors for ischaemic heart disease (IHD) [1,2]. Both study designs followed identical protocols. First follow-up investigations were carried out after approximately 4 yr (second phase), second follow-up's after observation periods of 120 (standard deviation = 6) and 112 (standard deviation = 3) months, respectively, which approximates to 10 yr (third phase) [6]. Since a detailled noise questionnaire was only administered during the second phase, most of the follow-up analyses presented here refer to the observation period from phase 2 to phase 3. The reconstructed cohort for phase 2 of the Caerphilly sample consisted of 1951 men of the original cohort who were seen again at the clinic, plus 447 men of the same age range who had moved into the area since the original cohort was identified. This gave a total of 2398 men between 47 and 67 yrs of age. The reconstructed Speedwell cohort consisted of the 2055 men of the original cohort who were seen again at the phase 2 clinics, aged 48-66 y. The statistical noise analyses with respect to the reconstructed cohorts were carried out in pooled sample of 3997 men, aged 47-67 yr, who actually filled in the noise questionnaire during the second phase. The average follow-up interval for these men was 61 (standard deviation = 6) and 75 (standard deviation = 6) months which approximates to 6 y.

Noise measurements were carried out in every street where the subjects lived. Outdoor noise levels were related to each individual's home. The subjects were grouped into 5 dB(A)-categories of the A-weighted average sound pressure level outdoors from 6-22 hr ($L_{eq, 6\text{-}22\,h}$). 24 hr continuous noise measurements were carried out in a number of different type of streets revealing day/night differences of 7 to 11 dB(A) of the average sound pressure level. This is a common finding in urban areas (no freeways). 24h noise levels are usually 1 to 3 dB(A) lower than daytime noise levels [7], which means that the daytime L_{eq} can be used as an indicator for the overall traffic noise emission from the streets. Subjective measures of annoyance and disturbance due to traffic noise at home were also assessed. The corresponding results are given in the original papers [4,5].

Incidence of ischemic heart disease was defined when a major IHD event occured between the follow-up phases. These events could be IHD death (coded ICD 410-414 on death certificate), definite clinical non-fatal myocardial infarction (MI) meeting WHO criteria regarding clinical history, ECG and enzyme changes, or ECG defined MI meeting WHO criteria [6]. Death certificates were available for all except three men who died before the final examination. In Caerphilly 94 % and in Speedwell 87 % of the 10 yr follow-up survivors were seen at the clinic again. A further 2 % and 3 %, respectively, had postal cardiovascular questionnaires after hospital admission for chest pain; then records from all local hospitals were searched for men from the cohorts who have been admitted to hospital with any diagnosis in the range ICD 410-414.

All statistical analyses on the relationship between traffic noise (dummy-coded) and IHD incidence were controlled (model adjusted) for the potentially confounding factors age, social class, maritial status, smoking, body mass index, family history of myocardial infarction, employment status, physical activity at leisure, prevalence of IHD and pre-existing-health conditions [4,5]. Furthermore, the analyses refering to the period between phase 2 and phase 3 were controlled for subjective noise sensitivity based on a single item and area (cohort) in the model. Room orientation (rooms facing the street or not) and window opening habits (windows closed or not) were considered in these analyses to improve individual exposure assessment. Where neither living rooms nor bedrooms were facing the street of the address (being checked for other noisy streets), subjects were grouped into a 15 dB(A) quieter noise category, which in fact was the quietest of 51-55 dB(A). Subjects who had answered that they never opened any windows facing the street when they spend time inside these rooms, were grouped into a 10 dB(A) quieter noise category. Simultaneous indoor/outdoor measurements carried out in 300 households in the areas revealed these average sound level differences in conditions of non-facing the street and open windows, and of facing the street and closed windows (only single framed windows). Years in residence before the subjects entered the study were considered in the analyses either by exclusion (subgroup ≥ 15 yr in residence) or interaction of residence period with noise level in the models. Unfortunately, this information was only available for the reconstructed cohorts (6 yr follow-up). Multiple logistic regression technique (using SPSS 6.0) was applied to calculate relative risk estimates (odds ratio) and 95%-confidence intervals (standard error).

3. RESULTS

10 yr follow-up (phase 1 to 3)

The 10 yr cumulative incidence of major IHD was 312 (of 2512) and 291 (of 2348) cases in Caerphilly and Speedwell, respectively. The mean age (recorded as age last birthday) of the men at recruitment was 52.1 yr (standard deviation = 4.4) and 54.2 yr (standard deviation = 4.4), respectively. The average annual incidence rates (unadjusted for decreasing size of cohorts) of 1.24 % and 1.32 % per year turned out to be very similar in both cohorts. Due to missing values in control variables the eligible sample size varies slightly between the variables. For 2369 and 2330 men, respectively, complete data were available in all the covariates considered in the multiple models. Table 1 gives odds ratios of the relationship between these variables and IHD incidence in the three samples. Smoking, IHD prevalence, family history of IHD, age, body mass index, unemployment, pre-existent disease and area were significantly associated with a higher IHD risk. In Table 2, crude and adjusted relative risks (odds ratios and 95%-confidence intervals) are shown in reference to the lowest traffic noise category of 51-55 dB(A). In Caerphilly, relative risks greater than 1 were found in the 56-60 dB(A)-category and the highest noise category of 66-70 dB(A), with marginal and non-significant odds ratios of ca. 1.1. In Speedwell, no relative risk greater than 1 was found for any higher noise categories. For moderate noise levels of 56-60 dB(A), a borderline significantly lower IHD risk was found compared with the reference group.

Table (1) Associations between control variables and IHD incidence

Control variable (C=Caerphilly 10 yr, S=Speedwell 10 yr, C+S=Pooled 6 yr)	Odds ratio C	 S	 C+S
Social class (manual vs. partly skilled or unskilled)	1.2	0.8	1.1
Social class (non-manual vs. partly skilled or unskilled)	1.4	1.2	1.2
Social class (professional or intermediat vs. partly skilled or unskilled)	1.0	0.9	1.1
Employment status (employed vs. unemployed)	—	—	0.7
Smoking (ex-smoker vs. non-smoker)	1.5	1.5	1.4
Smoking (current smoker vs. non-smoker)	2.4	2.3	2.1
Physical activity at leisure (active vs. inactive)	0.9	0.9	—
Family history of IHD	1.3	1.2	1.5
IHD prevalence	2.5	2.6	2.3
Prevalence of pre-existing diseases	1.5	2.0	1.5
Subjective noise sensitivity (not at all+a little+moderate vs. much+very much)	—	—	0.9
Age (per year)	1.06	1.06	1.05
Body mass index (per kg/m^2)	1.06	1.03	1.06
Area (Speedwell vs. Caerphilly)	—	—	1.55

6 yr follow-up (phase 2 to 3)

The 5-6 yr cumulative incidence of major IHD was 161 (of 2398) and 191 (of 2055) subjects with events in the Caerphilly and Speedwell cohorts with mean age 57.4 yr (standard deviation = 4.5) and 57.3 (standard deviation = 4.3), respectively. Altogether 3997 men filled in the noise questionnaire. Due to missing values, adjusted analyses refer to the pooled sample of 3950 men of whom complete information on noise questionnaire and control variables was available. The men of the pooled sample had an average age of 57.3 yr (standard deviation = 4.5). The average annual incidence rate was 1.38 %. Table 2 gives relative risks for each traffic noise category. Relative risks greater than 1 were only seen in the highest noise category with odds ratios of ca. 1.1 in the crude and adjusted analyses. These were not significant. When the noise level became corrected for window orientation the relative risk increased to 1.2 and further up to 1.3 when window opening habits was considered, still being not significant. Exclusion of subjects who had not been living at their last address when they were recruited for at least 15 years (which applies for a third of men), revealed odds ratios of 1.2 (address), 1.3 (corrected for window orientation), 1.6 (corrected for window orientation and window opening habits) for the remainder of men of the 66-70 dB(A)-noise-category compared to those in the quietest category of 51-55 dB(A). Again none of the results were significant due to the smaller numbers of men in the higher noise categories. At moderate noise levels odds ratios less than 1 were found and were sometimes significant. Another way to account for exposure period was to treat years in residence as an interaction term with noise level (noise * years of residence) in the model to replace the noise factor. The results are given in Table 2. Relative IHD risks greater than 1; 1.007 (address), 1.010 (corrected for window orientation) and 1.017 (corrected for window orientation and window opening habits) for a year's increase in residence at the given noise exposure (multiplicative model) were only found for men in the highest noise category - the latter was borderline significant ($p < 0.10$).

Table (2) Relative risk of IHD incidence for differently traffic-noise-exposed groups (odds ratio, 95%-confidence intervals)

Sample		Traffic noise level [dB(A)]		
(C=Caerphilly, S=Speedwell, C+S=Pooled)	51-55	56-60	61-65	66-70
C 10 yr - total, crude	1.00	1.04 (0.68-1.59)	0.96 (0.67-1.39)	1.11 (0.66-1.86)
C 10 yr - complete data, crude	1.00	1.06 (0.68-1.65)	0.91 (0.62-1.35)	1.06 (0.60-1.85)
C 10 yr - complete data, adjusted [1]	1.00	1.07 (0.68-1.68)	0.87 (0.58-1.30)	1.07 (0.60-1.91)
S 10 yr - total, crude	1.00	0.65 (0.41-1.01)	0.85 (0.54-1.33)	1.04 (0.70-1.54)
S 10 yr - complete data, crude	1.00	0.65 (0.41-1.02)	0.85 (0.54-1.33)	1.00 (0.66-1.49)
S 10 yr - complete data, adjusted [1]	1.00	0.67 (0.42-1.07)	0.76 (0.48-1.22)	0.92 (0.61-1.41)
C+S 6 yr - total, crude	1.00	0.78 (0.50-1.17)	0.72 (0.47-1.06)	1.13 (0.75-1.68)
C+S 6 yr - complete data, crude	1.00	0.76 (0.49-1.17)	0.71 (0.47-1.08)	1.08 (0.71-1.64)
C+S 6 yr - complete data, adjusted [1]	1.00	0.71 (0.46-1.11)	0.68 (0.44-1.03)	1.07 (0.70-1.65)
C+S 6 yr - as above, per year in residence	1.00	0.989 (0.971-1.007)	0.990 (0.974-1.006)	1.007 (0.992-1.023)
C+S 6 yr - subsample ≥15 yr in residence	1.00	0.70 (0.40-1.20)	0.60 (0.35-1.03)	1.20 (0.72-2.03)
Accounted for window orientation [2]				
C+S 6 yr - complete data, adjusted [1]	1.00	0.82 (0.51-1.31)	0.64 (0.39-1.04)	1.16 (0.73-1.86)
C+Sl 6 yr - as above, per year in residence	1.00	0.995 (0.976-1.014)	0.989 (0.971-1.007)	1.010 (0.993-1.028)
C+S 6 yr - subsample ≥15 yr in residence	1.00	0.82 (0.46-1.46)	0.49 (0.25-0.95)	1.30 (0.73-2.32)
Accounted for window orientation and window opening [2] [3]				
C+S 6 yr - complete data, adjusted [1]	1.00	0.69 (0.42-1.12)	0.64 (0.44-1.03)	1.31 (0.78-2.21)
C+S 6 yr - as above, per year in residence	1.00	0.988 (0.969-1.008)	0.983 (0.961-1.006)	1.017 (0.998-1.036)
C+S 6 yr - subsample ≥15 yr in residence	1.00	0.67 (0.36-1.24)	0.45 (0.20-0.98)	1.59 (0.85-2.97)

[1] Adjusted for covariates

[2] In case of no living or bedroom windows are facing the road: noise level = noise level minus 15 dB(A)

[3] In case of windows are kept close throughout the whole year: noise level = noise level minus 10 dB(A)

4. DISCUSSION

In the earlier cross-sectional analyses of the Caerphilly and Speedwell studies, adjusted non-significant relative risks for the prevalence of IHD between 1.2 and 1.3 were seen in higher traffic noise level exposed men ($L_{eq, 6\text{-}22\,h}$ = 66-70 dB(A)) as compared to non-exposed men ($L_{eq, 6\text{-}22\,h}$ = 51-55 dB(A)) in both cohorts [3]. The prevalence of endogenous risk factors in these men suggested a relative risk of 1.1 for the incidence of IHD during the follow-up period. Intermediate 4-years follow-up analyses (phase 1 to 2) which were based on a very few incident cases (5-15 depending on the subgroups considered) revealed non-significant relative risks between 0.6 and 0.8 in men of the highest exposed noise category of the pooled cohort [3]. The data presented here refer to phase 3 of the prospective cohort studies carried out in the two locations. After 10 years of follow-up, the number of incident cases in the highest traffic noise group was considerably higher (18-50) than at phase 2, due to aging of the subjects and length of observation period. No statistically significant noise effects could be detected when the traffic noise level was considered as factor of exposure. The adjusted relative risks for men in the highest traffic noise category of 66-70 dB(A) were 1.1 and 0.9 in Caerphilly and Speedwell, respectively, after 10 yrs of follow-up, and 1.1 after 6 yrs of follow-up in the reconstructed pooled cohort which refers to the observation period from phase 2 to 3. To account for a longer induction period, a subsample of men was formed who had lived at least for 15 years at their present address when recruited. This led to a slightly higher adjusted relative risk for men of the 66-70 dB(A)-category of 1.2 in the pooled 6 yr follow-up cohort where the corresponding information was available. Given the range of the confidence intervals these findings can hardly be interpreted as noise effects. Nevertheless, the results are within the magnitude of effect that was to be expected, considering the findings of the cross-sectional phases and other new studies in mind [8].

From the methological point of view, the detection limit of observational epidemiological studies has to be considered as 1.2-1.3 for the risk or odds ratio because of the unknown impact of random variation and weak or residual confounding [9]. The precise measure of exposure (for magnitude of effect estimate), the precise measure of disease, the recruiting of large samples (for precision of effect estimate), and the comprehensive assessment of potential confounding factors (to reduce bias) is essential to handle the problem of small effects. In the present study, sample size (under aspects of noise research) was not a matter of influence because the noise team joined in with a running heart program. Also, the entire topic was new and suggestions from other studies about the magnitude of the effect hardly known. With regard to disease assessment, misclassification was minimized, and its impact on the results was estimated to be extremely low. This was due to the standardized protocol, the integrative use of all information obtained from the own clinical measurements, hospital and general practitioner records, and death certificates, and to the effort made to follow up each subject. A number of possible confounding factors were considered in the analyses. However, exposure misclassification may very well remain because the outdoor noise exposure differs from the perceived noise of the individual.

The 6 yr follow-up investigation of the pooled reconstructed cohorts gave an opportunity to further reduce exposure misclassification on the basis of the questionnaire information about room orientation and window opening habits. While adjusted relative risks of 1.1 and 1.2 were found for men in the 66-70 dB(A)-category in the total sample and in the 15 yr in residence subsample with respect to the outdoor noise level, the odds ratios rose to 1.2 and 1.3, respectively, when the orientation of the living and the bedroom was included in the analyses. It increased further to 1.3 and 1.6, respectively, when the information about window opening habits was considered. Still, none of the results were significant. Living in streets with traffic noise levels of 66-70 dB(A) was associated with an increase in relative risk of 1.01 and 1.02 per year in residence, the latter which accounts for window orientation and window opening habits achieved borderline significance. The finding of an increase in effect estimate when improving exposure assessment is improved supports the noise hypothesis and may be interpreted to imply causality, to some extent.

From the Caerphilly and Speedwell studies on their own, it cannot be deduced that traffic noise (level) increases the risk for myocardial infarction or any other form of ischaemic heart disease. However, the results provide another source of information concerning the potential hazard of traffic noise. At present, opinion will have to be based on mostly non-significant but consistent findings amongst studies. The data presented here may feature future meta-analytic approaches, once further studies are available on this topic which is of great environmental concern [10].

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INFLUENCE OF THE NUMBER OF IMPULSES AND THE IMPULSE DURATION ON HEARING THRESHOLD SHIFTS

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1. Introduction and Objective

The energy-equivalent rating of noise stress situations of varying time structures has long been met with skepticism by scientists in the field of work-physiology. In earlier experiments carried out by our institute, e. g., the influence of the splitting up of continuous noise with a rating level L_{Ard} of 85 dB(A) into energy-equivalent impulse noise events (finally into 9000 impulses with a level of 113 dB(A) for 5 ms, each) was studied [1]. Although it could be proved by a series of equal-energy-balanced experiments that the temporary threshold shift (TTS) and restitution time (t(0 dB)) increase when the number of individual impulses is increased and the duration of those impulses is decreased, it remained unclear whether this mainly results from the shorter duration of the impulses or their greater number. Therefore, additional experimental studies were carried out.

2. Methods and Materials

In the hypotheses for the influence of the number of impulses on the one hand and the impulse duration on the other hand on the hearing threshold shifts, it was assumed that an increase in the number of impulses at a constant impulse duration and an increase in the impulse duration of a constant impulse number result in different physiological responses.

In order to examine this, 5 different impulse noise test series (TS) were chosen; TS I served as a reference measurement for both parameters. The parameter 'number of impulses' was studied in the TS III, I, and II. The influence of the 'impulse duration' was examined in TS V, I, and IV. As in similar preceding experiments, the impulses had a level of 113 dB(A). In order to establish a mathematical relationship between all the noise exposures, the exposures were based on the 3-dB rule. In other words, in comparison with a rating level L_{Ard} of 82 dB(A) for 8 h in TS I, the noise level in TS III and V was 3 dB lower and the level in TS II and IV was 3 dB higher. This resulted in a halving and a doubling, respectively, of the number of impulses on the one hand and of the impulse duration on the other hand in the test design.

In a further test series (TS VI), the 10 test subjects (Ss) (8 male and 2 females from 22 to 41 years of age) were exposed to continuous noise of 94 dB(A) / 1 h. Since, according to [2], similar threshold shifts can be expected from the exposure to a continuous noise of 94 dB for 1 h and an energy-equivalent exposure of 85 dB over 8 h, an experimentally feasible exposure was defined with the above-described noise level-time constellation in order to standardize the results of the tests which were carried out in a cross-over design.

By using an audiometer during the selection process, it was ensured that only test Ss with normal hearing according to ISO 4869 [3] were chosen for the study. Since it is the basis for further measurements and evaluations, each subject's individual hearing threshold was determined before each test series.

A nominal value setting via an artificial head measuring system ensured identical noise stress situations for all Ss. The actual noise was exposed via headphones in a sound-insulated cabin in which the measurement of the physiological responses to the noise exposure was also carried out via pure tone audiometry.

While taking into account the individual resting hearing threshold, the frequency of the maximum threshold shift, i. e., the increase in the hearing threshold, was determined within the first 2 min after completion of the noise exposures. Thereafter, the hearing threshold shift at the frequency of the maximum threshold shift, which was usually 4 or 6 kHz, was measured at exactly defined times until the resting threshold was reached again.

3. Results

If the results of the three test series with equal impulse duration (TS III, I, and II, cp. upper part of Figure 1) are examined, it becomes clear that an increased, that is, a doubled, number of impulses at an equal impulse duration leads to a highly significant increase in all the characteristic values which had been measured and calculated by a regression analysis: the $TTS_{2\ reg.}$ values, the $t(0\ dB)_{reg.}$ values (i. e., the restitution time), and the IRTTS values (i. e., the Integrated Restitution Temporary Threshold Shift). A doubling of the number of impulses leads to more than twice the strain, i. e., over-proportional physiological costs, in the form of the following IRTTS values: 73, 172, and 457 dBmin.

In contrast to the aforementioned series and especially with respect to the restitution time t(0 dB), the test series with equal impulse number (TS V, I, and IV, cp. lower part of Figure 1) exhibit smaller differences between the tests. This also leads to a slightly lower significance level between the results of these tests. Finally, the difference between the restitution time of TS V and that of TS I is not significant.

The IRTTS values of the test series are graphically represented in Figure 2. With regard to the influence of the number of impulses (n) on the physiological cost in the form of IRTTS values, a great increase in physiological responses results when the number of impulses is doubled (from 450 to 900 to 1800 impulses), as seen in the upper left graph of Figure 2. Each doubling of the impulse duration (t_{Imp}) – according to the upper right graph of Figure 2 – leads to a smaller increase in strain than the variation of the number of impulses does.

Unfortunately, the different rating levels L_{Ard} which are due to the test design (also cp. middle part of Figure 2) complicate the interpretation of the results. The dose of energy of the test series which varied ±3 dB represents an interference variable whose influence can be eliminated as follows: The IRTTS values were converted to a reference level (L_{Ard} also 85 dB(A)) in order to compare the test series to one another. The IRTTS values that corresponded with a rating level of 82 dB(A) were multiplied by a factor of 2 and those which corresponded with 79 dB(A) were multiplied by 4, since only half and a quarter, respectively, of the energy affected the ear in these cases. It should be mentioned that this is a mathematical procedure which merely allows a comparison of threshold shifts after exposure to noise with varying rating levels and does not represent the acceptance of the dose principle.

If the energy equivalence principle for aural strain were valid, this principle would have to lead to almost identical IRTTS values since the rating levels are now the same. Yet, with the rating level now equal, an increase in the number of impulses still leads to an increase in physiological cost, as can be seen in the lower left graph of Figure 2. The influence of the impulse duration on the physiological cost (again with equal rating level) can be seen in the lower right graph of Figure 2. At first, the physiological cost is almost constant, i. e., energy-equivalent, with decreasing impulse duration; for impulse durations below 25 ms, however (i. e., the 12.5 ms given here), the physiological cost increases greatly. These results show that the energy equivalence principle is not suitable for the evaluation of noise exposures. The influence of the number of impulses in particular, but also the influence of the impulse duration and of the rating level, do not follow this principle by any means.

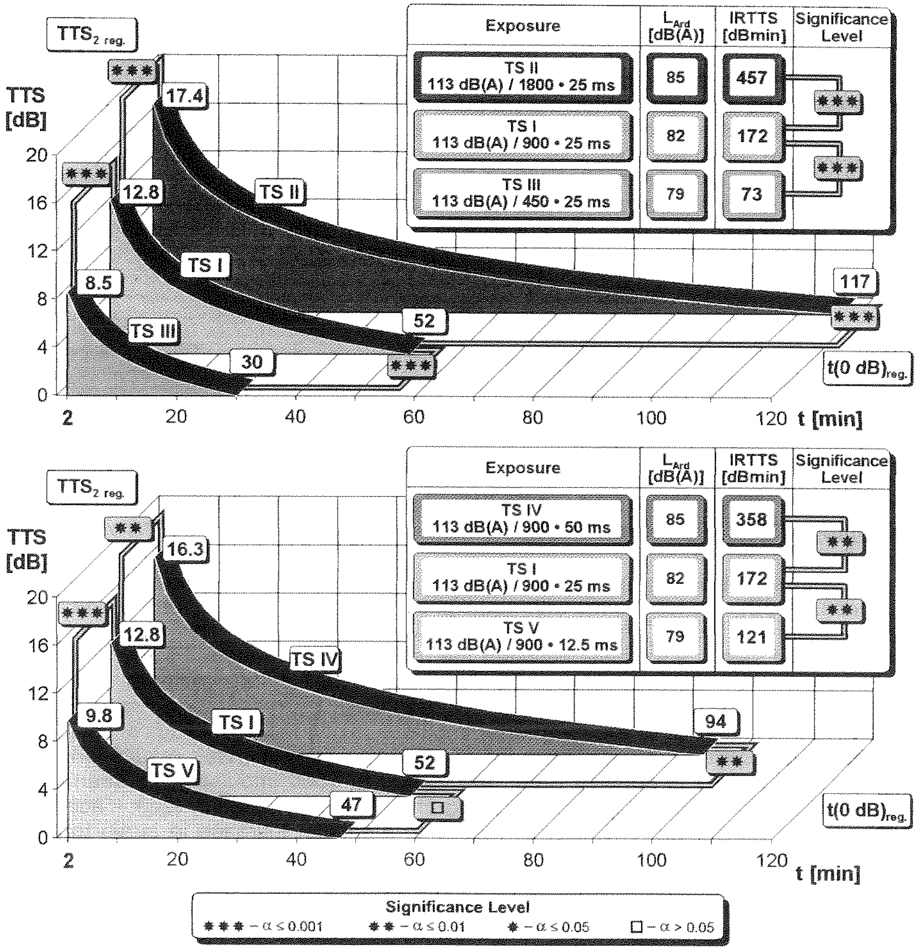

Figure 1: Restitution time course TTS(t) with characteristics $TTS_{2\,reg.}$, $t(0\ dB)_{reg.}$, and physiological cost IRTTS as well as symbolic labeling of significance levels for the differences between the responses to the exposures with equal impulse duration t_{Imp} = 25 ms (top) and to the exposures with equal impulse number n = 900 (bottom) (according to the one-tailed WILCOXON-test)

4. Conclusions and Outlook

The evaluation of the experiments in this study has shown that an increase in the number of impulses (with constant impulse duration) leads to a substantially larger increase in the physiological cost – expressed as IRTTS values – than was expected based on the utilized dose of energy. The test series with varying impulse durations also showed that the energy equivalence principle is not relevant in practice for aural stress. The physiological cost does increase with longer impulse durations, but this was to be expected due to the increased amount of energy associated with the rating level L_{Ard} (79 dB(A) | 82 dB(A) | 85 dB(A)). On the other hand, short impulse durations lead to an over-energetic increase in physiological responses of the hearing.

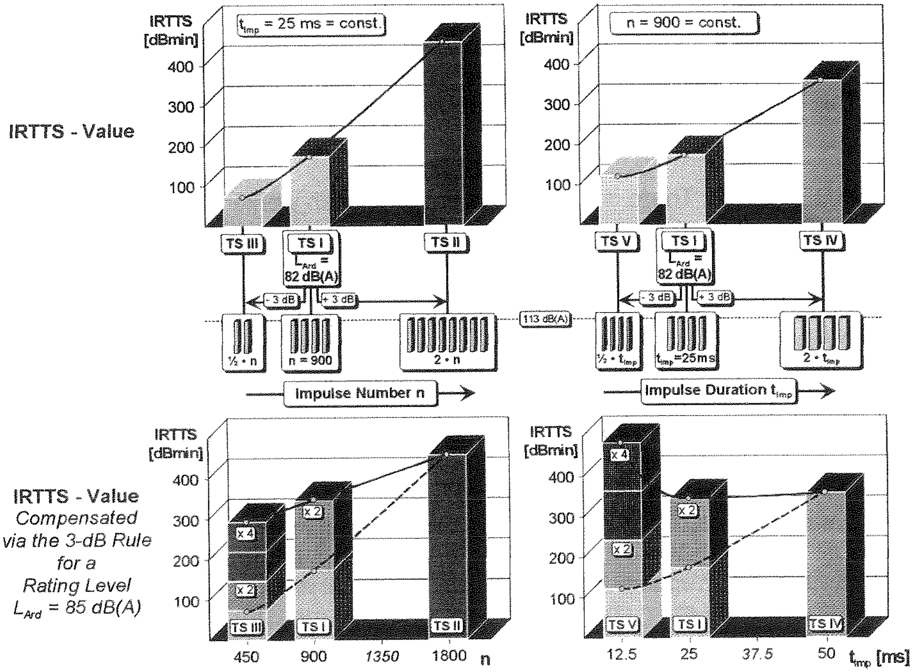

Figure 2: Influence of impulse number n and impulse duration t_{imp} on the Integrated Restitution Temporary Threshold Shift (IRTTS) as an indicator of the total physiological cost

The results of this study clearly show that the number of impulses is more important than the impulse duration when stress from impulse noise is evaluated, at least under the conditions in this study. From an energy-equivalent point of view, however, the influences of the impulse duration below a critical impulse duration may not be underestimated. Since the number of persons subjected to impulse noise is comparable to the number of those subjected to continuous noise, these aspects of the research of noise effects should be paid more attention. The rigorous application of the energy equivalence principle in the incorporation of the 'EC Directive on Noise Protection' [4] into the 'UVV-Lärm' [5] will not be able to contribute to a decline in the occupational hazard NIPTS, i. e., 'noise-induced hearing loss.'

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Menstrual disorders in noise exposure female workers: a systematic review from Chinese literature

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Abstract

BACKGROUND: There is a large amount of women worked in excess noisy environment. It is an interesting topic on long-term noise exposure and changes of menstrual function among these women. Since middle of 1980's, more than thirty papers were published in Chinese journals to observe above effects. Unfortunately, no paper is found in English journals for the topic by MEDLINE. **STUDY OBJECTIVE:** Thirty-two papers were collected from Chinese journals of 1985-1995. It comes from more than twenty provinces and metropolis of China. Textile female workers were selected in thirty-one of the papers. The total observers cover 26701 cases in the thirty-two papers. **DESIGN:** A systematic review and pooled analysis were performed based on reported prevalence of irregularity of menstrual cycle, irregular duration of flow, abnormal amount of flow and dysmenorrhea. A logistic model was used to estimate odds ratio of sound pressure level (SPL) for the outcomes. **MAIN RESULTS:** Irregularity of menstrual cycle, irregular duration of flow, abnormal amount of flow and dysmenorrhea are main changes for noise induced menstrual disorders. Pooled analysis showed that the $OR_{SPL\ 1dB(A)}$ of irregularity of menstrual cycle (1.025, 1.022-1.029), irregular duration of flow(1.013, 1.007-1.018), abnormal amount of flow (1.017, 1.014-1.020) and dysmenorrhea (1.011, 1.009-1.014) were higher than one with significance. Scatter plot showed positive dose-response trends between noise exposure and prevalence of menstrual disorder by individual investigate. Pooled data showed detail relation for noise induced menstrual disorders. By which, the safe criteria could be suggested by 100 dB(A) for dysmenorrhea, 95 dB(A) for irregularity of menstrual cycle, 90 dB(A) for irregular duration of flow and abnormal amount of flow. **CONCLUSIONS:** The present knowledge can explain adverse effects of noise on menstrual disorders. An important advance of this research is to find detail dose-response relationship and noise exposure criteria for noise induced menstrual disorders. It suggests that the present industrial noise exposure criteria in each country (80-90 dB(A)) could protect menstrual functions against long-term noise exposure for female workers. By present of publicative bias in data source of the systematic review, the evaluation of this paper might be slight higher than real dose-response relation. It is lack of truth to confirm presents of cumulative effects of noise on menstrual disorders. The author suggests to observe effects of earplugs or earmuff to protect health of female workers against high level noise exposure.

Key Words: abnormal amount of flow, adverse effects, dose-response relationship, dysmenorrhea menstrual disorders, irregular duration of flow, irregularity of menstrual cycle, systematic review, noise

It is known that many women work in excess noisy environment in all over the world. It is still not clear for the possible adverse effects of noise on menstrual disorders. Since 1985, more than thirty papers were published in Chinese medical journals for long-term noise exposure and menstrual disorders. This paper summarizes on the topic by pooled analysis and systematic review methods. It will focuses on dose-response relation and safety criteria for noise induced menstrual disorders.

Material and Methods

Data sources and review including standards: thirty two papers were found from Chinese occupational health medicine key journals and Chinese domestic conference materials by hand check and Chinese medical database on industrial noise exposure and menstrual disorders. The authors were distributed at about twenty province, metropolis and municipality of China in universities, institutes, hygiene stations and hospitals. Each paper was checked carefully on research design, observe subjects, noise exposure feature, level and exposure group division, and observe outcomes. Thirty one papers included noise exposure levels[2-8,10-33], twenty two had prevalence on different kinds of menstrual disorder[2-7,10-12,16,17,19,20,23-25,27-29,31-33], fifteen designed equal or more than three groups (include control group)[2-4,7,8,10,14,16,17,20,26,28-31], twenty seven had out control group[2,3,5-10,12-15,17-25,27-30,32,33] , fifteen had inner control group[2-4,7,8,10,14,16,17,20,26,28-31], eleven had both inner and out control groups[2,3,7,8,10,14,17,20,28-30], one designed self control on before-after noise exposure in work day[11], thirty one paper observed textile female workers[2-17,19-33]. Most papers did not introduce the diagnose standards for each kind of menstrual disorders. We know that an occupational health workshop was opened in 1985 in Beijing Medical University for female worker health. In the workshop, the diagnose standards for each kind of menstrual disorders was discussed. After this, all participants attended a field investigation in a textile factory of Beijing and finished a paper[7]. After this workshop, most of participants started their noise-menstrual disorders studies at their living cities. Most authors included in the review were participants of the workshop. Bao Yushu made a summery for diagnosis of menstrual disorders which includes results of the workshop[7]. By above background, it is reasonable to say that the diagnosis standards of menstrual disorders in most of collecting papers were comparable at each other.

Data Analysis: Noise exposure levels and prevalence of menstrual disorders were collected from each paper and summarized in datasets. EGRET and SAS software were applied to calculate OR and 95%CI for each papers and pooled data by logistic model. Prevalence of each exposure level at each paper, prevalence of pooled each exposure level and logistic model fitting curve were plotted at scatter figure. Safe criteria of noise level was defined by significant difference of prevalence in statistics and by professional evaluation.

Results

The four menstrual disorders were observed associated with noise exposure in all thirty two papers. They were irregularity of menstrual cycle, irregular duration of flow, abnormal amount of flow and dysmenorrhea. Part authors observed pre-menstrual syndrome[2], pre-menstrual mood changes[18], bleed at non-menstrual period[27], lumbago[14,23,24,29], engorgement of breast[11,30] and amenorrhora[25].

Table 1 had twenty papers in which each paper had real data about equal or more than one parameter of menstrual disorder. It included irregularity of menstrual cycle, irregular duration of flow, abnormal amount of flow and dysmenorrhea with OR and 95% CI. The authors were listed by publishing year from 1985 to 1995. Pooled OR and 95% CI were calculated at 1985, 1988,1990, 1991 and 1995. The pooled ORs showed stable trend by increasing pooled case number. All last pooled ORs were over 1 with significant. It means that long-term noise exposure could increase irregularity of menstrual cycle, irregular duration of flow, abnormal amount of flow and dysmenorrhea in female workers.

The relationship between noise level and irregularity of menstrual cycle, irregular duration of flow, abnormal amount of flow, dysmenorrhea were showed in figure with real prevalence (hollow cycle), pooled prevalence (filled cycle) and fitting curve of logistic model. The hollow cycles showed positive trend between noise level and menstrual disorders without detail. The pooled prevalences of menstrual disorder were placed at middle level of real prevalences with stable trends. They were also near the fitting curve of logistic model. By the figure, it was the possible noise exposure level criteria of irregular duration of flow and abnormal amount of flow at 90 dB(A), irregularity of menstrual cycle at 95 dB(A) and dysmenorrhea at 100 dB(A). Chi-square test was applied for determining the possible safe criteria levels with significant. Table 2 showed case numbers, pooled ORs and safe criteria levels for each parameter of menstrual disorder. All the safe criteria were equal or over 90 dB(A). It suggested present safe criteria level for industrial noise exposure (80-90 dB(A)) could protect menstrual function against long-term noise exposure.

Table 1. Simple and pooled analysis (Odds Ratio) for long-term noise exposure and menstrual disorders in female workers from Chinese literature

First author name	Publish year	Case number	Irregularity of menstrual cycle (OR)	Irregular duration of flow (OR)	Abnormal amount of flow (OR)	Dysmenorrhea (OR)
Chen Xiang	1985	501	1.060(1.015-1.071)	——	0.991(0.948-1.036)	——
Ye Xiaoyun	1985	1431	1.028(1.013-1.044)	——	1.035(1.025-1.045)	1.008(0.997-1.020)
Total	-1985	**1932**	**1.032(1.017-1.047)**	——	**1.006(0.994-1.018)**	**1.008(0.997-1.020)**
Chang Jizeng	1988	557	1.047(1.023-1.071)	——	1.070(1.030-1.111)	1.286(1.161-1.425)
Shi Xiaofeng	1988	1155	1.035(1.013-1.058)	——	1.077(1.038-1.118)	1.047(1.024-1.070)
Wang Qianying	1988	197	1.037(1.006-1.070)	0.975(0.944-1.007)	0.998(0.983-1.013)	0.989(.0951-1.003)
Wuxi Weixiao	1988	2968	——	——	1.001(0.991-1.011)	——
Zhao Shufen	1988	779	1.061(1.026-1.097)	1.028(0.972-1.087)	1.097(1.064-1.103)	1.074(1.041-1.108)
Zhao Yujie	1988	217	1.037(1.004-1.072)	——	0.964(0.924-1.006)	0.971(0.933-1.011)
Total	-1988	**7805**	**1.040(1.031-1.050)**	**0.976(0.952-1.002)**	**1.025(1.019-1.030)**	**1.004(0.996-1.012)**
Shao Rong	1989	2860	1.021(1.006-1.036)	1.019(0.992-1.047)	1.021(1.007-1.035)	1.038(1.024-1.052)
Liang Zhenjie	1990	150	——	——	1.043(0.998-1.090)	——
Chang Jizeng	1990	9760	1.028(1.023-1.033)	1.017(1.009-1.026)	1.006(1.001-1.010)	1.011(1.007-1.015)
Jiang Huzhen	1990	1221	1.025(1.013-1.037)	——	——	1.023(1.016-1.031)
Lang Yanying	1990	1538	1.055(1.037-1.074)	1.075(1.051-1.099)	1.029(1.016-1.041)	1.026(1.017-1.036)
Total	-1990	**22334**	**1.024(1.020-1.028)**	**1.019(1.012-1.026)**	**1.018(1.014-1.021)**	**1.011(1.009-1.014)**
Feng Jing	1991	264	1.049(1.004-1.097)	——	1.029(0.995-1.064)	1.054(1.021-1.097)
Sun Xu	1991	647	1.015(1.000-1.031)	1.010(0.992-1.028)	1.028(1.013-1.044)	1.000(0.988-1.013)
Tang Qianzhi	1991	433	1.070(1.042-1.099)	1.061(1.036-1.086)	1.119(1.090-1.148)	1.054(1.032-1.078)
Xu Qing	1991	260	——	——	1.081(1.057-1.106)	0.996(0.972-1.021)
Zhan Chenglie	1991	916	1.086(1.060-1.114)	1.027(1.004-1.050)	1.000(0.984-1.016)	1.040(1.023-1.057)
Total	-1991	**25854**	**1.025(1.022-1.029)**	**1.013(1.007-1.019)**	**1.016(1.013-1.019)**	**1.011(1.008-1.014)**
Liu Jingfang	1994	200	1.037(0.988-1.088)	——	1.037(0.988-1.088)	——
jiang Qide	1995	291	——	1.018(0.999-1.036)	1.020(1.003-1.037)	1.025(1.008-1.041)
Wei Guihai	1995	356	1.014(0.990-1.038)	——	1.019(1.000-1.038)	1.070(1.039-1.101)
Total	-1995	**26701**	**1.025(1.022-1.029)**	**1.013(1.007-1.018)**	**1.017(1.014-1.020)**	**1.011(1.009-1.014)**

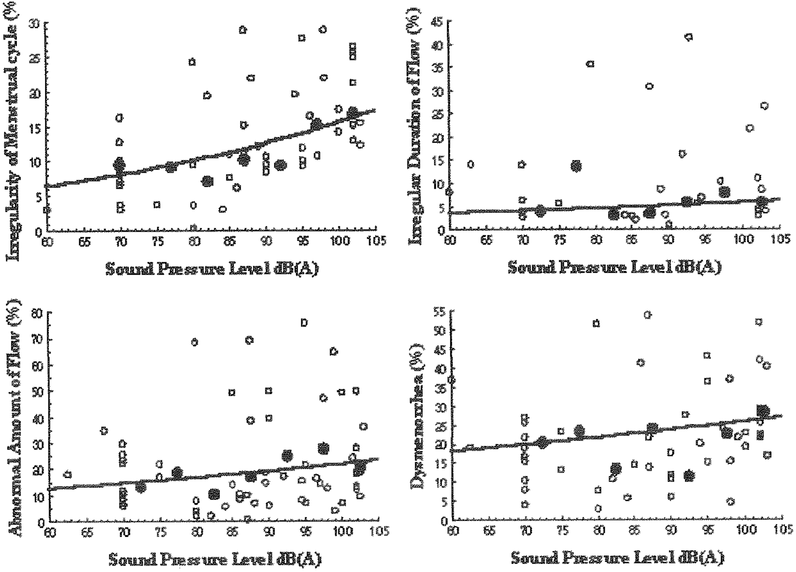

Figure Pooled analysis for noise exposure level and prevalence of menstrual disorders

Table 2. Comparison of pooled OR and safe criteria for noise induced different menstrual disorders

Outcome	Cases	Pooled OR	Safe Criteria dB(A)
Irregularity of menstrual cycle	23032	1.025 (1.022 ~ 1.029)	95
Abnormal amount of flow	25480	1.017 (1.014 ~ 1.020)	90
Irregular duration of flow	17421	1.013 (1.007 ~ 1.018)	90
Dysmenorrhea	22882	1.011 (1.009 ~ 1.014)	100

Evaluation

Statistical evaluation: In publications of the review, each paper designed a lot of different noise exposure level groups. It was difficult to compare the prevalences directly for different papers. Another challenge was how to compare relative risk for different noise induced menstrual disorders. For the challenges, logistic regression model was applied to calculate OR of 1dB(A) as a standard method. $OR_{1dB(A)}$ could be compared one parameter among different papers and different parameters of menstrual disorder for their dose-response relation. The $OR_{1dB(A)}$ levels were the highest for irregularity of menstrual cycle, second for irregular duration of flow, third for abnormal amount of flow and last for dysmenorrhea (see table 2). This risk order showed feature of noise induced menstrual disorder by dose-response relation.

It was found a significant publication bias by reason of detail positive results described at papers but lack of negative data. The pooled ORs we calculated in the review might be little higher than real ORs. If possible, it is important to collect unpublished negative data for detail pooled analysis.

Occupational health evaluation: It is known that long-term strong noise exposure can induce a series disorders in nervours-endocrinologic systems. It is reasonable to say that changes in nervours-endocrinologic systems could introduce menstrual disorders. Most of papers and pooled analysis results showed irregularity of menstrual cycle, irregular duration of flow, abnormal amount of flow and dysmenorrhea were main changes for noise induced menstrual disorders. Dose-response relation supports strongly on the hypothesis for long-term noise exposure and menstrual disorders. Unfortunately, it is lack of truth to confirm presents of cumulative effects of noise on menstrual disorders in all collected publications.

It is lucky to say that we found the criteria of noise exposure levels for noise induced menstrual disorders were equal or higher than present criteria of industrial noise exposure level (85-90 dB(A)). It means present criteria of industrial noise exposure can protect health of female workers. It is still unclear hearing protector could protect health of female workers if they work in noise environment higher than industrial noise exposure criteria level.

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TRAFFIC NOISE AND HEALTH EFFECTS

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1. INTRODUCTION

Well-known non-auditory effects of noise exposure include general annoyance, disturbances in psycho-social well-being and impaired sleep quality [1,2]. Effects on cardiovascular risk have also been suggested [3]. Regarding the relationship between long term noise exposure and hypertension evidence is still conflicting [4,5]. Previous epidemiological investigations have most often been performed in occupational settings, with high noise exposure levels [6,7]. However, some studies have focused on exposure to traffic noise and the risk of hypertension [8,9,10]. Noise annoyance in combination with other stress factors might increase the influence of chronic noise exposure on blood pressure [11]. Our objective was to analyse possible health effects of exposure to medium and high levels of traffic noise in an area where noise annoyance was known to be extensive.

2. STUDY POPULATION AND METHODS

Study population

The study was performed in Sollentuna, a municipality with 56 000 inhabitants located 10 miles north of Stockholm, Sweden. A questionnaire, used in a countywide study of health effects due to various environmental factors, was distributed in April 1997 to 1 000 persons between 19 and 80 years of age living in the municipality. The study population consisted of two random samples of 500 individuals each. One sample was drawn from buffer zones which were constructed using Geographic Information System (GIS) and included 100 meters on each side of the main roads and highways — road-exposed group (ROAD, n=365), and 100 meters on each side of the main railway — train-exposed group (TRAIN, n=135). The other sample was drawn from the remaining part of the municipality and constituted a group exposed to low traffic noise (LOW, n=500). The sampling was performed by Statistics Sweden by combining the National Population Register containing background information for the study population, with the Real Estate Register, containing geographical co-ordinates for the individuals residences. According to a Nordic prediction model for traffic noise, the noise levels comparative to ROAD were 50-65 dBA, and the noise levels comparative to TRAIN were 55-65 dBA [12].

Questionnaire

The questionnaire included 87 questions in all, mainly focusing on prevalence of allergic diseases and environmental risk factors for asthma and allergy. In addition to general background factors (sex, age, ethnic background), the questionnaire provided information on education level, employment status, living conditions, smoking habits, outdoor exercise, and food preferences. Data were also collected on general annoyance from traffic noise and air pollution, noise-induced sleep disturbances, and prevalence of medical diagnosis of hypertension during the last 5 years. General annoyance, and sleep disturbance (difficulty falling asleep and/or waking up due to noise) were defined as frequent when occurring at least once a week.

Statistical analysis

Differences in prevalence between background factors were computed using chi square tests. For comparison of mean age, two-tailed students t-test was used. Odds ratios for road traffic noise exposure and hypertension risk were weighted with the Mantel-Haenszel method and are shown with 95% confidence intervals. All statistical analyses were performed using the statistical software packages SPSS and Epi-Info.

3. RESULTS

The response rate was 76% in ROAD, 75% in TRAIN and 76% in LOW. Table 1 shows the distribution of background factors in the three sampling groups.

Table (1). Distribution of background factors in three sampling groups exposed to road traffic noise (ROAD), train noise (TRAIN), and low traffic noise (LOW) respectively.

	ROAD	TRAIN	LOW
Background factor	n=278	n=101	n=380
Men	48%	46%	45%
Mean age	51*	46	46
Immigrants (born outside Sweden)	13%	16%	16%
Education level (>high school)	23%*	20%*	33%
Employment status (≥35h/week)	46%	55%	51%
Residence (single family house)	58%	92%*	57%
Smoking (current or former)	58%*	56%*	43%
Outdoor exercise (≥1/week)	27%	21%	22%
Consumption of fruits or vegetables (>1/day)	44%	46%	44%

*Differs significantly ($p \leq 0.05$) from LOW

Regarding employment status, 37% of the women in the group exposed to road traffic noise did not work full time and 29% were retired, compared to 26% and 16% respectively among males.

Overall 15% of the men and 12% of the women were diagnosed as hypertensive. Prevalence of hypertension was 18% in ROAD, 8% in TRAIN and 10% in LOW. There was a significant difference between ROAD and LOW ($p<0.01$), but not between TRAIN and LOW ($p=0.58$). In Table 2 prevalence of hypertension in ROAD and LOW is shown for men and women, respectively.

Table (2). Prevalence of hypertension among men and women exposed to road traffic noise (ROAD) and low traffic noise (LOW).

Sex	Noise exposure	Total	Hypertension	Percent
Men	ROAD	128	20	16%
	LOW	159	23	14%
Women	ROAD	138	28	20%
	LOW	206	14	7%
Total	ROAD	266	48	18%
	LOW	365	37	10%

Table 3 shows odds ratios (OR) for medical diagnosis of hypertension in ROAD compared to LOW. The overall crude OR was 1.9 (95% CI 1.2, 3.2). Adjusted for factors that significantly differed between the groups, i.e. age, smoking, and education level, the overall OR was 1.8 (95% CI 1.0, 3.2). When analysing men and women separately, the crude and adjusted OR were significantly increased only for women.

Table (3). Odds ratios (OR) for hypertension among men and women exposed to road traffic noise (ROAD) compared to the group exposed to low traffic noise (LOW).

	OR (95% CI)	
Sex	Crude	Adjusted**
Men	1.1 (0.5, 2.2)	1.0 (0.4, 2.3)
Women	3.5 (1.7, 7.3)	3.3 (1.4, 7.3)
Total*	1.9 (1.2, 3.2)	1.8 (1.0, 3.2)

* OR for the total are weighted by sex

**Adjusted for age, smoking and education level

Frequent annoyance from road traffic noise was reported by 15% in ROAD and 4% in LOW. More than 40% experienced frequent annoyance due to railway traffic noise in TRAIN, compared to 2% in LOW. Frequent sleep disturbances was present among 5% in TRAIN, 4% in ROAD and 2% in LOW. The prevalence of any sleep disturbance (sometimes or frequently disturbed) was 30% in TRAIN, 22% in ROAD and 13% in LOW.

4. DISCUSSION

A higher prevalence of hypertension was found in the group exposed to road traffic noise. This finding was also suggested in other investigations [8,9]. Surprisingly this was the case only for women in this study. A possible explanation could be that women spend more time at home, with a greater exposure to residential road traffic noise. In the present study this was indicated by a sex difference in employment status. Among general risk factors for hypertension, data on heredity and body mass index (BMI) were not available. However, information about risk factors associated with BMI such as physical activity and food preferences were recorded.

Few people reported frequent sleep disturbances, but several were occasionally disturbed. Laboratory studies have indicated that self-reported noise annoyance could give an underestimation of the physiologic effect of noise exposure [2]. Thus, even if many people only experience sleep disturbances, occasionally it may indicate more serious influence on sleep quality. Difference in frequent traffic noise annoyance was considerably greater between LOW and TRAIN than between LOW and ROAD. This could be due to higher contrast in exposure when comparing the group exposed to railway traffic noise and the low-exposed group.

In conclusion, this cross-sectional study showed a positive association between road traffic noise exposure and diagnosis of hypertension among women, suggesting that chronic noise exposure is a risk factor for elevated blood pressure. A possible sex difference has to be further analysed.

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EVIDENCE OF OPTIMISM BIAS REGARDING THE HEALTH EFFECTS OF EXPOSURE TO NOISE

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1. INTRODUCTION

A large body of research is directed towards determining the physical and psychological (health) effects of noise exposure [for reviews see 1,2,3,4], and many campaigns against noise pollution claim that noise harms health.

Surprisingly little research has considered peoples' beliefs regarding the health effects of noise exposure. Several psychological variables (including attitude toward the noise source) appear to influence reaction [see 5,3] and in turn health outcome [3,6,7,8,9]. Similarly, peoples' expectations regarding the health effects of noise may influence reaction and health. Here we examine one aspect of peoples' beliefs about the health effects of noise which may influence reaction and health outcomes.

In particular, we investigate whether people are optimistically biased about the health effects of noise. Optimism bias refers to peoples' tendency to underestimate their own likelihood of experiencing negative events (and overestimate their likelihood of experiencing positive events) relative to their peers [see 10,11,12]. Thus, a belief that noise is less likely to harm ones' own health than the health of ones' peers, would be an optimistically biased belief.

Optimism bias is likely to influence the effect of noise exposure on reaction and health outcomes. The belief that noise exposure is a health risk is associated with general reaction [13,14] and perceived relative risk influences behaviour, cognition and emotion at least as much as perceived absolute risk [15]). Thus, optimism bias about the health effects of noise is likely to influence health outcomes at least as much as beliefs about personal health effects of noise.

Optimism bias has been demonstrated in relation to a wide range of events [see 11,16] in a variety of populations, and is extremely difficult to undermine [17]. Further, at least some putative theories of optimism bias [for reviews see 18,11,16] predict optimism bias in relation to the health effects of noise. For example, the defensive denial account proposes that people underestimate their relative risk in order to protect themselves from the anxiety produced by the risk.

Thus, we expect that people believe themselves less likely to be troubled by noise exposure than are people otherwise similar to themselves. In order to better understand this effect we compare it with optimism bias regarding non-noise events and examine its relationship with several personality traits.

2. METHODS

Subjects and Sample Selection

28 male and 78 female first year Psychology students at the University of Sydney (average age =19.42) volunteered as subjects in a study of "perceptions of the future" to fulfil course requirements.

Materials

Subjects received a package comprised of four printed questionnaires:

i) Optimism Bias Questionnaire (OBQ): Subjects rated the likelihood of each of 21 negative and 4 positive events (including "be troubled by the noise of modern cities") happening to them relative to the average Sydney University student of the same age and gender (1= "much less', 2= "less", 3= "slightly less", 4= "same as", 5= "slightly more", 6= "more", 7= "much more").

ii) The Automatic Attributional Style Questionnaire (AASQ) [19] assessed the degree to which subjects regard the causes of negative events to be internal, stable, global and uncontrollable (each indicating pessimism) [20].

iii) Life Orientation Test (LOT) [21] measured optimism as a trait.

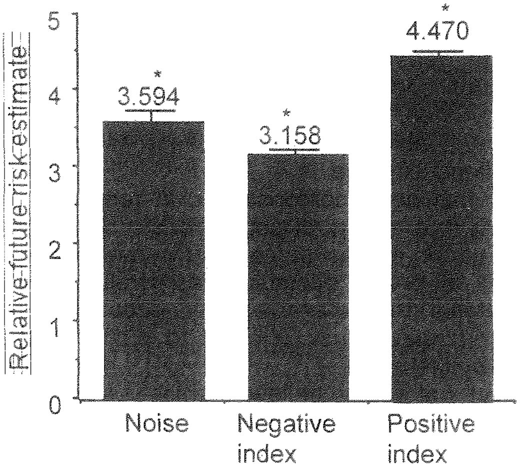
Procedure

Subjects completed the questionnaires in groups in a quiet room attended by a female experimenter (JH). Subjects received assurance of their anonymity and standardised instructions. They completed Part 1, consisting of an OBQ and the AASQ. This was removed and they were given Part 2 (consisting of LOT and another OBQ, not reported here) to complete.

3. RESULTS

For each subject we calculated noise-unrelated negative and positive indices, by averaging optimism bias scores on the negative (except "troubled by the noise of modern cities") and positive events (see Fig. 1).

Figure 1: Relative future risk estimates for the noise event, the negative index and the positive index with standard error bars (* = significantly different from 4 at p<.05), demonstrating optimism bias for each



Optimism bias was assessed by comparing scores to the scale-point "about the same as average" (score=4) using 1-tailed single sample t-tests (alpha=.05). Optimism bias is reflected by a sample average significantly lower than 4 for negative events, and significantly greater than 4 for positive events.

Optimism bias was demonstrated on the noise event (t_{100}=2.74, p=.004), the negative index (t_{95}=11.83, p=.000) and the positive index (t_{98}=-6.08, p=.000). Sixteen of 20 non-noise negative events (lowest sig. t_{100}=2.57, p=.006), and 3 of 4 positive events (lowest sig. t_{100}=-2.37, p=.010) demonstrated optimism bias.

We compared optimism bias regarding noise to optimism bias regarding other negative events using a 2-tailed single sample t-test (alpha=.05). Optimism bias regarding the effect of noise was significantly lower than the optimism bias found for the negative index (t_{95}=2.82, p=.003), and for 10 of the 16 non-noise negative events which had demonstrated optimism bias (lowest sig. t_{100}=2.54, p=.007).

As predicted, optimism bias on the non-noise negative index correlated significantly and positively with pessimism (lowest significant r=.166, p=.027), and negatively with optimism (r=-.204, p=.012). Contrary to prediction, relative estimates of the likelihood of being troubled by noise did not correlate significantly with these measures (highest r=.036, p=.181).

4. DISCUSSION

Subjects believed that they were less likely to "be troubled by the noise of modern cities" than were their peers. Optimism bias was also demonstrated in relation to noise-unrelated negative and positive events.

Optimism bias regarding non-noise negative events was consistently greater than that regarding noise. This may be due to the "egocentrism" mechanism of optimism bias [22,12] combined with differential perceived sphere of efficacy of measures which reduce the risks presented by noise exposure versus other negative events. According to the egocentrism account, when asked to estimate their relative risks of negative events, people may focus egocentrically on their own precautionary behaviours and, failing to consider others' precautions, underestimate their relative risk. However, people may believe that measures which reduce the noise exposure risks (eg. protesting against aircraft noise) benefit others as much as themselves, whereas precautions against many other negative events are personally effective. Thus, focussing on their own precautions is not as likely to produce optimism bias in relation to noise.

Dispositional pessimism and optimism were related to optimism bias regarding non-noise negative events, but not to optimism bias regarding the effects of noise. Beliefs about noise exposure may be overdetermined by media and other external influences, rather than personality, and thus more ammenable to external change, but less influenced by personality factors.

Optimism bias regarding the effects of noise is likely to have a protective influence on noise effects. Given the impact of relative risk judgements on emotion, cognition and behaviour [15], if a person believes that they are less likely than their peers to suffer detrimental effects of noise exposure they may react less negatively to the noise. As a result, they may be less susceptible to the health effects of noise exposure. However, efforts to increase optimism bias regarding the effects of noise exposure should be undertaken with caution. Such optimism bias may reduce peoples' motivation to avoid exposure to noise, increasing their risk of direct effects of noise exposure.

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HUMAN RESPONSE TO OPEN OFFICE NOISE

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1. INTRODUCTION

Most research on noise and human psychophysiology has utilized either acute, experimental exposure to very loud sound levels, examined occupational noise exposure, or investigated communities exposed to various noise sources such as airports or vehicular traffic [1,2]. Generally psychophysiological responses to acute noise habituate rapidly; the evidence for occupational noise is tenuous; and community studies, particularly of children proximate to airports, suggest small effects.

This work leaves out one of the largest sources of noise exposure experienced by people, namely office noise. It is clear that office noise, particularly speech related sounds, are among the most annoying aspects of work, especially in open office settings [3]. However there is very little research on the physiological impacts of low level, speech relevant, auditory interference on psychophysiological stress [4]. Loewen and Suedfeld found self reported stress from a simulated exposure to open office noise. They also found some task decrements. Our research builds on the work of Loewen and Suedfeld by exposing clerical workers to several hours of recorded open office noise while performing typical clerical tasks. We extend their work by the inclusion of psychophysiological measures and an index of task motivation. One reason we might expect effects of even moderately low noise levels is if they occur in the context of sustained cognitive task demands. There are several trends both in the acute experimental noise literature and in the occupational literature suggesting that cardiovascular and neuroendocrine responses are less likely to habituate under sustained task demands [2].

Noise and other stressors increase muscle tension. Lundberg [5] has suggested that occupational stressors may play a role in musculoskeletal disorders in concert with poor ergonomic conditions related to sustained postures and poor anthropometrics. Noise and other stressors might affect risk for musculoskeletal injury because of postural invariance. Under stress, more dominant, less variable responding occurs. Thus we examined the extent to which people working under noise made adjustments in their work station in order to vary postural conditions.

In addition to psychophysiological noise effects, noise has the potential to interfere with task performance. High noise levels interfere with attention allocation, verbal memory, and certain types of speech processing [6,7]. Given the generally null effects of low to moderate levels of noise on performance, we did not expect typical office noise to degrade typing performance; whereas effects were expected on memory.

Finally both task performance under noise and chronic community exposure to noise sources have been associated with deficits in achievement motivation [2,8,9]. Thus we examined participants willingness to sustain cognitive effort in an achievement context, immediately following a prolonged working session.

2. METHOD

Participants

Participants were 40, middle aged women (M=36.5 years) who were all employed at least half time in clerical jobs (primarily secretarial) requiring word processing. All had been screened for hearing loss and repetitive strain disorders.

Procedure

Participants worked for three hours under either simulated, open office noise (M=55dBA, 66dBA peak, representative of typical exposure [4]) or under quiet conditions (M=40dBA) in the Cornell University Human Factors Laboratory. The primary clerical task was manuscript preparation with several task interruptions inserted, designed to simulate a realistic office work protocol (e.g., prepare expense report). Participants worked at a typical office work station with a computer. To obtain baseline resting psychophysiological measures, participants returned to the laboratory at the same time period within a week after the experimental session and sat comfortably for three hours. Participants were asked to drink water throughout the procedures and reminded to do so periodically. Urine was voided prior to each experimental or resting session and then collected at the end of the session, approximately 3.5 hours later. Urine samples from the post session void were extracted, deep frozen, and then subsequently assayed for catecholamines and cortisol.

In addition to epinephrine, norepinephrine, and cortisol, the other physiological relevant measure taken was work station adjustments. A highly trained observer monitored the participants unobtrusively from a distant vantage point in the laboratory. Every ten minutes the observer coded whether any one of six items (e.g., chair, monitor) had been adjusted. At the end of the session job stress was measured by a reliable (a=.86) seven item questionnaire. Participants also rated levels of noise in the room on a eight item scale (a=.89). Typing performance was assessed (words per minute) as well as memory for the contents of the manuscript typed. Participants were not informed that either of these performance measures would occur. Motivation was assessed with the Glass and Singer [9] puzzle persistence paradigm in which individuals are given several solvable and unsolvable puzzles. Task persistence on the unsolvable puzzles is the primary index of motivation.

3. RESULTS AND DISCUSSION

Noise elevated epinephrine, t(38)=1.79, p<.05, but not norepinephrine or cortisol. Epinephrine levels increased 5.61 ng/minute for the noise group compared to an average of 3.90 ng/minute for the quiet group over each person's respective baseline. Epinephrine is the more reliable index of stress and not always accompanied by changes in norepinephrine which is particularly sensitive to physical exertion. Cortisol changes are more strongly affected by distress. Thus we have some evidence that prolonged exposure to typical, open office noise causes elevated neuroendocrine activity indicative of stress. Interestingly, participants did not perceive the noisy working conditions as more stressful (M=1.72) than those working under quiet conditions (M=1.88), t(38) < 1.0. At the same time, however, participants did accurately discriminate the levels of perceived noise (M [noise] = 3.19; M [quiet]=3.87, t (37)=2.90, p < .01. These data, taken in combination, reveal the importance of not relying solely on self-report measures of human well being. Although participants did not appear to feel more stressed at the end of their three hour working session as a function of noise levels, they evidenced more psychophysiological stress.

Perhaps of greatest interest and potential importance is the finding that noise significantly lowered adjustments of the work station, t(38)=5.91, p < .0001. While performing typical office clerical tasks under normal, open office noise levels, experienced clerical workers were less apt to make postural adjustments in their work station (M=4.2) than their counterparts working under quiet conditions (M=8.4). These findings, if accurate and generalizable, suggest an additional pathway through which noise may increase health risks. These data need to be replicated in a field setting.

There were no effects of noise on typing performance or memory. These results are generally in accord with the noise and human performance literature, indicating that moderate levels of noise have little or no impact on performance [6,7].

Finally, in accordance with previous literature [2,8,9], working under prolonged noise appears to inhibit task motivation following exposure. Participants who had worked under noise attempted significantly fewer unsolvable puzzles (M=11.50) following the work session in comparison to those working in quiet (M=19.10), t(38)=4.75, p < .0001.

4. SUMMARY

Three hours of clerical work under typical, open office noise conditions using experienced workers in a controlled, but realistic office work setting, causes elevated psychophysiological stress and reduced persistence on a task index indicative of motivation. Moreover, these effects occur under conditions wherein no performance decrements occurred and workers did not perceive greater job stress. Furthermore, we show for the first time, that noise appears to inhibit postural adjustments at a work station. The latter may indicate a new health risk associated with occupational noise exposure.

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A dose-response relationship for noise induced hypertension in chemical fertilizer factories

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Noise is one of the most serious environmental risk factors in chemical fertilizer industry. The workers in chemical fertilizer factory are exposed to both noise and some kinds of toxical gases, for example, CO, NH_3, H_2S and CO_2. It is not clear there are any combined effects of noise and toxical gases for noise induced hypertension in the population. This paper focuses on dose-response relationship for noise induced hypertension and possible combined effects of noise and toxical gases.

Subjects and Methods

Seven large scale of chemical fertilizer factories in China was selected in the investigation. 1593 workers in these factories, who were employed equal or more than one year, were included in the research. Mean age of them were 30.2±7.7 (18.1–58.1) years, working years 9.5±6.7 (1–35) years, male 1168 and female 425. Sound pressure level (SPL) of noise was measured by sound level meter in working position of ear level. The safety officers of the factories conducted noise and chemical toxical substances (CO, NH_3, H_2S and CO_2) in working place survey every two years and reported that the SPL in each working position has been essentially steady since producing chemical fertilizer. Working schedule of each worker was investigated to estimate real noise exposure duration in every working day. By equal energy rule, cumulative noise exposure (CNE) was calculated by lower function:

$$CNE=10\times\log(\Sigma 10^{0.1\times SPL}\times \text{working years} \times \text{noise exposure minutes} \div 480)$$

Questionnaire and health examination were done at spring or autumn during October 1991 to December 1992. A few occupational physicians went to the seven factories, one worked on asking and filling questionnaire table, one measuring blood pressure, one organizing the survey and checking data quality. Questionnaire table includes general information, occupational history, hypertensive history and personal living habits. Mercury sphygmomanometer was used to measure blood pressure by sitting position after 10 minutes rest with twice measurement. According to the recommendation of the World Health Organization Expert Committee[6], hypertension was defined as systolic pressure great than or equal to 21.7 kPa, or diastolic pressure great than or equal to 12.7 kPa, or both. The subjects were also classified as hypertensive if they had hypertensive history and currently using antihypertensive drugs. The borderline hypertension was defined as systolic pressure great than or equal to 18.7 kPa and less than 21.7 kPa, or diastolic pressure great than or equal to 12.0 kPa and less than 12.7 kPa, or both. The data were input into IBM personal computer by dBASE III. The data were analyzed by SPSS, Epilnfor and EGRET software.

Results

The SPLs of noise exposed by these workers ranged 53.0~96.7 dB(A) (85.9±8.6), CNE 60.1~108.2 dB(A) (81.8±), noise exposure duration in every working day 30~480 minutes. All of the workers reported that they did not wear earplugs or earmuff during their working history. None of them reported that they had been diagnosed as hypertension at the time they were first employed in these factories. According to the data of routine environmental survey, the concentration of CO, NH_3, H_2S and CO_2 during producing period was lower than national health criteria standards in their working position (except accident).

In all 1593 workers, 108 borderline hypertensive and 85 hypertensive cases were found with 5.3% of hypertensive prevalence. The crude hypertensive prevalence in six SPL groups (table1) and eight CNE groups (table 2) increased appreciably at higher exposure groups with significance. It did not find any hypertensive case in highest group (case number=9) by possible reasons of healthy worker effects and small case number. The hypertensive prevalence of male (6.4%, 75/1168) was significantly higher than that of female (2.4%, 10/425), P<0.01). The prevalence of CO group (7.9%, 23/290) was significantly higher than that of control group (4.8%, 62/1303), P<0.05. It was not any significant association between other chemical substances' exposure and hypertension.

Table 1. Dose-response relationship between sound pressure level (SPL) and prevalence of hypertension in chemical fertilizer factories

SPL (dB(A))	Hypertension	Total	Prevalence of hypertension (%)
95-	0	9	0
90-	15	175	8.6
85-	23	489	4.7
80-	35	528	6.6
75-	2	64	3.1
<75	10	328	3.0
Total	85	1593	5.3

X^2_{trend}=4.048, df=1, P<0.05

Table 2. Dose-response relationship between cumulative noise exposure (CNE) and prevalence of hypertension in chemical fertilizer factories

CNE (dB(A))	Hypertension	Total	Prevalence of hypertension (%)
105-	0	9	0
100-	7	37	18.9
95-	25	214	11.7
90-	23	301	7.6
85-	13	336	3.9
80-	10	305	3.3
75-	4	192	2.1
<75	3	199	1.5
Total	85	1593	5.3

X^2_{trend}=35.580, df=1, P<0.01

A logistic regression model is carried out using hypertension as the dependent variable, using CNE, age and sex as the predictor variables. Table 3 shows that the coefficients of CNE, age and sex are all associated with the probability of hypertension. It indicates that noise exposure associates with increase of hypertension. Table 4 shows the influence on the logistic coefficient associated with CNE as other variables are added to the analysis. The coefficient of CNE, column 1, remain essentially constant when age and sex are included in the analysis, particularly after age is taken into account. The crude OR_{CNE} ($e^{0.08735}=1.091$) changes little as age and sex added into the model (adjusted $OR_{CNE}=e^{0.03474}=1.035$). To evaluate the magnitude of the individual influence of each variable on the risk of hypertension, a set of commensurate values is achieved by the comparison of two likelihood values, one likelihood value measuring the influence of the entire set of variables (all three variables) and a reduced likelihood where one variable at a time is deleted from the model. The difference in these likelihood shows that age (difference=44.356, $P<0.001$) is the strongest risk variable for hypertension. It is about ten times than that of CNE (difference=4.662, $P=0.031$). The sex (difference=5.894, $P=0.015$) has little more influence than CNE for probability of hypertension.

Table 3. Estimated parameters for logistic regression model for hypertension in chemical fertilizer manufacture workers

Variable	Coefficient	S.E.	P-value	Odds Ratio
Constant	-9.911	1.380	——	——
CNE (dB(A))	0.035	0.017	0.035	1.035
Age	0.099	0.015	<0.001	1.104
Male	0.783	0.350	0.025	2.189

Table 4. Confounding influence on logistic model: regression coefficients for a series of sequential analysis

CNE	Age	Sex
0.08735		
0.03940	0.100	
0.03474	0.099	0.7833

In comparison with SPL model, the CNE model shows stronger association with hypertension ($OR_{CNE}=1.035$, $P_{CNE}=0.035$) than SPL model ($OR_{SPL}=1.019$, $P_{SPL}=0.228$). It suggests that cumulative effects present in noise induced hypertension. In CNE model, it is not significant when CO added into the model. The main reason of the difference between crude OR_{CO} (1.723, $P=0.031$) and adjusted OR_{CO} (1.121, $P=0.683$) is CO exposure associating with age in these factories. The age of CO exposure workers (31.7±8.2 years, n=290) were more senior than control group (29.8±7.5 years, n=1303), $P<0.01$. After adjusted by age and more, logistic model shows no any significant association between CO exposure and hypertension. By this reason, the CO exposure is not included in the last model (table 3).

A goodness of fit test was applied for 1593 workers with 32 categories using hypertension, age and CNE. The expected and the observed show close agreement. Formally, the X^2 value for goodness of fit is 8.1 with 27 degrees of freedom producing a P value of 0.9.

Discussion

It has been investigated for relation between long-term noise exposure and hypertension in working population for many years[1]. Many reports showed positive association for noise induced hypertension. As with the studies, those findings were no association between noise and hypertension until beginning of 1990's. In 1991, we published a paper[8] for dose-response relation between noise and hypertension in a group of textile female workers. It showed an adjusted OR_{SPL} of 1.031 for hypertension. In 1993, the data were re-analyzed [9] by CNE instead of SPL with result of adjusted OR_{CNE} of 1.033 (Table 5). The associative strength of the study took the position of middle level among all researches[3]. The results were believed as an important evidence for noise inducing more hypertension[4,5]. It was included in WHO criterion's document[7] on community noise as one of main evidences for industrial noise exposure and hypertension. In epidemiologic studies, it is important to find same facts among different population. This paper shows same trend of dose-response relation as our finding in textile factory (Table 5). It strong supports the hypothesis that long-term noise exposure could induced more hypertension.

Table 5. Comparison of noise exposure and hypertension between textile factory and chemical fertilizer factories

Parameter	Textile factory	Chemical fertilizer factories
Subjects	1101 female workers	1168 male, 425 female
SPL (dB(A))	75~104	53.0~96.7
CNE (dB(A))	82.2~119.1	60.8~108.1
Age (years)	35.5±8.4 (22.1~53.0)	30.2±7.7 (18.1~58.1)
Noise exposure years	16.2±9.6 (5.0~38.4)	9.5±6.7 (1.0~35.0)
Noise exposure hr/day	8.0	0.5~8.0
Adjusted OR_{SPL}	1.031, P=0.047	1.019, P=0.228
Adjusted OR_{CNE}	1.033, P=0.034	1.035, P=0.035

The feature of hypertension study in chemical fertilizer factory is mixed exposure. This study explores any possible combine effects of noise and toxical substance for hypertension. The results show no significant combine effects in the population. Low level exposure of toxical substances might be main reason of the negative outcome.

Age is the most important risk factor in the study. It is same as textile study and other former research. The sex is used in analysis mainly to adjusted possible confounding.

One feature of noise exposure in this study is different exposure hours in each worker. It ranges from half hour to eight hours per day. I former analysis, the OR of SPL is lower without significant (table 5). Later, the OR of CNE without including exposure hours per day is 1.030 with p value of 0.07. All results showed the exposure duration is a very important parameter in noise exposure assessment. It is an another explain of different results of noise and hypertension among former studies[1].

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THE COMBINED EFFECTS OF ROAD TRAFFIC - IMPLICATIONS FOR ENVIRONMENTAL GUIDELINES

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1. INTRODUCTION

Road traffic gives rise to noise, air pollution, vibration, severance and visual aesthetic effects in addition to people's perception of traffic as being unsafe for themselves and their children. Urban populations often also have to put up with additional environmental stressors in the form of rail-and aircraft traffic together with local and regional air pollution. Urban dynamics ensure that the areas with the heaviest environmental loads also are populated by groups most lacking economic and social resources. A contextualistic approach [1, 2, 3] might be therefore be appropriate for dealing with the combined effects of road traffic in urban areas.

Taylor & al. [4] detail 5 distinct pathways through which the environment gets under one's skin. In addition to the direct route, the environment has an effect on mental health, chronic stress, coping efforts, and health behaviours. While air pollution from road traffic have direct impacts on health that have to be dealt with separately, all environmental effects have in common that they induce stress, hamper health-promoting activities and give rise to some of the same types of coping efforts. People air their apartments less, sleep with their windows shut, abandon trips in their neighbourhood both on account of noise and air pollution [5].

We examine in this paper the simple accumulation of highly annoyed people by the different environmental effects and the number of annoyances people report. We also examine the shifts in exposure-annoyance curves for people that also are annoyed with other environmental effects. We consider the implications these combined effects have for the development and application of environmental guidelines and criteria.

2. METHOD

Three environmental studies with approximately 1000 respondents each were undertaken in the autumn of 1987, 1994 and 1996. They function as before and after studies of two separate tunnel projects alleviating a centrally located town-area in Oslo of through traffic. The study area is composed of 14 sub-areas. The quality of life in the central part of the study area is among the lowest in Norway. The questionnaire has introductory questions on neighbourhood qualities and then inquires into annoyance with noise and perceivable elements of air pollution (dust/grime, odour/exhaust), insecurity and daily inconveniences. The 1996-survey also included annoyance with vibrations.

Noise calculations are of 24h equivalent noise levels at the apartments most exposed side. Calculated noise levels include 3 dBA from facade reflection. Noise levels at 157 representative points where calculated using the Nordic method [6] for calculating road traffic noise [7]. A terrain model was utilised for three study areas overlooking the road crossing a valley and its connections [8]. Air pollution calculations of hourly values of PM_{10}, $PM_{2.5}$, NO_2 and NOx were undertaken with Episode 2.1 [9] on the basis of meteorological data for a three month period each year using a combined line and area model [10]. PM_{10} values include road particles generated from studded tires.

3. RESULTS

As air pollution not only depends on nearby traffic, but also on city-wide and background emission levels, wind direction, temperature gradients, rain, topography and photochemical reactions, correlation with noise is not necessarily high. In our study 24h equivalent noise levels correlated 0.50 with 3-month average NO_2-levels. We have used logistic regression to illustrate the accumulation of people that are highly annoyed by either road traffic noise or air pollution as a function of 24h equivalent noise levels. A substantial number of people in this area are highly annoyed by air-pollution outside and/or inside the apartment even at low noise levels – see figure 1 left panel. 20 per cent highly annoyed can in this town area be reached as a result of noise alone at 60dBA or (not distinguishing between types of annoyance) as a result of either effect at 50dBA.

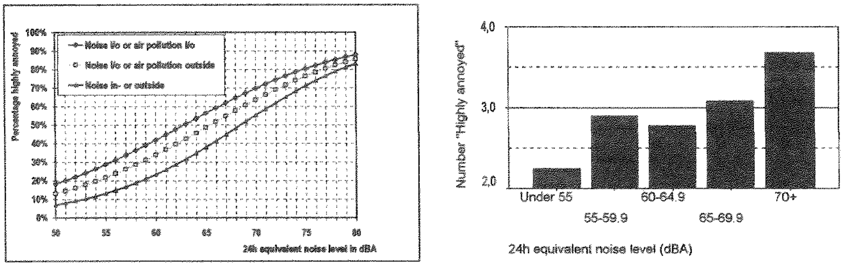

Figure 1: People highly annoyed by noise in- and outdoors, and/or exhaust/odour, and/or dust/grime from road traffic either outside or outside/ inside their apartment by 24h equivalent noise level. Pooled data. N=2990. Calculated percentages (left panel). Average sum "highly annoyed" + "highly insecure" + "severe difficulty negotiating traffic" by 5 dBA 24h equivalent noise intervals. People reporting at least one of the above. N= 1017 (right panel) Environmental surveys 1987,1994 and 1996.

Most often people exposed to high noise levels are also exposed to high traffic levels. Especially the elderly run the risk of feeling insecure and having problems negotiating traffic. In this area people are also more likely to being exposed to higher levels of pollution. People usually experience several problems at once (see figure 1 right panel).

Exposure-effect curves relating noise exposure and noise annoyance are affected by additional annoyances. Both the stress, drain on coping resources and reduction in health behaviours from one environmental effect may render some people more vulnerable to additional stressors. Logistic regression models show the percentage highly annoyed by noise are significantly and substantially influenced by people's annoyance with other stressors see figure 2 and 3, left and right panel. For similar results see [10].

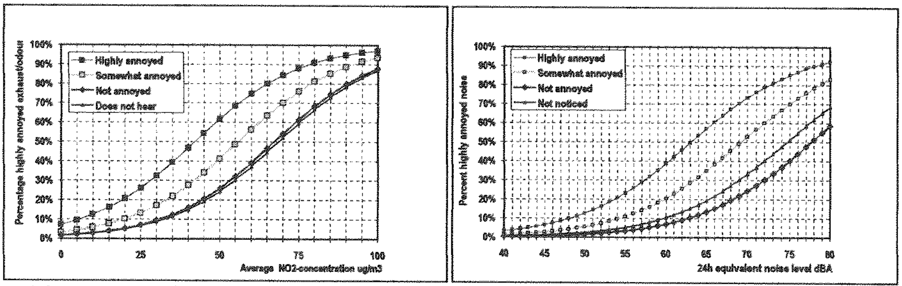

Figure 2: People highly annoyed with exhaust/odour either in- or outside apartment by average NO_2-level outside apartment. Separate curves for people differing in degree of annoyance with noise outside their apartment (left panel). People highly annoyed by noise by 24h equivalent noise levels outside apartment. Separate curves depending on annoyance with exhaust/odour outside apartment (right panel). Environmental surveys 1987, 1994 and 1996. Pooled data. N=2990. Calculated percentages.

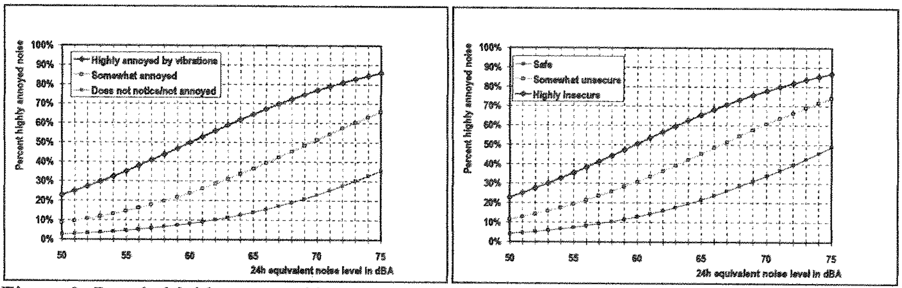

Figure 3: People highly annoyed by noise by 24h equivalent noise levels outside apartment. Separate curves depending on annoyance with vibrations. Environmental survey in 1996. N=1049 (left panel). People highly annoyed by noise by 24h equivalent noise levels outside apartment. Separate curves depending on insecurity in traffic. Environmental surveys 1987, 1994 and 1996. N=2990 (right panel) Calculated percentages.

A multivariate analysis show that annoyance with noise is significantly and substantially dependent on NO_2-pollution levels in addition to the 24h equivalent noise level (controlling for gender, marital status, age group, education level, small children). This indicates that the shifting of exposure-annoyance curves is the indirect result of a higher environmental load. We lack objective vibration measures. Feelings of insecurity correlates highest with traffic volume in nearby streets. There is a sex/age difference in that elderly women more often label themselves highly insecure. More often they also report problems negotiating traffic. In urban situations with a combination of environmental effects we can thus have crossovers with respect to vulnerability. People declaring themselves as noise sensitive are not only more annoyed with noise but also with air-pollution. People having allergies are more highly annoyed with noise.

The implication of exposure effect curves being significantly and substantially shifted by the presence of other pollutants is far reaching as it means that exposure effect curves linking noise levels and noise annoyance will be dependent on air pollution levels and the level of other environmental effects. On an imprecise level this was the observation in the Norwegian Traffic and the Environment programme [5,12] leading to this research.

4. IMPLICATIONS FOR ENVIRONMENTAL GUIDELINES

Environmental guidelines and criteria should ideally be based on a measure of total environmental load. Lacking such a measure the level of other pollutants should be measured and controlled for in studies used for establishing environmental guidelines.

When applying environmental criteria or guidelines limits should be made stricter in areas with several known environmental effects, and priority should be given to efforts in such areas. A GIS-system with different noise and air-pollution contours can be a convenient tool to better be able to capture the different types of coverages/overlaps.

Efforts should target not only noise, but be a package also targeting other environmental effects. This entails co-operative efforts between different authorities.

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THE MUNICH AIRPORT NOISE STUDY - EFFECTS OF CHRONIC AIRCRAFT NOISE ON CHILDREN'S COGNITION AND HEALTH

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1. INTRODUCTION

The shutdown of the former Munich International Airport in May 1992 and the inauguration of the current one at the same time have provided an unprecedented opportunity to investigate in a longitudinal, prospective design the psycho-physiological, perceptual cognitive, motivational, and quality of life effects of noise exposure on children. The broad, long-term objective of this research program is to understand how chronic environmental stress from aircraft noise affects children.

Beginning in the fall of 1991, before the change over of airports, children at both sites were recruited into experimental and control groups. The two experimental groups were comprised of the children at the old airport that were exposed to high levels of aircraft noise, and the children who were to be so exposed at the new airport. The two control groups, one for the former airport and one for the new one, were selected from areas that were not or would not be exposed to much aircraft noise. The control groups were matched with their respective experimental groups on the basis of sociodemographic characteristics. One wave of data collection occurred prior to the change over of airports, the second wave one year later, and the third wave two years later. The children were aged 9-12 years when the study started. Three hundred twenty-seven children took part in all three measurement waves. At each wave they were tested individually for 1.5 hr on two consecutive day in a specially designed air-conditioned and sound-attenuated trailer. The trailer has four closed booths that accommodate a child and an experimenter.

The children were assessed on psycho-physiological, perceptual, cognitive, motivational and quality-of-life measures. Results from the first measurement wave at the old airport have been reported elsewhere [1]. Blood pressure and neuroendocrinal data for the three measurement waves at new airport have also been reported elsewhere [2]. In the present paper longitudinal results from cognitive measures will be presented and compared to health indicators.

2. RATIONALE AND METHOD

Prior research has uncovered associations between chronic noise exposure and reading deficits, but those studies have been cross-sectional and have not assessed reading ability under quiet testing conditions [cf. 2, 3]. Testing under quiet conditions is important in order to disentangle chronic from acute noise effects. The present study did that. To further study and corroborate previous findings (see [3] for a critical review) different aspects of noise effects on children's cognition and their interactions several different kinds of cognitive tests were employed.

At yearly intervals one time before and two times after the relocation of airports in Munich 1992, 327 children were assessed on psychophysiological, perceptual, cognitive, motivational and quality-of-life measures. At both airports children who were or would be exposed to high levels of aircraft noise were sociodemographically matched with groups with low levels of aircraft noise.

Simple reaction time was performed both in silence and in aircraft noise. Running memory was assessed by presenting consonants at a rate of one per second. Randomly the sequence was stopped and the child asked to recall the consonants in order.

In an embedded figures task the children searched for any one of five targets contained within complex line drawings.

A long-term recall test was mapped on a previous classroom experiment [4] which reported impairments of one week long-term recall in children exposed to 15 min. acute aircraft and road traffic noise. The children read a text in noise on the first day and were tested on the next day.

A standardized German reading and word list test was employed [5]. The children first read paragraphs and word lists aloud. Paragraphs and word lists were presented in order of increasing difficulty. Speed and different types of errors were scored.

The aftereffect test was mapped on the work of Glass and Singer [6]. The children were given unsolvable puzzles consisting of geometric lines, with the instruction to travel from one destination to another without lifting the pen or tracing any line twice.

The psychological health of children was investigated with a standardized quality of life scale as well as with a motivational measure derived from the Glass and Singer stress aftereffects paradigm. In addition a self report noise annoyance scale was used.

Twelve hour overnight urinary levels of epinephrine, norepinephrine and cortisol were assessed. Blood pressure was taken several times both while resting and working on the different tasks in the trailer.

3. RESULTS

A questionnaire with various questions about sociodemographic characteristics indicated that the matching between groups within airports was successful.

Our own, preliminary noise-measurements with a Brüel & Kjær Community noise level analyzer for a very limited number of 24 hr periods during data collection did not show much of a change in dBA Leq-levels in the old airport control group from before to after the closing down of the airport (59 to 60 dBA Leq). In the experimental group at the old airport there was a drop in levels (68 to 58 dBA Leq). At the new airport both groups increased their noise levels from before to after the new airport opened (experimental group: 53 to 65 dBA Leq, control group: 53 to 62 dBA Leq).

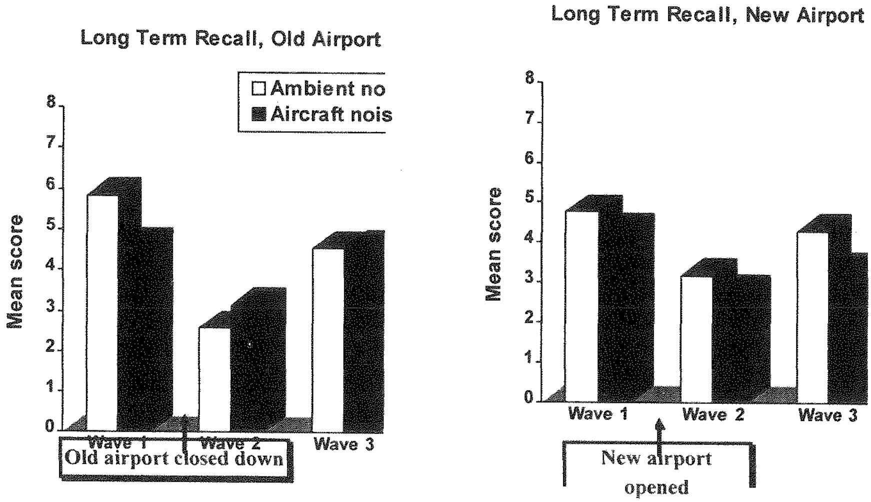


Figure 1. Mean scores on the long-term recall test

On the long-term recall task (see Figure 1), there was a significant interaction Airport x Groups x Wave ($F(1.9, 595) = 5.03, p < .01$, Greenhouse-Geisser). Separate t-tests showed a significant difference between groups at the old airport at wave #1 ($t(104) = 1.88, p < .05$ one-tailed), but not in waves #2 and #3. At the new airport there was a significant difference only at wave #3, $t(208) = 2.72, p < .01$.

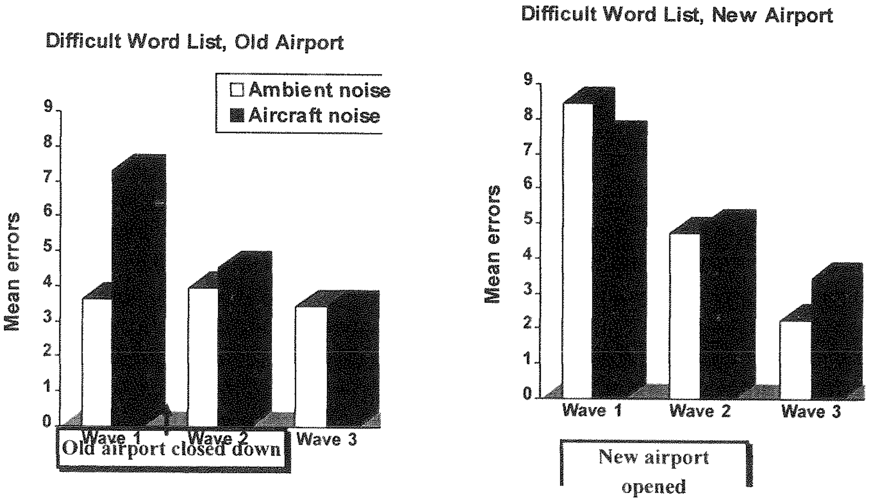


Figure 2. Mean scores on the difficult word list

On the vocabulary component of the reading test the difficult word list showed differences between the groups. See Figure 2! The interaction Airport x Groups x Wave was significant ($F(1.9, 476) = 6.37$, $p < .002$, Greenhouse-Geisser). At the old airport (see Figure. 2) there was a difference between groups at wave #1 ($t(99) = 2.68$, $p < .01$), but not at waves #2 and #3. At the new airport (see Figure 3) the difference between groups was significant at wave #3 ($t(154) = 1.80$, $p < .05$ one-tailed).

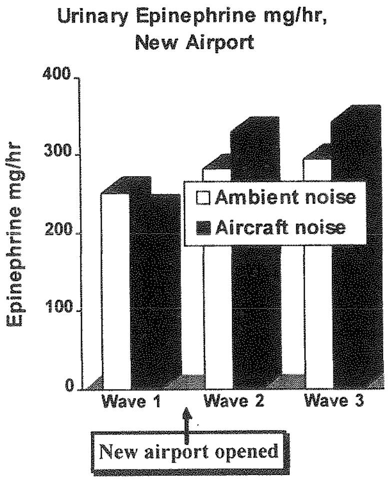
The results for the prose component of the reading test were similar to those for the word list test, but not as marked. That is, with increasing difficulty of the list, there was a trend that for the difficult passages, the chronically aircraft noise exposed children performed worse. This difference generally increased across waves at the new airport and decreased at the old airport.

There were no significant noise effects on reaction time. For the running memory task there was a noise effect with across time, $F(2, 103) = 5.97$, $p < .01$, meaning a relative improvement in the aircraft noise group. That is, running memory became better when the airport closed down. For the embedded figures task there were no consistent noise effects, and there were no noise effects for the reaction time task.

At the new airport urinary neuroendocrine levels and resting blood-pressure were significantly elevated after the new airport was taken into operation. See Figures 3 and 4!, Fs$(2, 214) > 22$, ps $< .001$. For the resting blood pressure the pattern of effects was similar to that of neuroendocrines, but not as pronounced Fs$(2, 214) > 2.8$, ps $< .06$

At the old airport, before the close down, there were increased urinary neuro-endocrine levels for the aircraft noise exposed group compared to their quiet controls (ts > 2.89, ps $> .05$), but no difference in blood pressure. Neuroendocrines and blood pressure for measurement waves #2 and #3 at the old airport has not yet been analyzed.

New airport opened



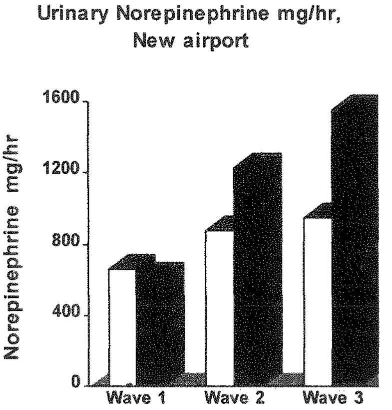


Figure 3. Mean overnight epinephrine and norepinephrine levels at the new airport

The self reported annoyance at the new airport (see Table 1) increased from wave #1 in comparison to the control group $F(2, 201) = 39.75$, $p < .001$, following the opening of the airport. Similarly, with the close down of the old airport, children from the formerly noisy environment (Old-Noise) dropped from a high annoyance score at wave #1 to a lower score at wave #3, $F(2, 201) = 125.57$, $p < .001$.

Quality of life declined significantly in the noise impacted communities 18 months after the opening of the new airport, but remained relatively stable in the quiet comparison group, $F(2, 202) = 3.07$, $p < .05$. At the old airport there were no significant changes in quality of life measures.

The motivational data showed that children from the new noisy community (New-Noise) made fewer attempts at solving the insoluble puzzle then the controls (New-Quiet). At the third measurement wave, eighteen month after the airport move this interaction effect becomes significant, $F(2, 202)=3.64$, $p < .05$ (see Table 1). At the old airport before the close down, aircraft noise exposed children persisted less than their controls on the puzzle, $t(130) = 2.35$, $p < .02$.

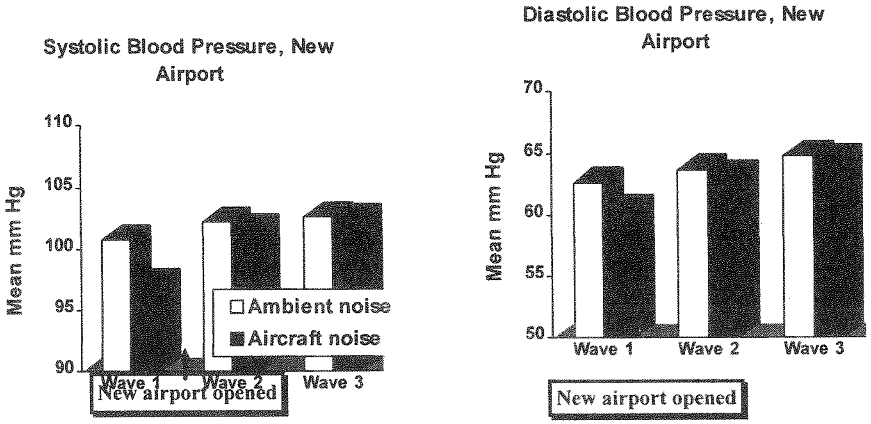


Figure 4. Systolic and diastolic blood pressure at the new airport

	Annoyance/Wave			Attempts/Wave		
Community	1	2	3	1	2	3
New-Noise	3.6 (2.5)	5.9 (2.6)	5.6 (2.5)	5.7 (2.9)	7.3 (5.4)	6.3 (4.1)
New-Quiet	3.8 (2.5)	2.7 (2.4)	2.2 (2.1)	5.8 (3.2)	7.2 (4.7)	7.9 (4.0)
Old-Noise	7.4 (1.9)	0.5 (1.2)	0.3 (0.9)	5.4 (2.5)	7.4 (4.4)	6.8 (5.2)
Old-Quiet	1.7 (1.9)	1.0 (1.4)	0.8 (0.9)	6.5 (3.3)	8.8 (5.6)	7.9 (5.6)

Table 1. Reported annoyance from aircraft, and number of attempts at the insoluble puzzles, means and (standard deviations) for waves #1 to #3.

4. DISCUSSION

Tasks relying on central cognitive processing, including language mastery, reading and memory, are more vulnerable to chronic aircraft noise exposure than tasks involving less of central processing.

At the new airport urinary neuroendocrine levels and resting blood-pressure were elevated after the new airport was taken into operation. Motivation and self reported quality of life also was impaired by aircraft noise. At the old airport before it was taken out of operation, epinephrine and norepinephrine were elevated in children chronically exposed to aircraft noise.

Thus, the effects of chronic aircraft noise on cognition were partly paralleled by effects on motivation, self reported quality of life and physiological stress and health indicators.

The effects of chronic aircraft noise on cognition is reversible, at least for the age span (9-12 years) studied. When chronic aircraft noise is introduced, it takes 1-2 years for impairments to develop. When the chronic aircraft noise exposure ceases, the relative impairments wane off within the same time period.

A general conclusion is then that for cognitive tasks requiring central processing, such as memory and reading, there are deficits for children chronically exposed to aircraft noise. Some of the other cognitive tasks did not show any effects of noise. A simple explanation to this is that they were not difficult enough to be affected by the noise.

The interdependency between different subsets of response systems in the Munich study, in terms of mediators and moderators has not yet been analyzed, but such work is in progress.

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Cross-sectional relationship between blood pressure of school children and aircraft noise

by

Stephen Morrell, Richard Taylor, Norman Carter, Soames Job & Peter Peploe

Introduction

A cross-sectional study of school children near Los Angeles Airport found mean diastolic and systolic blood pressures to be ≈ 3 mmHg higher in children attending schools heavily exposed to domestic aircraft noise compared to children from quieter schools.[1] While the comparison schools in the LA study were socio-economically similar, 32% of children in the high noise schools were African Americans, compared to 18% in the low-noise schools. In the USA African Americans have higher mean blood pressure than Caucasians,[2] so to some extent the finding of the Cohen et al study may have been confounded by ethnicity.

The present study is a replication of the Cohen et al study, using accurate school and home aircraft noise measurements,[3] with allowance for potentially confounding influences on blood pressure such as body size, child activity levels, use of salt on food, a family history of high blood pressure, whether the child ate breakfast before school, ambient temperature, and the possible influence of non-aircraft noise sources.

Methods

Data

A sample of children (n=1230), from Year 3 of a random sample of primary schools within a 20km radius of Sydney Airport, was examined during 3-11-94 to 5-6-95. Blood pressure, anthropometric, demographic and other variables were measured and collected. Blood pressure readings were taken with a Dynamap Vital Signs Monitor 8100 automated BP machine, accurate to ±2 mmHg. The average of each child's second and third systolic and diastolic blood pressure readings were used as the outcome measures.

A Harpenden Skinfold caliper was used to measure skinfold thicknesses of biceps and triceps of the left arm, and the right subscapular area, as measures of adiposity. Children's heights were recorded using a Harpenden pocket stadiometer and bodyweight was measured with a Tanita System 502 digital bathroom scale, accurate to ±100g.

A self-administered parental questionnaire were used to collect information on child activity levels and diet, family history of high blood pressure, and the location and type of residential structure. Most items covered in the questionnaires were derived from standard instruments including the Census (Australian Bureau of Statistics) and National Health Survey (also ABS). Other data items collected included type and structure of domestic accommodation and activity measures of the surveyed child (participation in organised sport, activity during school recess/lunch and the parent's rating of their child's activity level).

The response rate for the study was ≈ 80% of schools approached and ≈ 40% of children in Year 3 from the participating schools. These response rates are considered adequate as the outcome measure of the study, blood pressure, is a physical measurement.

Aircraft noise exposure data, obtained from noise measurements conducted and processed by the National Acoustic Laboratories (NAL), were geocoded to individual school and residential addresses of the study participants. Monthly energy-averaged noise levels, accurate to single ANEI (Australian Noise Energy Index) units, were assigned to each survey participant. These ranged from 15 to 45 ANEI covering the period of blood pressure measurements (November 1994 -- May-June 1995). Because aircraft noise measurements become increasingly inaccurate at lower magnitudes, noise levels below 15 ANEI were not processed by NAL. For the purposes of this study any school or residence outside the 15 ANEI contour was set to zero. A single school and residential noise level, coinciding with the mean level for the month that the blood pressure of each individual was measured, was used in subsequent analyses.

An ordinal scale (1 to 6) of road and rail traffic noise exposure was used to assign to each residential and school address levels of noise from these sources. Road traffic noise exposure levels were derived from street directory colour coding of streets according to traffic use, and an exposure rail noise assigned if the street of residence or school was immediately adjacent to a railway. Other noise sources (eg, industrial noise) were not measured or assessed.

Analysis

Allowance for the effect of cluster sampling (the so-called 'design effect' ≡ 'DEFF'), since schools rather than individuals were the primary sampling unit. Consequently, levels of statistical significance (p-values) are inflated to compensate for the design effect.

The following design effect formula was used:

$DEFF = 1 + (* - 1)*r_i$, where $*$ = average cluster size, and r_i = intra-cluster correlation coefficient.

Design effects based on the final sample of measured children were found to be 1.74 for systolic blood pressure, and 3.08 for diastolic blood pressure. Consequently, a statistical significance level of $p \leq 0.05$ would be equivalent to $p \leq 0.029$ for systolic blood pressure and $p \leq 0.016$ for diastolic blood pressure after taking the effects of cluster sampling into account.

Multiple linear regression was used to determine simultaneously the magnitude and statistical significance of the effect of aircraft noise and other potentially confounding variables on blood pressure. Systolic and diastolic blood pressure (the mean of the second and third measurements) were the main outcome (dependent) variables used in the regression models. Exposure to aircraft noise at home was also assessed with respect to these outcome variables. The effect of the change in noise exposure due to the opening of the new runway and the elapsed time from when the new runway became operational and when the child was measured were also assessed. The change in noise exposure was taken as the difference between the average noise level for the month of each child's blood pressure measurement and the average noise level in the month prior to the opening of the new runway (October 1994).

Results

From Table 1 below, aircraft noise or other noise sources were not statistically significantly linked either to systolic or diastolic blood pressure. Factors found to be significant were weight, pulse rate, not eating before school (systolic BP only), using salt on food (diastolic BP only), being from a non-English speaking background (systolic BP only), and whether the child's residence was insulated (systolic BP only). The regression models using cross-sectional differences in aircraft noise exposure accounted for 28% and 14% of the variance in systolic and diastolic blood pressures respectively.

Table 1. Regression models of systolic and diastolic blood pressure and school aircraft noise level (ANEI), with control for factors confounding blood pressure and aircraft noise relationship

Factor		Systolic BP		Diastolic BP	
		Estimate (mm Hg)	p-value	Estimate (mm Hg)	p-value
	Intercept	69.732	0.0001*	32.022	0.0001*
Noise	School aircraft noise level	-0.017	0.5890	-0.043	0.1592
Sources	Resident aircraft noise level	-0.010	0.7660	0.010	0.7380
	Road/rail noise sources	0.267	0.4829	0.582	0.1005
Sex	Female	0.183	0.7208	-0.830	0.0827
Body size	Weight	0.521	0.0001*	0.208	0.0001*
	Subscapular skinfold	-0.069	0.2255	-0.054	0.3096
	Pulse rate	0.263	0.0001*	0.212	0.0001*
Eating	Not eat before school	2.963	0.0276*	2.744	0.0281
Behaviours	Salt on food	0.112	0.8313	1.369	0.0055*
Family	Parental history of high BP	1.092	0.1514	0.182	0.7963
Back-	Family history of high BP	0.569	0.3095	0.446	0.3911
ground	Child history of high BP	2.697	0.3650	0.551	0.8420
	Non-English speaking background	1.499	0.0087*	1.066	0.0446
Child	Organised sport	-0.156	0.7699	-0.312	0.5313
Activity	Child less active	-0.260	0.7972	-1.219	0.1950
	Play actively during recess	-0.097	0.8852	-0.782	0.2106
House type	Glass doors	-0.553	0.2845	-0.649	0.1767
and	Insulated	-2.199	0.0002*	-0.778	0.1533
structure	Top floor occupancy	0.096	0.8872	-0.589	0.3532
	Large windows	-0.325	0.5747	-1.061	0.0490
	Timber/fibro house	-0.920	0.2105	-0.756	0.2679
	Ambient temperature	0.098	0.1639	0.147	0.0246
		Adj. $R^2 = 0.275$		Adj. $R^2 = 0.136$	
		* $p \leq 0.028$		* $p \leq 0.016$	

Table 2. Regression models of systolic and diastolic blood pressure and *change* in school aircraft noise level (ANEI), with control for factors confounding blood pressure and aircraft noise relationship

Factor		Systolic BP		Diastolic BP	
		Estimate (mm Hg)	p-value	Estimate (mm Hg)	p-value
	Intercept	71.284	0.0001	34.325	0.0001
Noise	Change in school aircraft noise level	-0.042	0.1488	-0.019	0.4741
Sources	Change in resident aircraft noise level	-0.019	0.5686	-0.042	0.1744
	Road/rail noise sources	0.109	0.7752	0.401	0.2594
	Elapsed time since change	-0.007	0.0363	-0.011	0.0017*
Sex	Female	0.177	0.7290	-0.871	0.0670

Body size	Weight	0.539	0.0001*	0.225	0.0001*
	Subscapular skinfold	-0.095	0.1008	-0.078	0.1504
	Pulse rate	0.264	0.0001*	0.214	0.0001*
Eating Behav.	Not eat before school	2.899	0.0305	2.672	0.0316
	Salt on food	0.065	0.9023	1.297	0.0084*
Family back-ground	Parental history of high BP	1.110	0.1440	0.212	0.7640
	Family history of high BP	0.580	0.2986	0.463	0.3714
	Child history of high BP	2.730	0.3576	0.840	0.7604
	Non-English speaking background	1.523	0.0074*	1.113	0.0349
Child Activity	Organised sport	-0.021	0.9681	-0.164	0.7417
	Child less active	-0.245	0.8081	-1.173	0.2103
	Play actively during recess	-0.258	0.7001	-0.918	0.1411
House type and structure	Glass doors	-0.494	0.3386	-0.599	0.2110
	Insulated	-1.913	0.0013*	-0.410	0.4575
	Top floor occupancy	0.115	0.8655	-0.523	0.4085
	Large windows	-0.140	0.8090	-0.835	0.1215
	Timber/fibro house	-0.835	0.2549	-0.624	0.3591
	Ambient temperature	0.035	0.6275	0.057	0.4016
		Adj. $R^2 = 0.280$		Adj. $R^2 = 0.145$	
		* $p \leq 0.028$		* $p \leq 0.016$	

Table 2 above shows the effects of the previous *change* in aircraft noise exposure, and the elapsed time from the beginning of operations of the new parallel runway to the day of blood pressure measurement. The effect of change in aircraft noise level was not significantly linked to systolic or diastolic blood pressure. The elapsed time interval was found to be significantly and negatively related to diastolic blood pressure, but not to systolic blood pressure. Other factors significantly associated with blood pressure included weight, pulse rate, not eating before school (systolic BP only), using salt on food (diastolic BP only), being from a non-English speaking background (systolic BP only), and whether the child's residence was insulated (systolic BP only). The regression models of the effect of previous change in aircraft noise accounted for 28% and 15% of the variance in systolic and diastolic BP respectively, slightly more than the models using cross-sectional differences in aircraft noise exposure.

Discussion

Blood pressure normally is highly variable, both between and within individuals, as partially indicated by the low explanatory power of the regression models above. These models accounted for no more than about 28% and 14-15% of variance in systolic and diastolic blood pressures respectively. Some of this variability was minimised by using the mean of the second and third blood pressure readings as dependent variables in the regression models. Clearly from the above, cross-sectional differences in aircraft noise exposure or changes in exposure account for little child blood pressure variability. The only factor associated with aircraft noise found to be statistically significantly linked to (diastolic) blood pressure was the elapsed time since the opening of the new runway. The effect was negative (ie, the parameter estimate was less than zero) and is consistent with the hypothesis that blood pressure responses to changes in aircraft noise levels are reversible over time.

The above findings indicate, at best, a suspicion of an aircraft noise effect on childhood blood pressure. This can only be confirmed or disproved with a longitudinal follow up of the same individuals. Data for this follow-up phase of the study has been collected and are currently under analysis.

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GENERAL HEALTH QUESTIONNAIRE SURVEY AROUND KADENA U.S. AIRFIIELD IN THE RYUKYUS — AN ANALYSIS OF THE DISCRIMINANT SCORE AND THE FACTOR SCORE —

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1. INTRODUCTION

This is the report of the analysis of the factor score and discriminant function value calculated from the result of THI(Todai Health Index) survey on general health of residents living around Kadena airfield reported by T. Miyakita *et al.*[1] in this conference.

2. MATERIALS AND METHODS

The material and the methods of the survey are described by Miyakita *et al.*[1] except the number of the valid answers available for the analysis in this report to be 3,988 in the noise-exposed group and 760 in the control group.

Principal factor analysis was applied and then Oblimin rotation was carried out using the 12 scale scores obtained in the analysis reported by Miyakita *et al.*[1] The discriminant function (DF) value is calculated by the discriminant function equation given by Suzuki *et al.*[2]

The dichotomous variables converted from the discriminant function(DF) values and the factor scores were applied as the dependent variables in the logistic regression analysis with the independent variables of age, sex and their interaction. The conversion of the variables was done with the threshold of null of the DF value. The factor scores of 80 and 90 percentiles of the control are taken as the thresholds in the conversion of the variables of factor scores.

3. RESULTS

3.1. Analysis of DF values

In Figure 1 is shown the result of the analysis of the DF values of psychosomatics, where the odds ratio is plotted as a function of the level of noise exposure expressed by WECPNL. The vertical bars indicate 95 % confidence limits of the odds ratio and asterisks show that the ratio is significant. The clear dose-response relationship is found and the tendency of increase is statistically significant. In the figure p_t shows the significance probability of trend test in which linear dose-response relationships are assumed between WECPNL and logarithmic values of odds ratio. The odds ratio of the area of WECPNL over 95 is over 2.0. The result of the analysis of DF value of neurotics is shown in Figure 2, which also indicates that the odds ratio is significantly high in the area of WECPNL 95.

3.2. Analysis of factor scores

Table 1 is the factor pattern matrix of two factors extracted by the factor analysis. The factor showing close relation with somatic symptoms is named as somatic factor and the other related with mental symptoms as mental factor.

The factor scores of the 80 and 90 percentiles of the subjects in the control group were used as the thresholds to carry out the logistic regression analysis.

Figures 3 and 4 show the odds ratios of somatic factor and mental factors plotted as a function of WECPNL, respectively. Clear dose-response relationship is found in Figure 3 where the odds ratio starts increasing from comparatively lower level of WECPNL of 75. Although in the case of mental factor the dose-response relationship shown in Figure 4 is not as clear as in the case of somatic factor, higher odds ratio is observed in the high noise exposed area. Odds ratios are over 2.0 in the area where WECPNL is over 95.

Table 1. Factor pattern matrix

Scale	Somatic factor	Mental factor
SUSY	0.871*	0.034
RESP	0.730*	−0.066
EYSK	0.700*	−0.001
MOUT	0.587*	0.072
DIGE	0.689*	−0.003
IMPU	0.003	0.718*
LISC	0.084	−0.601*
MENT	−0.018	0.908*
DEPR	0.178	0.655*
AGGR	−0.144	−0.384
NERV	0.034	0.506*
LIFE	0.425	0.265

* : > 0.5

4. CONCLUSIONS

Response of the questionnaire survey with respect to general health carried out around Kadena US airfield is analysed by means of multiple logistic regression analysis using discriminant function values and factor scores. Results indicate that the odds ratio of DF values regarding psychosomatics and that of the score of somatic factor show clear dose-response relationship. The odds ratio of DF value of neurotics and that of the score of mental factor increase in the area where noise exposure is very intense.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Okinawa Prefectural Government for its support to carry out the study.

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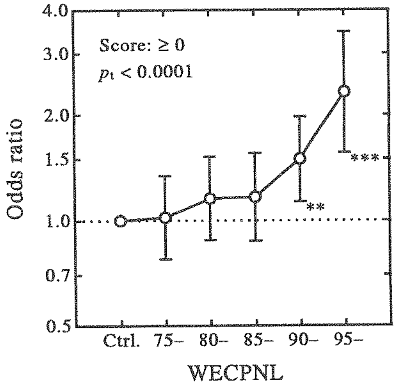

Figure 1. Odds ratio on DF values of psychosomatics.

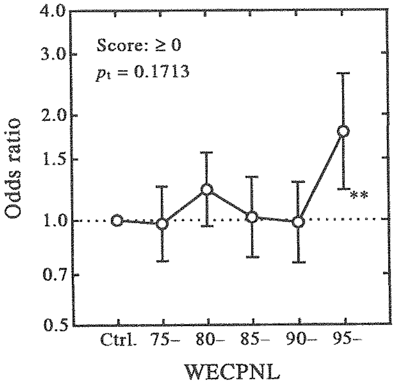

Figure 2. Odds ratio on DF values of neurotics.

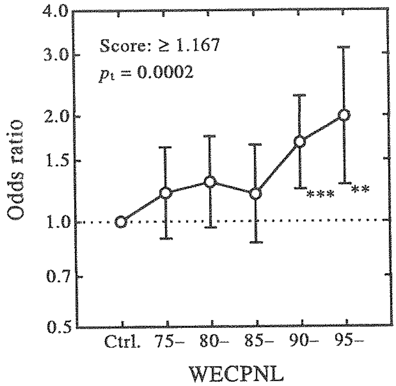

Figure 3. Odds ratio on somatic factor.

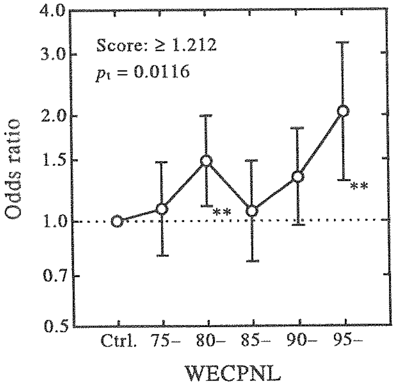

Figure 4. Odds ratio on mental factor.

HIGHER RATE OF LOW-BIRTH WEIGHT INFANTS OBSERVED IN THE VICINITY OF US AIRFIELD IN THE RYUKYUS

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1. INTRODUCTION

It was reported that the rate of low birth weight of infants was found higher in the vicinity of Osaka International Airport than the average rate of non-noise exposure area in Japan and that the aircraft noise exposure could be a factor of raising the rate[1]. Taking the high level of noise exposure around the U.S. airfields in Okinawa, particularly in the vicinity of Kadena Airbase, into account, the present authors find it worth investigating whether the higher rate of low birth weight infants are observed.

2. MATERIAL AND METHOD

Japanese government accumulates the birth records for every municipality. The birth weights of 356,549 infants included in the records having been filed up for 20 years from 1974 to 1993 in Okinawa Prefecture are used for the analysis of the areal difference in the prefecture of the rate of low birth weight infants. The odds ratio with respect to the birth rate of infants with low birth weight which is under 2,500 g was tested by means of the method of multiple logistic analysis taking the rate of non-noise exposed area in Okinawa Island (see Figures 1 and 2) as the control. The primary factors that could be related to infants' weights such as mother's age, single or multiple embryos, sex, legitimate child or not were applied as the independent variables in the logistic regression model. The information available does not include the precise address of birthplace. The statistics are only given for the unit of municipality. As a result the dose-response relationship between the odds ratio and the aircraft noise exposure cannot be obtained.

3. RESULTS OF THE ANALYSIS

The statistics concerning low birth weight infants around Kadena Airbase are tabulated in Table 1. The birth rate of infants with low birth weights in Kadena Town, which is located in the most vicinal of Kadena airfield as shown in Figures 1 and 2, was 9.1 %, while that of the other municipalities around Kadena and Futenma (Okinawa City, Ishikawa City, Gushikawa City Yomitan Village, Kitanakagusuku Village and Ginowan City) airfields was on average 7.6 %. The average rate of low birth weight in the non-noise exposed municipalities in Okinawan Island was 7.1 %.

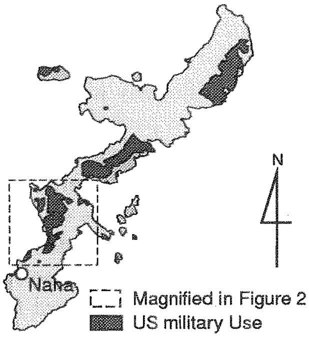

Figure 1. US military base in Okinawa Island.

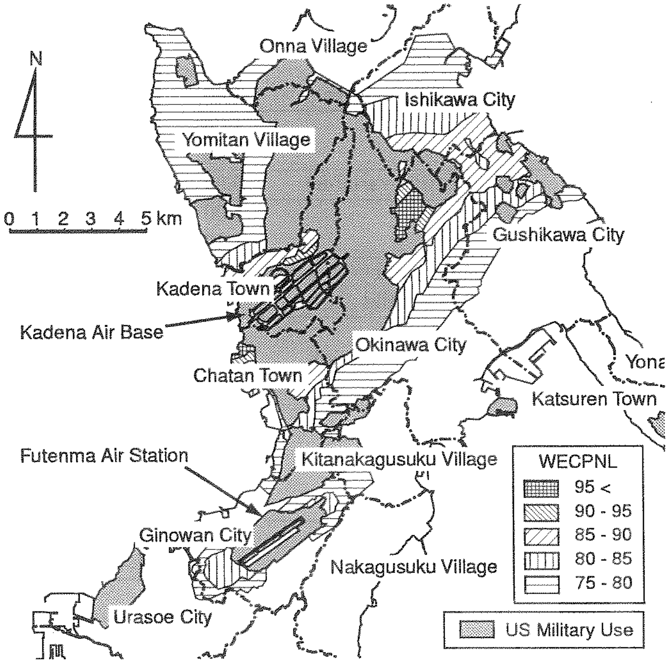

Figure 2. Kadena, Futenma airfields and surrounding municipalities. WECPNL contour is measured by Defense Facilities Administration Agency (DFAA) in 1977.

Table 1. Ratio of infants with low birth weights

Noise exposure	Number of birth	<2,500g
Kadena town	4,542	407 (9.0%)
Chatan town	6,178	465 (7.6%)
Okinawa city, etc.	98,036	7,482 (7.6%)
The others	247,793	17,673 (7.1%)

In Table 2 are shown the results of logistic analysis with regard to low birth weight. In the table 'factor' indicates independent variable. The odds ratio of Kadena Town, 1.16, is significantly higher than that of the non-noise exposed municipalities with the significance probability less than 0.001.

Though the reason why the rate of low birth weight is higher in Kadena Town is not very clear, the high level of noise exposure could be a factor raising the rate. The area of Kadena Town is small and the noise exposure is comparatively homogeneous over the town. The Defense Facilities Administration Agency (DFAA) of Japan designates the aircraft noise exposure in WECPNL from 85 to 95 in the town. Note the environmental standard for aircraft noise set by the Environment Agency is 70

Table 2. Odds ratio on low birth weights (<2,500 g)

Factor	Category	Odds ratio	95% CI	p value
Noise exposure	Kadena Town	1.16	1.07–1.26	<0.001
	Chatan Town	0.97	0.90–1.05	
	Okinawa City, etc.	0.96	0.93–1.00	
	Other municipalities	1.00		
Sex	male	1.00		
	female	1.08	1.06–1.09	<0.001
Mother's age	(quantitative variable)	0.99	0.99–1.00	<0.001
Number of embryo	1	1.00		
	≥2	4.30	4.17–4.43	<0.001
Legitimacy	legitimate child	1.00		
	illegitimate child	1.30	1.26–1.34	<0.001
Ocupation of householder	full-time farmer	1.00		
	farmer with a side job	0.96	0.90–1.04	
	self-employed	0.96	0.91–1.02	
	executive	0.86	0.82–0.90	<0.001
	worker	1.04	1.00–1.09	
	other	1.12	1.07–1.18	<0.001
	unknown	0.98	0.78–1.25	
Stillbirth	not experienced	1.00		
	experienced	1.58	1.49–1.68	<0.001
Live birth order	1	1.00		
	≥2	0.96	0.87–1.07	
Period	1974–1978	1.00		
	1979–1983	0.89	0.87–0.91	<0.001
	1984–1988	1.00	0.98–1.03	
	1989–1993	1.19	1.16–1.21	<0.001

Table 3. Ratio of infants with low birth weights

Noise exposure	Number of birth	<2,500g
Kadena Town	4,542	407 (9.0%)
Around the base without airfield	25,940	2,016 (7.8%)

in WECPNL and WECPNL is calculated by the combination of the sound level and the number of flight events.

If the aircraft noise exposure is a possible factor of the higher rate of low birth weight, why are the rates in other municipalities in the vicinity of the base not as high? Actually, noise exposure is higher than in Kadena Town in a part of Chatan Town where WECPNL is designated to be over 95. Majority of the inhabitants of the town, however, reside in less noisy area where WECPNL is designated to be from 75 to 80. As a result, the number of low birth weight infants, possibly of high rate, of highly noise exposed group is, say, diluted through the operation of averaging over the municipality. Situation of other municipalities around Kadena airfield except Kadena Town is more or less the same as that.

Another theory may be raised: the mere existence of US base might have incurred the higher rate of low birth weight. In Table 3 are shown the numbers of birth and the rates of low birth weight of Kadena Town and of the area which is near a big base in the north part of the island. The difference of the rates between the two areas tested by Chi square test is found significant. Thus the theory is rejected.

4. CONCLUSION

The authors reached a conclusion that the reason why Kadena Town shows higher rate of low birth weight infants is likely that all the residents are exposed to aircraft noise more intense than other parts of the Island. However, the possibility that some factors other than noise might exist still remains.

ACKNOWLEDGEMENTS

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MONITORING OF INFLUENCE OF ENVIRONMENTAL NOISE ON HEALTH

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Monitoring is now under way in 21 cities in the Czech Republic. It consists of the measurement of noise and a health survey made using a questionnaire, which takes as a starting point the questionnaire already used in the earlier study of the impact of noise on health in the Czech Republic, and it has been adapted to the CINDI questionnaire. In every city where monitoring is underway, there are two selected basic locations, one representing a noisy and the other a quiet location of the city. The selection of the basic noisy and quiet localities was done so that it would be possible through repeated measurement of noise to monitor the noise level of the entire location and thereby the population's the level of exposure to noise with accuracy better than 2 dB LAeq. The fulfillment of those criteria was confirmed at several places at those localities. A further selection criterion was the actual number of persons living in the monitored area. The selected locality must have at least 300 people for further quantitative evaluation. Another selection criterion was the absence of significant difficulties caused by other negative factors such as the position of the locality in an area where there are frequent atmospheric inversions or where there is strong pollution from exhaust. During the selection process, care was also taken so that the social and demographic makeup of the inhabitants would be representative in comparison with the average population of the Czech Republic.

The Measurement of Noise

The measurement of noise is made 24 hours per day, so as to record the noise level for the entire day. The needed accuracy of measurement is attained by using the finest technology (2231 Bruel & Kjaer) and by strict adherence to measurement procedures. The microphone is placed 2 meters in front of the facade of a residential building, usually at the height of a window on the first aboveground floor and at least 3 meters above the ground. The measurements are made alternatively in noisy and quiet locations exactly once per month, preferably from Wednesday until Thursday for 24 hours, beginning at 10:00 a.m. on Wednesday.

The following processing of the results of noise measurements is made by the electronic transfer of data to graphs of the results. The results achieved are presented on a poster. From the results, it is apparent that the noisiness of the individual locations is evenly spread across the entire range of possible noise levels. Determined of values in LAeq range between 76 dB during the day and 69 at night in the noisiest locations, to 45 dB during the day and 37 dB at night in the quiet locations. From the graphic results on poster, it is clear how differentiated the noise situation is in particular places, so that the same noise values are rated as quiet areas in some locations and as noisy areas in other locations. From the determined differences of noise between the last (1994-1995) and the present monitoring period (1996-1997), it is apparent that changes of noise exceeding the limits of tolerance of accuracy of measurement, i.e. 1 dB, occurred only in a few of the locations.

Health consequences and the disruptive effects of noise

Monitoring of the effects of noise on the population is made in individual locations by the use of the above-mentioned questionnaire. The indicators of the public health are selected civilization-related diseases, information about the state of mind or the incidence of neurological symptoms among the inhabitants. The questionnaire also contains questions of a demographic and sociological character, and questions concerning lifestyle. This group of questions reveals the homogeneity of the monitored population, with the goal of minimizing the situation that the effect of noise on the population could be simulated by some other so-called "interfering" factor.

For the evaluation of the effects on public health, data on nighttime noise are used because at night, most of the population remains at home and their activities are similar in that phase, and their exposure to noise is more homogeneous than during the day.

An examination of the indicators of public health by questionnaire was made during the current monitoring period in 42 locations during April 1997. 11,000 questionnaires were returned by respondents (about a 35% return from all locations), a decrease of about 4,000 from the last monitoring period. Only 9,598 questionnaires from respondents of the ages between 30 and 90 were included in the final processing, because not all of the questionnaires were filled out completely. The lower age limit for monitored inhabitants is 30, because younger persons are not expected to have remained long enough at one residence (at least 5-10 years), and it is not possible to predict the results of noise exposure at such a young age. The upper age limit was chosen in order to gain a larger number of respondents and because the younger sub-group (30 – 70) did not show any significant differences in responses related to noise. In the chosen age range of 30 – 90 years, the age makeup of the respondents at the locations did not correlate to increasing noise of the locations, just as during the last monitoring period. From the evaluation of demographic and sociological questions including the results of the statistical evaluation, it appears that there is no significant difference among the individual locations in this respect. The evaluation has been made with the aid of a coefficient of correlation and is formulated on the basis of the hypothesis of random distribution of the monitored factor in relation to noise. If one rejects this hypothesis of randomness at the appropriate level of alpha significance, for the sake of simplification one may speak of "statistical significance" or "significant correlation." The makeup of the groups according to sex did not show any significant differences between locations. Similar results were attained with respect to the question of level of education and marital status. It was merely determined that there are statistically significantly fewer men and people living alone in the central areas of large cities, as was the case during the last monitoring period. No significant differences were found in the current economic activities of the respondents, just as during the last monitoring period.

Data concerning housing in the respondents' current apartments also show no statistically significant differences, except for the share of apartments in 50 – 100 year old buildings, of which there are significantly more in noisy areas (downtown areas), just as during the last monitoring period. This factor need not be considered to be misleading because significantly worse housing conditions are not necessarily to be expected in those apartments. Likewise, it is also possible to evaluate, just as last time, a statistically significant decline in apartments with central heating in noisy localities, compensated by an increase in apartments with gas and electric heating.

The length of residence in an apartment may have a significant influence on noise exposure. Just as last time, no significant differences were found here either. In noisier locations, just as during the last monitoring period, there is a significant increase in apartments with windows facing the street. This fact is caused by a difference between construction on the periphery and in the center of cities, and could mean relatively higher exposure of respondents in relation to quieter locations. This assumption was not confirmed, because in quieter locations, there is a smaller difference between the noise on the street and on the courtyard side of buildings.

The percentage of respondents with noise complaints increases statistically significantly, with a 99% probability (alpha = 0.01), with increased noise in outdoor space, from 24% to 91%. This is practically an identical result as was attained during the last monitoring period. Similarly to the last monitoring period, it was determined that there is a statistically significant decrease of persons with problems of noise from neighbors, because noise of that type is not so dominant from a psychological standpoint, and physically tends to dissipate in outdoor noise.

Data were also gathered on the respondents' workplaces and their means of transportation to work. Just as during the last monitored period, no significant differences or facts were determined in these questions either. In contrast to the last monitoring period, no differences were even found in the number of respondents with a dangerously noisy work environment among the various locations. The facts above imply that just as during the last period, exposure to noise at work does not effect the monitored effect of noise in the housing environment of the respondents.

In the physical activities of the respondents, as during the last monitoring period, no significant differences between individual locations were found. As with the occurrence of health risk factors such as smoking, drinking black coffee and alcoholic beverages, no significant differences between locations are shown. It was found that 21% of the respondents do not drink alcohol at all. From this figure one may infer that the group of respondents willing to cooperate on health questionnaire surveys is not a completely accurate sampling of the population at large. Nonetheless, this fact need not detract from the significance of the actual evaluation of the effect of noise, because this is a comparative method of evaluation.

From the evaluation of the questions concerning the noise and neurosis, it was found that just as during the last monitoring period, as the noise statistic increases, there is a significant increase in respondents who feel disproportionately tired after work, who sleep badly (11 – 20% on the 99th percentile of probability, last time the difference was 29 – 39%), and who have problems falling asleep. These findings were expected, and they appeared repeatedly during this monitoring period. It may be said that these findings are extremely likely to have been caused by increased noise. They may thus be regarded as the effect of noise on the inhabitants. On the other hand, just as last time, no differences were found concerning the amount of time slept or the occurrence of headaches. In contrast to last time, a significant increase in neurotic symptoms (48 – 56%) was recorded, particularly of cardiac palpitations. This may be related to the worsening social situation. In accordance with these findings, there is a repeated finding of a statistically significant increase in the use of sedatives and hypnotics in noisy locations among respondents using them regularly every day. Just as during the last period, significant differences among the locations were not observed in the quality of the subjective evaluation of the hearing of the respondents.

The main indicator of public health at present is the occurrence of so-called civilization-related diseases, such as hypertension, myocardial infarctions, ventricular and duodenal ulcers, cholelithiasis et urolithiasis, diabetes mellitus, tumors and frequent upper-respiratory catarrhs. Statistically significant differences were shown at the present time for hypertension (with a 95% probability) and for frequent upper-respiratory catarrhs (with a 99% probability). The increased occurrence of upper-respiratory catarrhs may be explained by the weakened resistance of persons subjected to the effects of noise. The same is the case with repeated cases of bronchitis, where a significant increase was observed in connection with noise. A reduced level of immunity may be the cause of the significant increase in skin diseases, because laymen are not generally able to recognize the difference between allergy symptoms and the effects of infections. In contrast with last time, the significant increase in tumors in connection with noise was not confirmed, so it is necessary to state that the finding during the last monitoring period was isolated, and therefore probably coincidental. For the rest of the individual cases of , just as last time, for myocardial infarctions and for the other illnesses mentioned above, the hypothesis of random distribution was not contradicted. This means that these individual cases of illnesses are not in correlation to the level of noise. This may be due to their relatively low frequency of occurrence among the population.

The repeated increase of incidence of all of the above-mentioned civilization-related diseases, as a whole in connection with the noise level of the location, has been shown during the present monitoring period to be significant only at the 10% level of significance (i.e. with a 90% probability), in the case of the evaluation of the noise equivalent level at night. This result has been presented on a poster. The poster illustrates the results of the monitoring of the occurrence of civilization-related diseases in relation to noise during the last monitoring period, and the results are there shown in comparison with the results of the above-mentioned earlier study of the impact of noise on public health from the year 1985. This comparison shows that the impact of noise on the health of the respondents or the inhabitants was maintained because the difference between noisy and quiet areas was maintained and the resultant curves are virtually parallel. On this graph it is, however, apparent that in the course of the year the number of cases of so-called civilization-related diseases has increased. This can be attributed to improved medical care and the availability of better medication and treatment methods, thus leading to the longer life expectancy of the inhabitants who are now shown as ill, and who would not have been in the survey earlier because they would have already been dead. This finding may also be caused by the fact that by the age at which these illnesses begin to appear to a greater extent, we are coming across age groups which spent their youth under the unfavorable economic and social conditions of the years during and after the war. The results shown serve as a basis for the construction of a model, which can be used to help make estimates of the relative risk to public health posed by noise. We refer to it as a risk assessment.

Risk assessment – evaluation of the health effects in adjacent localities

At selected basic localities, which are relatively small and where relatively few people live, in comparison with the total number of inhabitants in the monitored places, any changes to the traffic situation of the area or of another territorial unit would not have to be measurable at all. For this reason, so-called adjacent areas were selected for the evaluation of the disruptive effects of noise. In those adjacent localities, it is not possible for reasons of capacity to carry out a full 24-hour measurement of noise, so an approximating method was used. This method is based on making daily measurements and estimating the nighttime noise level on the basis of the determined difference between daytime and nighttime noise levels in the corresponding basic localities. The determination is made using a special algorithm containing the relation between noise and the sum of the monitored illnesses or indicators of state of health , which were determined during the last monitoring period. With the help of the above-mentioned approximating method, it is possible in those more extensive localities over a larger territory, if understandably with a lower degree of accuracy, to estimate the level of relative risk to health caused by noise, i.e. to make a noise risk assessment.

In adjacent areas, have now been identified 75,188 inhabitants according to voting lists. The estimated relative risk of harm caused by noise of a total of the population of the Czech Republic has been 4.9% determined.

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NOISE AS A RISK FACTOR FOR MYOCARDIAL INFARCTION: DESIGN OF A NEW CASE-CONTROL STUDY

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1. INTRODUCTION

On the basis of current knowledge, there is suggestive evidence in favour of the hypothesis that noise may increase the risk of cardiovascular disease including acute myocardial infarction and sudden cardiac death [1-4]. To date, however, there is no definite proof of this relationship. We, therefore, designed a case-control study to investigate the relationship between exposure to noise and the risk of acute myocardial infarction. The present study is based on the results of a prior case-control study, which showed a tendential increase of the risk of myocardial infarction in persons exposed to traffic noise with day time mean levels above 70 dB (A) [4]. With increasing subjectively scaled work noise, the relative risk of myocardial infarction adjusted for control variables (smoking, age, social status) was found to increase significantly and steadily. Possible bias due to overreporting of subjective noise exposure could not be excluded in the previous study[1]. Thorough epidemiological investigations are needed to confirm or reject the hypothesis of relevant chronic adverse extraauricular health effects of chronic noise exposure, in particular myocardial infarction.

2. METHODS

The following questions are being studied: Is exposure to noise which is being measured objectively as the sound pressure level and subjectively by questionnaire (both at home and at the workplace) a risk factor for myocardial infarction (MI)? Is subjective noise sensitivity related to the risk of MI? Is there a dose response relationship between noise exposure and risk of MI?

To answer these questions, a case-control study of myocardial infarction (MI) and noise exposure is being carried out. Cases are defined as consecutive incident cases of MI below the age of 70 years in 30 major hospitals in Berlin. Included are subjects who have been residents of Berlin for at least 5 years and who are of German nationality and therefore understand the language of the questionnaire. In addition to cases of acute MI, subjects with cardiac arrest due to ventricular fibrillation after successful resuscitation have also been included. Patients after accidents, from the same hospitals as the cases, are being recruited as controls. They are matched to the cases for age and sex. In men, 1 control is selected per case. Two controls per case are chosen for women to increase the statistical power of the analysis, given that a smaller number of female cases is to be expected. A sample size calculation has shown that1200 incident cases of MI and 1200 controls are needed to demonstrate an overall risk ratio of at least 1.2 with 80 % power. Both cases and controls are interviewed (duration: approximately 1 hour) according to a standardized computerized protocol to determine environmental and occupational exposure to noise, as well as relevant confounders, like noise sensitivity, social status, job stress, and family history of heart disease. Informed consent of the patients has to be assured before the interview. The interview comprises the following sections: noise exposure at home, noise exposure at work, noise sensitivity (Weinstein questionnaire), social status, job stress, and known medical risk factors. The sections on noise sensitivity and job stress use validated instruments that have been used in investigations published in international journals [4-6]. The German language versions of these instruments have also been validated [6]. The average noise exposure at the patient's home address is determined from a computerized noise map compiled by the city administration of Berlin. It provides mean noise levels in dB (A). From those values defined amounts will be subtracted for specified types of windows and position of the rooms of the patient's apartment. If the subjects lived in more than one apartment during the last five years, the exposure in different apartments is weighted according to the duration of stay.

Several measurements are taken to validate the information collected by questionnaires: To test the reliability of the questionnaire, the interviews of 20 subjects will be repeated after approximately 4 weeks. To validate the exposure information obtained from the interview, objective measurements of noise exposure are being carried out in the homes and workplaces of a subset of the study subjects. The first consecutive 100 patients are asked to participate in an examination by audiometry to estimate the frequency of hearing loss in the study population.

In addition to the computerized interview, a questionnaire has to be completed by the interviewer regarding machines the patient had worked with, or that caused noise in the patient's workplace. This information will be converted to estimates of noise exposure by engineers specialized in noise assessment. This procedure is based on lists of machines that indicate their average noise levels. To validate this information, the assessment will be undertaken independently by two experts, and will be compared with the information elicited from the patient during the interview

The data are stored in an ACCESS database. The statistical analysis will be carried out with the SAS statistical package. Several checks for completeness and plausibility, as well as descriptive statistical analyses will be performed. For statistical analysis, we will calculate odds ratios, stratified for age and sex, and possible confounders. In addition, conditional logistic regression analyses will estimate odds ratios adjusted for age, sex, social status, noise sensitivity, job stress, and known medical risk factors. In alternative analyses, exposure will be treated as a continuous or a dichotomized variable. In particular, statistical analyses will consider whether there is an increased risk of MI due to noise sensitivity, independent of objective noise exposure, and vice versa [7, 8]. The study has been approved by the ethics committee of the Charité University Hospital.

3. DISCUSSION

The ongoing case-control study in Berlin has sufficient sample size and takes noise sensitivity, social status, job stress, and family history of heart disease into account as confounders. Therefore, this study is expected to definitely confirm or reject the hypothesis of a relevant increase in risk of myocardial infarction due to chronic environmental and occupational exposure to noise.

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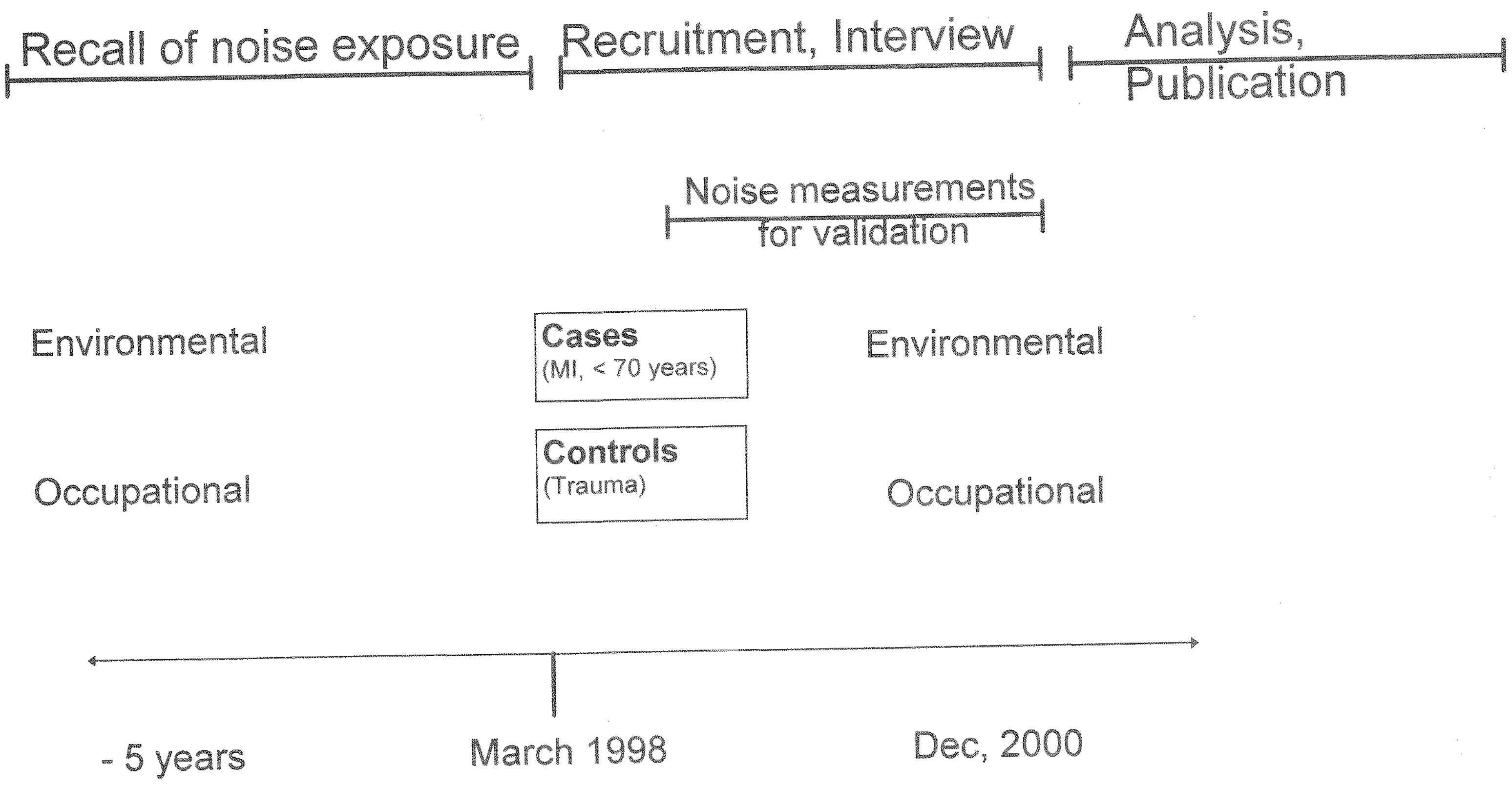
Study Protocol



Recall of noise exposure

Recruitment, Interview

Analysis,
Publication

Noise measurements
for validation

Environmental

Occupational

Cases
(MI, < 70 years)

Controls
(Trauma)

Environmental

Occupational

- 5 years

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SKULL VIBRATION IN THE PRESENCE OF WATERBORNE LOW FREQUENCY SOUND

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1. BACKGROUND

Waterborne Low Frequency Sound (WLFS) is being increasingly used for submarine detection by military surface vessels. Low frequency sound offers advantages over more conventional higher frequency sonar for detection at long ranges. The long distances that WLFS travels and a shift toward use in coastal waters increase the likelihood of unplanned diver exposure. One unplanned exposure and two experimental exposures have resulted in transient neurological symptoms. No confirmed mechanism exists to account for these occurrences. We hypothesize that WLFS induced skull vibration is the mechanism of injury. This work measures the vibration pattern of the human skull in response to WLFS in the frequency region from 50-1250 Hz.

Interest began in 1993 when a US Navy diver was inadvertently exposed to high level WLFS and experienced short term symptoms suggestive of vestibular insult.[1] Preliminary experimental work totaling 243 exposures (59 subjects) resulted in two further episodes.[2] One diver reported light-headedness, dizziness, lethargy, vibration in the extremities and blurring of vision approximately 10 minutes into a planned 15 minute exposure (240 ± 80 Hz warble tone at 160 dB SPL re 1 μPa). He also reported a sensation of being pulled toward the sound source and was described by the investigators as being incoherent while experiencing these symptoms. The second occurrence involved a 39 year old diver who completed his exposure (1000 ± 50 Hz warble tone at 181 dB SPL) without apparent incident, but seemed agitated during the post-dive interview. Upon questioning, he reported the sensation of vibration ("brain and teeth") and weeks later continued to report sensitivity to noise, increased irritability and inability to concentrate.

Similar effects have been observed in response to low frequency sound exposure in air,[3,4] but again, specific mechanisms, and how signal characteristics (frequency, intensity, duration etc.) effect responses are unknown. In air, skull resonances have been demonstrated at: 500 Hz, 800 Hz, 1800 Hz, and 2500 Hz.[5-8] WLFS induced skull resonances are potentially different from those in air given the increased loading and drag on the skull created by the water. Finally, depth effects on resonance and vibration amplitude are also unexplored.

2. OBJECTIVE

- Determine the vibration response of the skull at resonant and non-resonant frequencies in the presence of WLFS over the frequency region 50 - 1250 Hz.

3. METHODS

Subjects

Subjects consisted of six male and eight female cadavers that were preserved with a formaldehyde, phenol and ethanol mixture. These were obtained from an area medical school and tested individually.

Apparatus

The apparatus included a 1,100 gallon four-sided aluminum pool placed in a hyperbaric chamber. To minimize standing waves, the pool's walls were of unequal length and non-parallel. All dimensions were less than 1/2 the signal wavelength (the wavelength at which standing waves occur) at frequencies below 500 Hz. The walls, floor and mounting brackets were acoustically dampened with rubber and/or foam padding to reduce reflection of incident waves. These design specifications were necessary to simulate, as close as possible, far field conditions in a controlled setting. A J11 transducer was used to create a uniform sound field 0.5 m square at 1.5 m depth mapped without the cadaver in place. Acoustic field mapping across the frequencies of interest revealed a flat frequency response from 50-1250 Hz with the exception of a tank resonance at 950 Hz (skull vibration measures are suspect in this region and were not analyzed between 930-1000 Hz). The maximum variation in SPL over the analyzed frequency region was 1.5 dB. The noise floor was approximately 90 dB SPL.

Each measuring device consisted of three identical monoaxial accelerometers arranged 90° apart on a titanium mounting block creating a triaxial setup weighing 7.2gm. Two flat-headed stainless steel screws (#6, ½ inch wood screw and 10-32 x ½ inch machine screw) were soldered together at their heads. The machine end attached to the titanium block and the wood screw end served as the attachment to the skull. Accelerometer responses were run through a B&K pre-amp into a Data Physics analyzer (model DP 430) where fast fourier transforms (FFTs) were performed on each output allowing real time display of acceleration on two PCs.

Procedures

Measurements were taken simultaneously from three points on the skull. These sites were chosen on the basis that previous work, in air, had shown that their vibrational responses were independent of each other.[6] The frontal (midline, 4cm superior to line connecting bilateral supra-orbital foramen), temporal (squamous portion, 4cm superior to line connection zygomatic tubercle and external auditory meatus) and occipital (sagittal suture, 2cm anterior from occipital protuberans) bones were investigated.

Preparation involved removing a 6 mm diameter cylinder of skin overlying each site of insertion. With a 3/16^{ths} drill bit, a pilot hole was created at each location into which a triaxial setup was placed. The X axis at all three locations corresponded to a direction depicting 90° laterally from the skull. The Y axis represented movement vertically from the vertex of the head and the Z axis faced anteriorly.

Subjects were maneuvered and bound into a compact sitting position to allow proper skull placement within the sound field and isolation from the walls and floor. They were placed on a hammock of nylon webbing which was strapped around their chest and thighs. Two ropes (slung through O rings in the bottom of the tank) were attached to the inferior webbing and were used to overcome a slight positive buoyancy in each cadaver. Guide ropes (attached to each corner and to a grid suspended above the tank) allowed adjustments within the tank and sound field. The skull was positioned 18 inches from the front of the transducer to the posterior aspect of the skull, and 18 inches from the surface to the vertex of the skull. Two depths were used: chamber at 0FSW (Feet of Sea Water) and 60FSW (1.5FSW and 61.5FSW measured from the vertex of the skull.) The entire sound protocol described below was run once for each cadaver at each depth.

Our approach was to first, identify skull resonance(s), second, fully characterize the resonance(s), then finally, explore vibration amplitudes at representative non-resonant frequencies. Sweep tones were run from 50 to 1250 Hz (at 10 Hz per second) using successive sound levels from 70-160 dB SPL. Peak hold was used to record the responses as a function of frequency; resonances were identified as spikes in the acceleration curves. Successive step sines at multiple intensities were then used to determine the relative sharpness of each resonant frequency, thresholds for detection and linearity (step sines started 150 Hz below the resonant frequency and stopped at 900 Hz, running at a rate of 1 Hz per second with sound pressure levels ranging from 70 to 160 dB). Finally, pure tones were presented individually in 10 Hz steps from 180 to 900 Hz with intensities ranging from 90 to 160 dB to check for linearity at non-resonance frequencies.

4. PRELIMINARY RESULTS

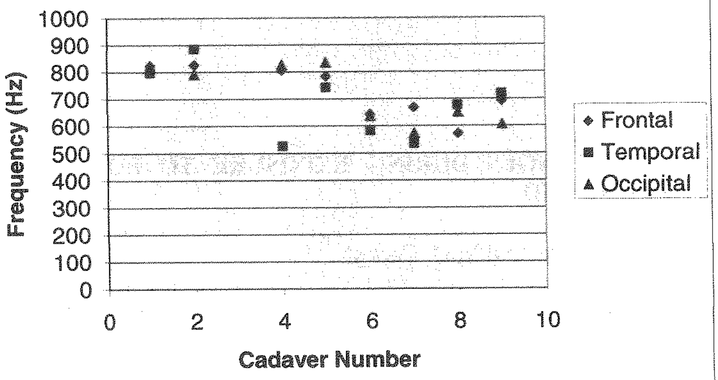
For each cadaver:

- Resonant frequencies were measurable between 500-900 Hz (Figure 1 demonstrates resonant frequencies for cadavers 1,2 and 4-9 and skull regions involved).
- Resonant frequencies did not change significantly as a function of signal intensity.
- The amplitude of acceleration increased linearly with signal intensity at resonant and non-resonant frequencies.
- Resonant frequencies did not change significantly as a function of depth.

5. CONCLUSIONS

WLFS will cause a cadaver skull to vibrate in the frequency region from 50-1250 Hz; the response is maximal between 500-900 Hz., with the frequencies at which resonance occurs varying across skulls. Ongoing analysis with comparison to available literature will help determine if displacement magnitudes are sufficient for neurological damage.

FIGURE 1.



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7. ACKNOWLEDGMENTS

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HEART RATE CHANGES DURING EXPOSURE TO LOW FREQUENCY UNDERWATER SOUND

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1. INTRODUCTION

Low frequency active sonar is increasingly being used in the world's oceans for military, commercial and scientific purposes. Due to its considerable propagation range in water there is an increasing probability that recreational divers will be exposed to low frequency underwater sound (LFUS). Unfortunately, knowledge of the biophysical effects of LFUS is limited. In particular, little is known about the effects of LFUS on cardiac control. The aim of the present study is to determine if heart rate (HR) is affected by the type of signal, sound pressure level (SPL), frequency, and sound duration of LFUS.

2. METHODS

Subjects

Nine female and 17 male recreational SCUBA divers participated. The subjects' age, height and weight were (mean ± S.D.) 32 ± 7 yrs, 173 ± 10 cm, 77 ± 14 kg, respectively.

Experimental Set up

Experiments were performed at a specially designed anechoic acoustic testing pool (TRANSDEC, Point Loma, CA) that had contoured sides and sound traps to simulate the acoustic transmission properties of an infinite expanse of water. Subjects were instrumented with a waterproofed 3 lead EKG and wore standard issue SCUBA gear that included mask, regulator, deflated buoyancy compensator, tank and 3-mm neoprene wetsuit with booties. Wetsuit hoods and gloves were not worn. The divers were made negatively buoyant and suspended 1.0 m below the surface in a prone position so that they remained exactly 4.0 m above the sound transducer (J15-3). Water temperature surrounding the divers was maintained between 21.1 and 27.8 °C. At the beginning of the study the sound field in the location of the diver was mapped without the diver present. The maximum spatial variation in SPL over the divers' location was 1.3 dB re. 1 μPa for frequencies between 100 and 500 Hz.

Protocol

Two experiments were conducted, EXP 1 and EXP 2. During EXP 1 sound exposures consisted of three sonar signals; a pure tone, a 30 Hz hyperbolic sweep up, and a 30 Hz hyperbolic sweep down. Each signal was presented for 7 s at 6 center frequencies (100, 200, 250, 300, 400, 500 Hz). Two control signals were also presented: a merchant ship propeller and a Minke whale with center frequencies of approximately 400 Hz and 150 Hz, respectively. Presentation order of frequency and signal was randomized. For all signals and frequencies, 6 SPLs ranging from 130 to 157 dB re. 1 μPa at the diver's head were delivered in an increasing, step-wise fashion. All sound exposures in EXP 1 were activated by the subjects.

In EXP 2 the three sonar signals were delivered only at a frequency of 100 Hz at 136 dB re. 1 μPa at the divers head. During EXP 2, sound durations of 7, 14, 21 and 28 s were each presented twice but in random order for each sonar signal and control sound with a duty cycle of 50%. Sound exposures greater than 7 s were composed of repeating units of the original 7-second signal.

Analysis

The EKG waveform was amplified, filtered (a high Q, 17 Hz band pass filter followed by a full wave rectifier, followed by a 7.2 Hz, two pole, low pass filter) and digitized (sample rate = 1000 Hz) using AcqKnowledge® III hardware (BIOPAC Systems Inc, Santa Barbara, CA) before being stored on hard disk for later analysis. Beat-to-beat intervals were determined from the peak of one R wave to the peak of the next (R-R interval) using AcqKnowledge® III software. Analyzed HR responses included the R-R interval immediately before and after each sound, and all R-R intervals during the sound exposures. Data were analyzed by repeated measures analysis of variance followed by Tukey's HSD post hoc test (when appropriate) to determine the effects of signal type, frequency, SPL and signal duration on HR.

3. RESULTS

In EXP 1 there was a statistically significant decrease in HR by the 2nd beat interval following sound onset compared with the beat interval recorded immediately before the onset of sound (i.e., beat # 0) ($p<0.01$). Figure 1 shows that the group mean ± S.D. maximum decrease in HR (increase in RR interval) of about 10% ± 8.8% occurred between the 5th and 6th beat interval from the onset of sound exposure. The form and magnitude of the HR changes shown in Fig. 1 were found to be consistent across all SPLs and were unaffected by the signal type and frequency of the sound ($p>0.05$). The pattern of heart rate responses to LFUS observed in EXP 1 was also shown in EXP 2. Heart rate decreased by about 5% during the first 5 beats from the onset of the sound exposure ($p <0.001$) and then remained at this level for the duration of the sound exposure (i.e., 7, 14, 21 or 28 s) and for the first beat interval immediately post sound exposure. In EXP 2 the maximum percent decrease in HR during the first sound exposure was the same as that during the last sound exposure (40th presentation).

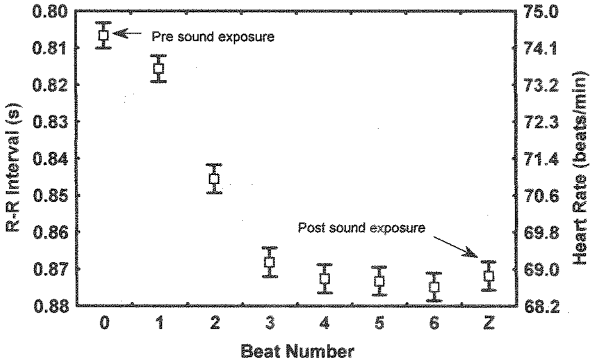

Fig. 1: Beat-by-beat heart rate changes following 7 s LFUS exposures. The data are mean ± SEM for 26 subjects averaged across all signal types, frequencies and SPLs from EXP 1.

4. DISCUSSION AND CONCLUSIONS

The results demonstrate a marked and consistent decrease in HR during the presence of LFUS. The maximum decrease in HR occurred within the first 5 to 6 beats from the onset of a LFUS stimulus and was maintained as long as the LFUS stimulus was present. It may be argued that the lack of a significant effect of SPL on the HR decrease in EXP I could be due to an order effect resulting from the sequential presentation of increasing SPLs. This insignificant effect of SPL on the HR response to LFUS may be the result of an habituation effect (i.e., a reduced HR response to repeated LFUS exposures which offset the possibly augmented HR responses that might occur with the greater SPLs). However, since EXP 2 showed no evidence of habituation of the HR response to repeated LFUS exposures at a constant SPL and frequency it is unlikely that the lack of an effect of SPL on the HR response to LFUS in EXP 1 is an artifact of the experimental design. It may be further argued that the decreased HR in EXP 1 was a result of an anticipatory breath-hold, which is well known to produce a rapid and pronounced bradycardia [1]. Evidence against a breath-hold bradycardia is provided in EXP 2 in which the post stimulus HR decrease was still observed when initiation of the sound presentations were not under the control of the subjects.

Decreases in HR of similar magnitude to those found in the present experiments have been found following the presentation of low intensity auditory stimuli in air [2]. The HR deceleration following an auditory stimulus has commonly been referred to as an orienting reflex or response (OR). However, Barry and Maltzman [3] have questioned whether this HR deceleration is a true index of the OR in accordance with the traditional construct of OR described by Sokolov [4]. According to Sokolov [4] the OR is a nonspecific reflex independent of the modality of the stimulating agent, that changes with stimulus intensity and shows a rapid habituation with repeated stimulus presentations. The findings of the present study and those of Barry [2] show that the HR deceleration following an auditory stimulus fails to habituate or discriminate stimulus intensity. Consequently, the HR response to LFUS fails to conform to the traditional view of an OR.

More recently the post stimulus HR deceleration has been attributed to a shift in attentional priorities reflecting the process of stimulus registration [5,6]. Due to the fact that the percent decrease in HR did not habituate with repeated sound exposures and the fact that subjects were instructed to rate their level of aversion and presence or absence of vibration during each sound exposure (findings reported in ref. 7) we believe that the HR responses shown in the current experiments were largely mediated by voluntary attentional processes. Further evidence implicating attentional process in the declarative HR response to LFUS stimuli was demonstrated in a separate unpublished study. In this study we instructed the subjects not to shift attentional priorities during an underwater reaction time task when the LFUS was presented. Under this situation we failed to find the same distinctive HR decrease following the sound stimulus. Based on these patterns of results we therefore favor the more recent theoretical construct of a voluntary OR as described by Maltzman [8]. In this theory, HR deceleration is a consequence of frontal lobe activation. According to this view the presence or absence of a HR OR to a given LFUS stimulus will depend on the experimenters' instructions to subjects regarding the amount of attention and/or significance to be paid to the stimulus and the subsequent ability or willingness of the subjects to follow these instructions.

In conclusion, exposure to LFUS provokes a temporary decrease in HR that is consistent with a normal non-habituating orienting response to sound. For the range of the sound stimulus parameters studied, the magnitude of this orienting response was unaffected by changes in SPL, frequency, sound duration and signal type.

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PHYSIOLOGICAL EFFECTS OF NOISE IN LOW-BIRTH-WEIGHT INFANTS

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1. INTRODUCTION

The possible effects of incubator noise on premature infants have long been debated [1]. The results differ with different age, with the nature of cohort studied and lastly with the method used for assessment of auditory and/or physiological functions. Our previous studies [2], [3] have demonstrated that the average noise levels in empty incubators (n=72) of different types were 64 - 80 dB SPL (51 - 62 dB/A). However, the real noise load on the infants in incubators represents the sum of the incubator noise itself and the noise produced during nursing and of other medical equipments (performed by the measurement of equivalent noise levels in the 24-hour cycles). This noise load was in average by 15 dB(A) higher, in the 29 % of case studied the noisy load in 24-hour cycle was even higher than the WHO limit for the 8-hours work time in industry (i.e. >75 dB/A). The maximal levels were recorded during baby's crying (100 - 110 dB/A), by opening (82 - 94 dB/A) and closing (94 - 97 dB/A) of incubator doors with maximal levels 110 - 123 dB, and by various inconsiderate contacts with the incubator walls (putting solid objects or knocking on the wall): 86 - 103 dB(A). These noise levels are in the zone of absolute noise with the effects on the vegetative nervous system and/or possible hearing damage. A low-birth-weight infant spend days, weeks or even months in this potentially damaging environmental conditions.

2. MATERIAL AND METHOD

To evaluate some non-auditory physiological effects induced by noise, in the present study changes of blood pressure (BP), heart rate (HR), respiratory rate (RR) and somatomotoric reactions (SR) were investigated in 120 low-birth-weight newborns exposed to two different types of noise stimuli. Characteristics of the cohort of infants see in Table 1. All infants were in good healthy status, sleeping, in rest, one hour after feeding, in standard incubator environment (constant temperature, humidity and steady-state noise). All used methods had to be non-invasive, simple, quick, did not disturb or irritate the babies, there was no need transferring them.

Systolic and diastolic BP was measured indirectly by using an ultrasound equipment based on Doppler's effect [4]. Changes of HR were registered electrocardiographically, changes of RR were registered with assistance of Brüel-Kjaer level recorder, SR were registered by using actograph (constructed in our Institute [5]) and Brüel-Kjaer level recorder. These non-auditory reactions on two natural noise stimuli were evaluated:

The first stimulus - a broad-band intermittent noise with a maximum energy in the range of 63 - 250 Hz ($L = 97$ dB, $L_A = 88$ dB/A, $L_{Aeq} = 78.9$ dB/A). This low-frequency (LF) stimulus was generated by closing the incubator door and was applied repeatedly for 5 times (by registration of SR only once) within a time interval of 30 sec.

The second one - a continuous, high-frequency (HF) steady-state noise with a maximum energy in the range of 4000 Hz ($L = 70$ dB, $L_A = 60$ dB/A) was generated by the incubator's alarm system and was applied for an interval of 30 sec.

Table (1) Characteristics of the cohorts of 120 infants

Characteristics	BP reactions (n=30) mean±SD	HR reactions (n=30) mean±SD	RR reactions (n=30) mean±SD	SR (n=30) mean±SD
Birth weight [g]	1613±431	1876±363	1786±399	1515±333
Gestational age [weeks]	32±3	35±3	35±3	31±3
Actual weight [g]	1861±249	1976±322	1904±305	1780±243
Actual age [days]	30±17	21±12	19±13	32±13

Measurements were undertaken repeatedly before application of the noise stimulus, immediately after the cessation of the stimulation and 5 minutes thereafter, until the physiological reaction returned to preexposure value.

3. RESULTS AND DISCUSSION

The physiological reactions on both stimuli were observed in all studied infants.

Preexposure systolic and diastolic BP were 63±6 and 31±8 mmHg respectively [6]. The LF stimulus led to an increase of both the mean systolic and diastolic BP by 9.7 and 6.9 mmHg respectively, however in a subgroup of newborns, consisting of 14.5 % of the subjects there was a decline in the levels of both parameters (by 8.1 mmHg systolic and 8.9 mmHg diastolic BP) - as observed in adults [7]. A similar picture was observed also after application of HF stimulus (Figure 1). All BP changes were significant $p<0.001$. Both the systolic and diastolic BP returned to the preexposure levels during the following 4 to 5 minutes, however the speed by which BP changed as well as the speed of the recovery to preexposure levels was slower after HF stimulus.

Preexposure mean basal HR of 132±16 min^{-1} was found. After the application of the LF and HF stimuli, HR increased by 30.4 min^{-1} and 30.0 min^{-1} respectively. Also in a subgroup of newborns (12.5 % after LF and 10.0 % after HF stimulus) there was a decline in the level of HR (by 15.0 min^{-1} and 24.0 min^{-1}) - Figure 1. All HR changes were significant $p<0.001$. Recovery to preexposure levels occurred usually in the 5th minute following the cessation of the stimuli.

Investigation of RR changes is most difficult because of its considerable irregularity in young infants. Some authors considered the RR changes the most sensitive indicator of acoustical irritation (utilized e.g. in respiratory audiometry). Preexposure mean basal RR was 52±14 min^{-1}. After application of both stimuli the slowing of RR by 21.0 min^{-1} and 22.2 min^{-1} respectively was found. However, in a subgroup of 25.8 % by 17.8 min^{-1} (after LF stimulus) and of 19.4 % by 17.7 min^{-1} (after HF stimulus) acceleration of RR was found (Figure 1). All RR changes were significant $p<0.001$. These reactions had longer duration, the return to preexposure levels during the following 5 minutes after both stimuli was not recorded. In 50 % infants there were also apneic pauses found with mean duration of 4.2±2.4 sec. After both stimuli the pauses were prolonged to 5.7±.1.8 sec. and to 5.9±1.5 sec. respectively. In 14.5 % cases appeared apneic pauses after stimulation also in infants not having them at rest (also oboserved by [7]).

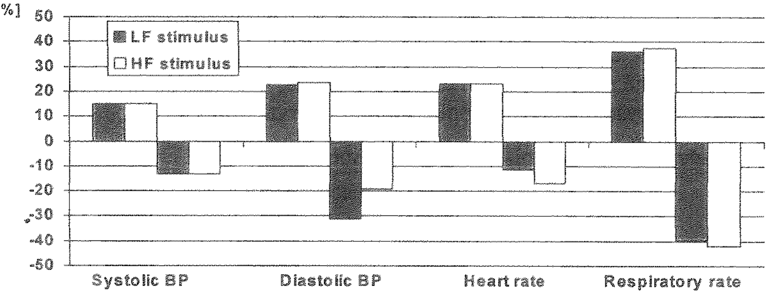

Figure (1) Physiological reactions after low-frequency (LF) and high frequency (HF) stimuli in relative numbers (%).

There were found two types of somatomotoric reactions: 1. immediate, intensive, generalized movements of the whole infant's body ("startle" reaction) - in 90 % infants after LF stimulus; and 2. smooth, slow, localized movements of one or more extremities with longer period of latency - in 67 % infants after HF stimulus.

The mean period of latency SR after LF and HF stimulus was 1 and 3 sec. ($p<0.05$), the mean duration of SR was 47 and 57 sec and the mean number of movements 61 and 75 (not significant) - Figure 2. In this type of reaction the older the infant was (i.e. the longer stay in incubator), the longer duration of reaction ($p<0.01$) and the more number of movements ($p<0.05$) were found, but only after LF stimulus (Figure 3). Not only it resulted in no habituation, but even in amplification of reactions after long stay in noisy environment. After repetition of both stimuli diminished SR were observed.

4. CONCLUSIONS

The present results suggest, that noise stimuli - with no regard to their frequency characteristics, intensity and/or duration - lead to substantial vegetative and somatic responses in low-birth-weight infants. In the most cases there were observed increases of both systolic and diastolic BP, acceleration of HR and slowing of RR with more frequent occurrence of apneic pauses and their longer duration. Less infants (10.0 - 25.8 %) had reverse reactions. The most sensitive were reactions of RR. All vegetative changes observed in this study were elicited by usual noise phenomena.

There were no statistical differences between vegetative reactions on LF and HF stimuli and no differences in dependence on different duration of infant's stay in incubator. This resulted in no habituation to acoustical irritation. The "startle" reactions were observed more frequently after LF stimulation, older infants had longer duration of SR reaction with higher number of movements after LF stimulus. Thus, the hazard of possible vegetative disturbances from noise exposure within infant incubators should be taken into consideration as a possible perinatal risk factor.

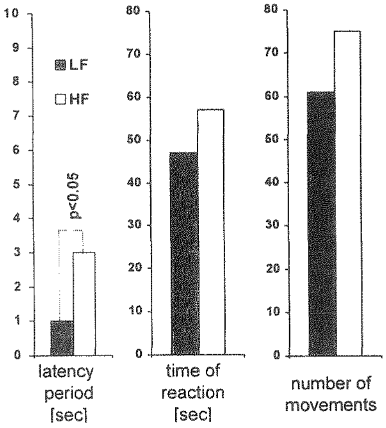

Figure (2) Somatomotoric reactions after low-frequency and high-frequency stimuli

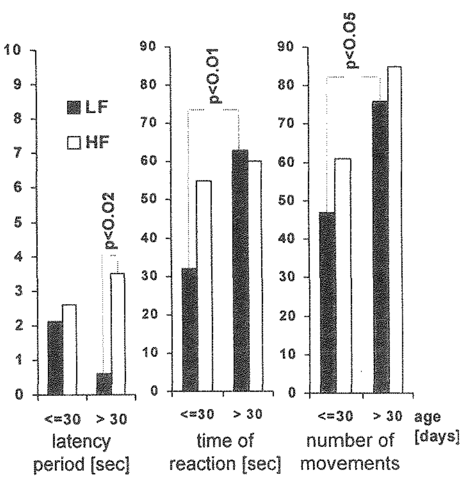

Figure (3) Somatomotoric reactions after LF and HF stimuli according to age of infants

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MOTIVATIONAL CONSEQUENCES OF EXPOSURE TO NOISE

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1. OBJECTIVES

A central process in human behavior is competency--striving for effective interaction with the environment [1]. Believing and having the opportunity to demonstrate that when one acts on the environment, a response in proportion to one's action ensues, is a critical component of human experience. When repeated attempts to cope with aversive, environmental conditions fail, learned helplessness may occur. Learned helplessness is a failure in coping due to perceptions of uncontrollability [2]. Among the consequences of learned helplessness is retarded motivation to interact effectively with the environment [3,4]. Furthermore, when faced with noncontingent environmental conditions, the attributions individuals make are important in determining outcomes. Impaired motivation is more likely when attributions for failure are made to internal, stable characteristics of the individual, such as ability. When external attributions are made to effort or luck, learned helplessness is less likely to occur [5,6].

The purpose of this paper is to critically review research on noise and motivation. Environmental noise is often uncontrollable and hence capable of inducing motivational deficits related to learned helplessness. Of historical interest, readers are reminded that the first empirical study of learned helplessness in human beings used uncontrollable noise to induce learned helplessness [7].

Research on noise and motivation can be classified into three types. The first type of evidence includes studies that have examined noise as a stimulus to induce motivational deficits. The second type of studies of noise and motivation examine children's behavior in noisy settings. The third type includes research on community annoyance with noise.

2. NOISE AND HELPLESSNESS INDUCTION

Four different paradigms have examined the capability of noise exposure to induce learned helplessness. In one paradigm, uncontrollable noise is used to induce helplessness during task performance. Helplessness is assessed by behavior on a subsequent, solvable task. Hiroto [7] examined college students performing a task in escapable or inescapable, loud noise or with no task under quiet conditions. Immediately following the induction phase, participants who had worked during inescapable noise were much less likely to successfully perform a moderately complex, learning task to avoid noise (50%) than those who had previously worked in escapable noise (13%) or the control group who had no pretreatment phase (11%). Furthermore these effects were stronger for external locus of control individuals--persons who believe that their destiny is controlled by luck or powerful external agents. Externals can be contrasted with internals who believe they are in control of their own destiny.

Learned helplessness implies that the belief in noncontingency induced by repeated exposure to an uncontrollable stimulus should generalize (hence, 'learned') beyond the immediate situation. To test this proposition, Hiroto and Seligman [8] replicated Hiroto [7], adding two conditions. For some subjects the test phase consisted of word problem performance instead of noise-avoidance learning; whereas for others the induction phase incorporated exposure to unsolvable, concept formation problems. This allowed them to test within and across modality (e.g., inescapable noise to noise-avoidance learning and to problem solving). As before inescapable noise induced helplessness, whether assessed by subsequent noise avoidance learning or performance on the word problems. Furthermore, the cross modality and within modality effects were equivalent. Krantz and colleagues [9] independently demonstrated the same effects of inescapable noise on subsequent, noise-avoidant learning among college males. Glass [10] found a similar pattern of results with 9-11 year old boys. Krantz [9] also showed that the effects of the pretreatment with inescapable noise were stronger with greater duration of exposure. The duration effect is important to consider when evaluating the potential for chronic, ambient noise exposure to affect motivation.

Several investigators have found similar impacts of inescapable noise on subsequent retarded task motivation [11, 12, 13, 14] utilizing moderately difficult word problems instead of noise-avoidance learning. In addition physiological and mood data have also been collected. Consistent with Seligman's theory of learned helplessness and depression [3], persons exposed to inescapable noise versus no noise had reduced skin conductance [11, 13], indicative of lowered autonomic arousal. Subjects in inescapable versus escapable noise also reported feeling more depressed [11,12,14]. These findings, in addition to providing further links between uncontrollable noise exposure and motivational deficits linked to learned helplessness, also raise concern about possible linkages between chronic noise exposure and depression. The latter concern has not been systematically investigated.

A few investigators have implemented similar learned helplessness paradigms in field studies. Third and fourth grade children attending either airport-impacted schools or well matched, quiet schools were given moderately difficult jigsaw puzzles under quiet, well controlled conditions [2]. Fifty three percent of children from quiet schools solved the puzzles whereas 36% from noisy schools solved them. Of greater interest, 31% of children from noisy schools and 7% from quiet schools who failed to solve the puzzles did so by giving up within the four minute time allotment. These data were replicated in an independent sample of third graders [2]. The giving up data indicate that the effects of chronic exposure to noise do not reflect cognitive deficits or learning problems. Giving up seems like an unambiguous index of helplessness. Maxwell and Evans [15] found that preschool children took longer to solve a solvable puzzle, following exposure to an insolvable puzzle as a function of interior, daycare noise levels. A sound attenuation program (approximately 5 dBA reduction) provided the opportunity to compare two, well matched cohorts from the same preschool.

A second paradigm that may be indicative of reduced motivation resembling helplessness was also used by Cohen and colleagues [2] in their airport noise study. Third graders attending noisy schools in comparison to their quiet school counterparts were more likely to relinquish choice over a reward following an experiment. At the conclusion of the experiment children were given the option to choose their own reward or allow the experimenter (college student) to choose for them.

The most ubiquitous index of helplessness following noise exposure is based on the stressor aftereffects paradigm introduced by Glass and Singer [16]. Individuals are exposed to a stressor for approximately a half hour. Immediately following exposure, under quiet, unstressed conditions, the participant is then given a second, aftereffects measure. Various aftereffect indices have been used but of most relevance to motivation is a task in which individuals are given a series of unsolvable and solvable puzzles. Persistence on the unsolvable puzzles is the primary index of motivation. Other aftereffects measures including proofreading, Stroop performance, and anagrams have been employed. How long one persists at a difficult, challenging set of puzzles seems like a more direct index of motivation since performance on the other aftereffect indicators also reflects skill and experience. Recall also the Cohen findings in chronic airport noise [2]. Not only were children in noisy schools less likely to solve challenging jigsaw puzzles, they were also more likely to fail because they gave up trying.

Among the many stressors studied with the unsolvable puzzles, aftereffect measure, Glass and Singer frequently used noise. Two of their findings, which have been widely replicated, are of particular interest. First, unpredictable or unsignalled noise causes stronger reductions in aftereffects performance than either predictable or signalled noise [16]. Second, the effects of unpredictable noise on motivation can be eliminated by instilling in participants a sense of perceived control over the noise source [16]. By providing subjects a button they can push to reduce noise exposure, the negative aftereffects of noise are eliminated, even when subjects do not avail themselves of the avoidance response. The effects of uncontrollability over noise have been replicated by several investigators [17, 18, 19]. These results are important because they indicate that the uncontrollability of noise exposure is a key element in its influence on motivation. Its also worth noting that Glass and Singer and several of these other investigators have found that although participants perceive the noise as more or less controllable as expected, they do not perceive differences in aversiveness or annoyance with the noise. This is an important and potentially practical finding. It suggests that controllability not aversiveness is the key element in linking noise to motivation. Moreover, measures of community annoyance with noise are not likely to be sensitive indicators of motivational difficulties.

In addition to many replications of noise controllability on task persistence, Sherrod [19] found that the more control participants had over noxious noise, the stronger the benefit of control. Rotton [18] also found that when the noise was speech rather than conglomerate noise, the residual aftereffects were stronger. Interestingly speech, even at typical volume, compared to quiet can have similar motivational effects on noise sensitive individuals [20]. The perceived control effects over noise also generalize to aftereffects measures of proofreading [16, 21] and anagram solutions [22].

Four studies have employed the Glass and Singer unsolvable puzzles paradigm in field studies of noise. Fourth and fifth grade children exposed to airport noise attempted fewer of the puzzles than well matched children living in quiet neighborhoods [27]. Instead of abstract line drawings, the puzzles consisted of a series of animals interconnected by lines. The child's task was to visit each animal without going over any line twice or lifting their pencil. Haines and colleagues [28] were unable to replicate these results. More recently the same noise effect was found but utilizing a prospective, longitudinal design [29]. Six months prior to the opening of the new Munich International Airport, six months after the new airport opening and then 18 months later fourth and fifth grade (at Time 1) children were tested under quiet, well controlled conditions. Eighteen months post-airport opening but not at six months, children residing in the newly noise-impacted communities showed deficits in the task, (M=6.3) relative to those in quiet areas, (M=7.9). Prior to the airport opening, performance was equivalent (M noise =5.7; M quiet =5.8). Of additional interest, attributional data also revealed corresponding, time-related shifts in reasons for failure. At Time 3, children from the noisy areas were more apt to blame their failure on ability and less likely to attribute it to task difficulty than the children living in quiet communities.

Recently we have investigated the possible motivational consequences of open office noise. Female clerical workers performed typical secretarial tasks for three hours under simulated open office noise (65 dBA Leq) or quiet, ambient conditions (40 dBA Leq). At the termination of the session, women who had worked in noise attempted significantly fewer of the unsolvable puzzles (M=11.50) than women who had worked under quiet (M=19.10).

Finally Moch-Sibony [30] compared two schools near Paris's Orly airport--one with extensive sound attenuation and one without. She employed a standardized, self report instrument for frustration tolerance that utilizes a projective technique. Kindergarten children in the unattenuated school scored significantly lower in tolerance for frustration.

Two studies have not replicated the effects of noise on unsolvable, aftereffects puzzles. Moran and Loeb [23] in two studies were unable to show any effects using tape-recorded aircraft noise played at 95 - 105 dBA peak levels. The authors reasoned that perhaps the nonreplication was created by the predictable onset and offset patterns in aircraft noise that yielded a signalled stimulus. Recall that Glass and Singer [16] had earlier found that exposure to unsignalled noise produced motivational deficits whereas signalled noise did not. Thus in a second study the authors included both typical aircraft noise and re-engineered aircraft noise with the onset and offset periods removed [24]. When the noise stimuli were altered, aftereffects were produced that closely matched Glass and Singer's earlier work. These two sets of findings obviously raise questions about the potential for ambient aircraft noise to induce motivational deficits. Given both the Los Angeles [2] and Munich [27, 29] airport studies showing such impacts, one resolution could be related to duration of exposure. Continuous, daily exposure to aircraft noise, even with its inherent signal properties, remains uncontrollable. Such noise may come to represent an inescapable, aversive stimulus that one can do little either behaviorally or cognitively to cope with. Recall as well that Krantz [9] found that greater duration of exposure to uncontrollable noise, intensified motivational deficits.

Glass and Singer and others using the unsolvable aftereffects paradigm interpret lower persistence on the unsolvable puzzles as indicative of retarded motivation. However an alternative interpretation is possible. Perhaps people give up on the puzzles because they believe (correctly) that the puzzles are unsolvable. In two studies when participants had to perform a demanding, complex task during noise rather than an easy, simple task as employed previously by Glass and Singer, the opposite pattern of results occurred [25]. Persistence on the unsolvable puzzles increased following the initial test phase session in noise relative to quiet conditions. In a third study participants again worked in the induction phase under quiet (40dBA) or noisy conditions (55dBA or 90dBA). For the aftereffects phase, they were given sheets of multiple, geometric line drawings like those used by Glass and Singer and others. For the quiet and high noise conditions, participants took longer to decide which puzzles were unsolvable than those who had worked previously under the moderate noise condition.

The authors suggest that perhaps high noise produces overarousal and thus impair decision making relative to the optimally aroused, moderate noise group. Unfortunately no indices of arousal were monitored. This interpretation is further clouded however by other studies varying task load and noise levels during the test phase of the aftereffects paradigm. Wohlwill [17] found no impact of task load during the test phase on number of attempts on the unsolvable puzzles but replicated the main effects of noise. Rotton [18] uncovered a more complex pattern of results. Speech caused fewer puzzle attempts than conglomerate noise at comparable sound intensities, but when participants were also informed they would be tested on the contents of the speech, even greater deficits occurred. However the addition of noise to the speech produced no further declines, possibly indicating a floor effect. Taken in their entirety it would seem fair to conclude that under acute exposure to uncontrollable noise, task demands may influence the degree to which individuals persist on challenging, tasks. One argument against using the Glass and Singer aftereffect paradigm relative to the more traditional learned helplessness paradigm is the construct validity of this measure as an indicator of motivational persistence. On the other hand, Glass and Singer and many others who have used this paradigm report that participants rarely indicate a belief the puzzles are solvable and express both verbal and nonverbal indices of frustration [16, 26]. It is also important to remember that many investigators have also shown retarded motivation on solvable tasks, following uncontrollable noise exposure [2, 7, 8, 9, 10, 11, 12, 13, 14, 15].

3. CHILD BEHAVIOR IN NOISY SETTINGS

Children in noisy schools appear to be less motivated as reported by their teachers. This has been found in anecdotal reports [31] from teachers around Heathrow, from systematic surveys of teachers near street traffic noise [32], and from children's self-reports when exposed to aircraft noise [30].

Systematic observations of children's mastery behaviors using a standardized, observational paradigm revealed that one year old males but not females who lived in noisier homes manifested more passive, less mastery oriented behaviors. Noise determination came from reliable and valid ratings of interior noise emanating from appliances, TV, and general levels of social interaction from within the home. It is noteworthy that these mastery oriented behaviors observed in infants have been shown to predict subsequent academic achievement [33].

Although to our knowledge there is no systematic work on teacher or parental motivation under chronic noise conditions, it is worth considering the potential role of both direct noise effects on children and indirect effects via their caregivers. It seems quite reasonable to propose that caregivers of children who are exposed to chronic, uncontrollable noise become fatigued and perhaps suffer detrimental motivational consequences of their own.

4. COMMUNITY ANNOYANCE STUDIES

Nearly half of a representative sample of residents within the 65 CNEL contour of a medium sized commercial and general aviation airport (600 flights per day) disagreed with the following statement: "The opinions of all the citizens directly affected by the airport will make a difference in the decisions made about the airport and area surrounding it" [34]. These authors and others [35] have also found that community annoyance with airport noise is higher among individuals who perceive less control over the noise.

These data are interesting to consider in light of the well documented finding that most people who are annoyed never complain or take any other direct action to combat aircraft noise [36]. Of particular interest from a motivational perspective, when queried, residents who are annoyed by aircraft operations but do not complain, typically explain that such complaints or actions will have no impact on aircraft operations.

5. SUMMARY AND CONCLUSIONS

Three different paradigms have been employed to examine the motivational consequences of exposure to noise. The first paradigm has investigated behavioral responses on tasks following exposure to uncontrollable noise. Preexposure to a period of short, acute noise that cannot be escaped produces learned helplessness both in a subsequent, noise avoidance learning task, and in performance on challenging word puzzles. Ambient noise exposure has also been associated with reduced persistence on challenging puzzles and greater giving up or quitting prior to allotted task time. One study found that children attending aircraft, noise-impacted schools were more likely to relinquish choice to an experimenter in comparison to children in quiet schools. Many studies have shown that both chronic and acute noise can reduce task persistence on unsolvable puzzles that children believe are solvable. The controllability of noise has been shown to be a critical factor in these effects. When individuals perceive they can control their exposure to noise, even if they do not act on it, the negative effects of noise on motivation are substantially ameliorated. Some questions have been raised about the meaning of the Glass and Singer aftereffects paradigm, given mixed findings on the role of task demands during the noise exposure period prior to the aftereffects measure. Although the preponderance of data indicate robust noise effects with the unsolvable puzzles, aftereffects procedure, one laboratory and one field study have failed to replicate the noise effects. There are also trends in the data suggesting that duration of exposure is an important variable with longer exposure more reliably inducing motivational deficits.

The second noise and motivation paradigm has examined children's behaviors in noisy settings. Teacher reports suggest that children working in noisy settings are more difficult to motivate. A standardized observational protocol of child mastery also suggests that boys living in noisy homes exhibit less mastery oriented play behaviors than boys living in relatively quiet homes.

Finally, numerous studies have found that people who are annoyed by aircraft noise typically do not complain. When asked about their reasons for inaction, citizens often report their belief that personal action will have no effect on airport operations. Two studies have also found strong associations between levels of community annoyance and citizens' beliefs about their ability to control airport noise.

Many studies have shown that short term exposure to acute, uncontrollable noise can induce learned helplessness both on a related noise, avoidance learning task and on a different modality task, problem solving. The latter results have also been found in the field in relation to chronic noise exposure. Some extensions of this research that would be valuable include more careful examination of vulnerable subgroups and possible long-term linkages to depression. Females, noise sensitive individuals, those with external loci of control, and people who are already depressed, are among the groups most likely to be vulnerable to the induction of helplessness from exposure to uncontrollable noise. Only one study has examined the attributions individuals make about their poor performance in reaction to noise exposure. More work is warranted on this topic.

The Glass and Singer aftereffects paradigm has met with substantial replication but two nonreplications raise questions. One study found that exposure to acute blasts of typical, simulated aircraft noise was insufficient to produce negative aftereffects. However when the noise was altered to make it less predictable, the expected effects occurred. These findings fit with earlier laboratory work by Glass and Singer showing that signalled or predictable noise caused few negative aftereffects. These results do not jibe well, however, with field studies suggesting that chronic aircraft noise can affect performance of children on similar puzzles. One possible explanation for this apparent contradiction could be duration of task exposure. More motivation research needs to examine not only level but duration of exposure to noise as well as cross domain, noise exposure (e.g., school and home, or work and home). The second nonreplication by Klein and Beith [25] raises questions about the construct validity of the unsolvable, puzzles task. Their work suggests that rather than being an index of motivation or frustration tolerance, the task actually measures the subject's ability to detect whether or not the puzzle is solvable. One strategy that might be worth following is some work comparing the unsolvable aftereffects paradigm with the classical, learned helplessness paradigm.

Clearly one major difference between these two paradigms is in the testing and post-helplessness induction phases. In the classical helplessness paradigm, following exposure to noncontingent noise, participants are confronted by **solvable** tasks; whereas in the Glass and Singer paradigm, following exposure to uncontrollable noise, participants are challenged by **unsolvable** puzzles. Another difference is that usually the traditional helplessness paradigm instills an expectation in subjects that some behaviors are possible for terminating exposure to the aversive noise; whereas in the Glass and Singer paradigm the noise is simply presented without any indication of possible control strategies. Although the two paradigms converge in a multitude of studies, indicating that exposure to uncontrollable noise causes retarded motivation in subsequent task performance in either paradigm, one noticeable difference between the two sets of findings is in negative affect [26]. As noted above, the latter is typically found in helplessness studies [11, 12, 14] but rarely uncovered in the unsolvable, aftereffects paradigm. One possible explanation could be expectancies for instrumental control that are often established in the classical helplessness paradigm but absent in the aftereffects paradigm. Furthermore although some classical helplessness studies as reviewed above have found evidence of dampened physiological arousal during the test phase [11, 13], attempts to link measures of physiological arousal either during the induction or test phase with the Glass and Singer unsolvable, aftereffects paradigm have proven futile [16, 26]. Thus although the paradigms converge in terms of performance indicators of motivation, they clearly do not converge in measures of negative affect or physiological arousal. Self reports of motivation could prove useful as an adjunct measure.

More research is called for to assess children's motivation in noisy schools and residential settings. Such work ought to also measure adult caregivers' feelings of fatigue, frustration, and index adult caregiver's motivation, since some of the potential link between noise exposure and motivation in children may be mediated by caregivers own reactions to noise. Observations of actual teacher or parental-child behaviors *in situ* might be revealing of both affective and cognitive content. For example, perhaps caregivers in noisy settings speak less often to children and are generally less responsive to them; are more critical when they do speak to children; tend toward more directive, authoritarian teaching/parenting styles; and are more likely to attribute failures on the part of children to stable, personal attributes of the child (e.g., ability) as opposed to less harmful attributions such as effort or distraction.

Both acute and chronic exposure to loud, uncontrollable noise can produce motivational deficits in both adults and in children. The linkages between such deficits and other behavioral endpoints of concern including cognitive development (e.g., reading acquisition) or psychological well being (e.g., depression) warrant further examination. The generalisability of noise-induced, motivational deficits as well as their longevity, particularly among children, remain to be investigated.

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RECENT DEVELOPMENTS IN NOISE AND PERFORMANCE

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1. BACKGROUND

The Position in 1993

The review by Smith [1] concluded that the effects of noise on human performance depend on the type of noise, the characteristics of the person exposed to noise and the nature of the task. Recommendations for further research included

- further field studies
- greater consideration of the mechanisms underlying the various effects of noise
- more research on effects of noise on children
- research on the irrelevant speech effect
- study of individual differences in the effects of noise

Published Research in the Last Five Years

Literature searches of this topic are difficult due to the imprecise nature of the terms "noise" and "performance". Such searches often include topics which are outside the current areas of interest (e.g. visual noise; auditory effects of noise; animal studies) and exclude central themes such as effects of irrelevant speech. More worrying is that the important work presented at ICBEN conferences is often missed. A crucial first point is, therefore, that a greater priority should be given to ensuring that a literature base covering current knowledge is available to a wider section of researchers and administrators.

2. AN OVERVIEW OF NEW RESEARCH

Two of the most important areas are covered in detail in later sections, distraction by irrelevant speech and sound, and effects on children's cognition.

Accidents and Productivity

There has been no new work in this area

Noise and Performance

Laboratory studies. Most of the research in this area has been concerned with very specific issues. Indeed, there has rightly been a move away from the traditional white noise/performance experiment.

Effort and adaptive cost. A number of studies (e.g. [2]) have demonstrated that effects of noise on performance may be counteracted by increased effort which leads to a physiological cost.

Noise and low levels of arousal. Studies have demonstrated that noise can cancel out the effects of reduced arousal [3] and that changes in noradrenaline may underlie this effect [4].

Individual differences. There has been several studies in this area and the individual differences examined have been gender [5,6], aspects of personality [7-10] and chronic illness [11]. Unfortunately, it is difficult to draw firm conclusions from this research.

Combined effects. Again, combinations of noise and other stressors have been examined [7,3,12,13,14]. In some cases the effects of noise appear to be independent, whereas in others there is an indication of interactions with other stressors.

New outcome measures. Studies have examined the acceptable levels for performing different tasks [15] and also the effects of office noise on perceived performance [16].

Overall, some developments have been made in a number of areas but none represent a substantial programme of work. The study of irrelevant speech and noise and children's cognition contrast with this view and these topics are now covered in detail.

Distraction by Irrelevant Sound and Speech

Even though experimental subjects are asked to ignore it, irrelevant sound presented during the execution of short-term memory tasks disrupts performance appreciably [17]. This classic finding has now been replicated many times. Generally, two features of this experimental setting have come under scrutiny, namely, the differential sensitivity of tasks to the effect and the acoustic parameters responsible for the effect. A number of key advances have been made since the last meeting of ICBEN in both these domains of study.

We may summarise the position at the last meeting as follows: acoustic factors, not ones associated with the meaning of the sound, are primarily responsible for the disruption; the key factor seems to be the degree of acoustic change within the irrelevant stream not the similarity of the stream to the to-be-remembered material [18]; additionally, tasks that embody memory for order seemed to be particularly susceptible to disruption by noise, although this was by no means proved beyond doubt.

Acoustic factors. Perhaps the most notable advance, at least in relation to issues connected with noise abatement, is the further understanding of the role of intensity and its relation to acoustic change. It had been supposed hitherto that change in any acoustic parameter was sufficient to cause disruption, but recent work has shown that a change in intensity is the exception to this rule. This is true whether the level changes from trial to trial [19] or from event-to-event within a trial [20]. The auditory distraction produced in these settings is therefore independent of the level of the sound, a result that should have implications for abatement in settings in which mental work involving memory is taking place (such as offices, air traffic control centres or the control rooms of nuclear power stations).

The role of auditory streaming in modifying the degree of disruption, a topic only just emerging in 1993, is now much more fully developed. It was then suggested tentatively that unattended sound is organised into streams in very much the same way as it is when it is attended. This view can now be supported more steadfastly since a number of lines of evidence have converged to support it. One line of evidence relates to the role of babble speech first touched on in 1993 [21]. For sound presented through a monaural source, as the number of voices is increased so does the degree of disruption, but only up to a point. As the number of voices exceeds four the degree of disruption diminishes significantly. This can be explained by supposing that adding more voices reduces the likelihood of segmentation of the sound. Interestingly, the relatively small degree of disruption produced by six voices can be increased appreciably if instead of presenting the sound monaurally each of the voices is assigned to an unique and distinct point in space [22]. That is, streaming by location allows the different voices to be registered and their contents segmented. From this and other demonstrations it is argued that the perceptual organisation that is typically encountered when a person is listening to a sound also governs the registration of unattended sounds.

A third key factor is that the disruption by sound does not diminish with repeated presentation, that is its effect does not habituate. This has been shown in a variety of ways. First, if the degree of disruption is charted over many trials then the degree of disruption is not diminished even when sessions a day apart are compared [23]. Another method has used the technique of examining the 'set size' of the syllables used in the irrelevant sound. As the number of different syllables or tokens constituting an irrelevant sequence increases from one to two, and beyond to seven, the number of repetitions of each tokens diminishes. If habituation is at play we can expect that the greater number of repetitions of a token (the inverse of set size) would be associated with relatively less disruption. In fact the disruption grows appreciably as the set size is increased from one to two but not beyond that [24]. It is argued that disruption is based on a contrast between two successive stimuli and that this contrast gives information about the order of events. It is this information about order that is the basis for disruption

Task factors. Although the volume of work on this topic has increased appreciably, the general implications are less clear than they were five years ago. In 1993 it was thought that the effects of irrelevant sound were confined to recall tasks that involved memory for order. However, a set of studies claiming to show effects in a range of tasks that appeared not to call for memory for order appeared quite soon thereafter [25]. So, for example, irrelevant sound effects were found in tasks in which the person was asked to recall the items in any order. More recent work has claimed that despite instructions to recall in any order the experimental subjects tend to engage in rehearsal of the sequences in their order of presentation. Indeed, in the case of recall in any order errors induced by irrelevant sound took the form of order errors not ones of forgetting the to-be-remembered items [26]. At about the same time further examples emerged of settings in which the irrelevant sound failed to produce effects even in tasks that were very demanding of processing resources [e. g., 27]. Mental arithmetic was shown to be immune to disruption by irrelevant sound until the task was modified to include memory for order [28]. On balance, these studies suggest that the original conclusion was correct but that great care needs to be taken in checking the actual degree to which the task calls upon memory for order; simply claiming that the task has certain characteristics is not enough, some independent check on the functional character of task needs to be undertaken.

The abstraction that unifies the effects of the task and acoustic factors is that the interference is the result of a conflict of processes related to keeping order; one arising from the obligatory processing of sound that takes place without conscious awareness and the other from the conscious deliberate rehearsal of sequences for recall.

Future research should focus upon further refinement of the acoustic factors associated with streaming at a level of granularity far finer than has been employed hitherto. Far more needs to be done to chart out the pattern of sensitivity of different tasks. Finally, work on individual differences in the susceptibility to disruption by irrelevant sound needs to be extended beyond the single excellent study already undertaken [29].

Effects on Children's Cognition

In 1993 Evans and Lepore [30] published a critical review of nonauditory effects of noise on children. In their conclusions on cognition and intellectual achievement it was pointed out that chronic exposure to noise was associated with reading deficits in a majority of studies, particularly for children in higher elementary school grades. In discussing the mediational processes between chronic noise exposure and cognitive deficits they pointed to several main possibilities, including: (a) noise masking speech (b) noise impairing language acquisition, (c) noise leading to techniques for filtering out auditory sounds, and (d) noise narrowing attention.

Studies published on children's cognition after that review have been of relevance to both the nature of the noise effects and how it is mediated.

Hygge [31] reported that 15 min acute noise exposure to children aged 12-14 years, while reading a text impaired one week long-term recall, when the noise came from aircraft and road-traffic. Aircraft noise impaired recall both at 66 and 55 dBA L_{eq}, road-traffic noise only at 66 dBA L_{eq}.Train noise and verbal noise did not impair recall and recognition was not impaired by any noise source. Attention, measured as number of pages read of the text, did not differ between noise groups, and can thus be ruled out as a mediator. Instead, quality of cognitive processing in memory, not encoding, was pointed to as a crucial mediator.

In a contributed paper to this conference [32] a research program on the acute noise effects on different memory systems and memory processes is presented. Preliminary results from a first study suggest impaired attention from speech-noise and road-traffic noise.

For first- and second grade children exposed to chronic air-craft noise Evans and Maxwell [33] reported reading deficits. The chronically exposed children also had impaired speech perception, but not sound perception. Impaired speech perception was assumed to partially mediate the noise-exposure -- reading-deficit link

In the Munich-study children (aged 9-12 years when the study started) chronically exposed to aircraft noise [34, 35, 36, 37] at the old and new airports have been compared to matched controls before and after the relocation. At the new airport, long-term recall and language abilities became impaired when the airport went into operation. At the old airport, the opposite was true. Long-term recall and language abilities improved when the old airport stopped to operate. Attention, measured as number of pages read of the text read, did not differ between groups. At both airports most other cognitive measures were unaffected.

In the Munich data there is a correspondence at the new airport between noise effects on impaired cognition and increases in stress hormone levels and blood pressure in the aircraft noise exposed areas. The mediation between these, and other theoretically interesting variables in producing the noise effects have not yet been analysed, but such work is underway. (See an outline of this work in [38] at the present meeting).

Data from the Munich study are still in the process of being analysed. Some of the analyses are reported elsewhere in this meeting [37, 38, 39], and more will be reported during the next years.

3. SUMMARY AND CONCLUSIONS

Although literature searches of these topics are difficult due to the imprecise nature of the terms *noise* and *performance*, there seems to be an increase in the total number of papers published in the main research areas during the period 1993-98 compared to the preceding five year period. Also, there seems to more focus in the research, meaning that some research areas, e.g., irrelevant sound and speech, and effects on children's cognition are covered by several reports, also from different research groups.

Reiterating and the updating the recommendations from the former ICBEN meeting, it can be stated that:

- Further field studies have been done, particularly in the field of children's cognition. There is still a need for further field studies in the area if of irrelevant sound and speech.
- Greater consideration of the mechanisms underlying the various effects of noise is underway. The progress made in the areas of distraction by irrelevant sound and speech, and effects on children's cognition is significant and the work should be continued. The practical and theoretical implications of further progress in identifying mechanisms in these areas are indeed import.
- Much the same can be said about more research on effects of noise on children. Significant progress has been made and a continuation is wanted. Pin-pointing foci of noise effects on cognition, maybe with laboratory experiments, is a possible future research line.
- Research on the irrelevant speech and sound effect has, as stated in the above points, moved ahead theoretically to a significant extent. Field studies in this domain would be interesting.
- Only a few studies have been reported on individual differences in the effects of noise. More such studies are welcome.

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CHRONIC AIRCRAFT NOISE EXPOSURE AND CHILD COGNITIVE PERFORMANCE AND STRESS

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1. INTRODUCTION

Chronic exposure to aircraft noise in children has been linked to impaired reading ability and attention, reduced motivation, noise annoyance and raised blood pressure. In Los Angeles, school children exposed to high levels of aircraft noise had poorer cognitive performance compared to children exposed to lower levels of aircraft noise (1). Reading comprehension and long term memory were impaired in children around the old Munich airport which improved after this airport closed and developed in other children following new noise exposure around the newly opened airport (2,3). These results raise questions about the causal mechanisms underlying these noise related cognitive impairments and the long-term effects of persistent exposure to aircraft noise. It is still unknown whether prolonged chronic aircraft noise exposure results in: increasing adverse effects, or the effects remain constant, or the effects lessen or disappear.

This is the first study of the non-auditory health effects of aircraft noise on British school children. The main aim of this repeated measures field study was to compare the cognitive performance and stress of children attending four schools exposed to high levels of aircraft noise with children attending four matched control schools exposed to lower levels of aircraft noise around Heathrow Airport in West London. We examined for the first time whether the association between noise exposure and reading comprehension was mediated by sustained attention and if it was confounded by social deprivation and language spoken. By repeating these measures on the same children after a year, an impression of the long-term course of noise effects and adaptation to noise can be obtained.

2. METHODS

Design

In this repeated measures study, the school performance and health of children attending four schools exposed to high levels of aircraft noise (16-hr outdoor Leq > 66 dBA) were compared with four matched control schools exposed to lower levels of aircraft noise (16-hr outdoor Leq < 57 dBA) around Heathrow Airport, in West London. The children first examined at baseline in 1996 were examined again after a period of one year at follow-up in 1997. The schools were chosen such that children were matched across high and low aircraft noise by: age, sex, and sound level at the school from non-aircraft sources; existing noise protection in the schools; socio-economic status and ethnicity of electoral wards. There is no reason to assume that these matching criteria would have changed over the year between baseline and follow-up. The children were already randomly selected into mixed-ability classes. The performance measures and health questionnaires were group administered in the classrooms. Parents of all the school children were given a questionnaire to complete at baseline. Noise measurements were conducted at the time of testing to assess school noise exposure at both baseline and follow-up.

Participants

Eight co-education state schools were chosen according to the noise exposure of the school area. The baseline participants were 340 fourth (n=163) and fifth (n=177) grade pupils (mean age = 9 years and 8 months, 50% girls, 50% boys). 169 attended school in a high-aircraft noise-impact urban area and 171 attended school in a low-aircraft noise-impact urban area. 284 parents of these children also completed questionnaires. The follow-up participants were 275 fifth (n=121) and sixth (n=154) grade pupils (mean age = 10years and 8 months). 148 attended school in a high-noise-impact urban area and 127 attended school in a low-noise-impact urban area.

Outcome Measures

Reading Comprehension. Reading comprehension was measured by the Suffolk Reading Scale which is a nationally standardised reading comprehension test. The Suffolk Reading Scale is designed to measure the reading ability in primary aged students in the United Kingdom. Age standardised scores range from: -70 up to +130. The higher the score the greater the reading comprehension.

Sustained Attention. Sustained attention or vigilance was measured by the Score task taken from the Tests of Everyday Attention for Children (TEACh) battery of measures for the assessment of attention in children. In this Score task the children are asked to imagine that they are keeping score by counting the scoring sounds in a computer game. This test measures ability to count tones with irregular inter-stimulus intervals. There are 10 trials each scored for correct number of items counted. Scores range from 0 - 10. The higher the score the better the sustained attention.

Noise Annoyance. Noise annoyance was measured with a child adapted standard question (4). This question assessed the level of annoyance (very much, quite a bit, a little, not at all) felt by the child when they heard aircraft noise at school. The higher the score the higher the noise annoyance (range 0 - 3).

Socio-demographic. Parents completed a questionnaire measuring the child's age, main language spoken at home and socio-demographic variables to measure deprivation. Household deprivation was assessed with an index based on Townsend's Scale incorporating income, home tenure, car ownership, social class and unemployment in a single scale (5).

Procedure

Testing at the schools was conducted in exactly the same way at baseline and follow-up. The group administered testing was conducted on 3 days each a week apart, counterbalanced for questionnaire order and time of day across noise exposure in the classrooms. The study was introduced as a Health and Environment study in to the teachers, parents and children. This introduction did not focus on noise to avoid response bias, a technique successfully used in previous studies. Noise questions were embedded in the health and environment section to counter the possibility of 'halo effects' biasing responding. Measurements at individual schools were carried out to assess indoor sound levels of aircraft noise during testing. Three factors were adjusted for in the analyses of the covariance (ANCOVA) in the fully adjusted model namely: age, main language spoken at home and household deprivation. All statistical tests were two-tailed and the alpha value was set at 0.05. A procedural error occurred in the testing session, over which the researchers had no control. The final low noise control school (26 students included in the analyses) supplied classes of lower ability rather than the requested representative children. Therefore, the results will be presented on all 8 schools and the 7 schools excluding the school with the biased sample selection.

3. RESULTS

Descriptive Results

Response Rates. The overall child response rate at baseline was 77 % across the eight schools. The overall child response rate at follow-up was 81% of the baseline sample across the eight schools.

Socio-demographic characteristics. The sample was well matched across sound levels for: class at school and sex (see Table 1). The high noise school sample had a higher proportion of non-white pupils and pupils with languages other than English as the main language spoken at home than the low noise schools (see Table 1). The high noise school sample had a slightly higher proportion of deprived participants than the low noise schools at baseline (see Table 1).

Home noise exposure. : Noise exposure at home was strongly associated with noise exposure at school according to local noise contours (1991 CAA noise contours); 80% of the children in high aircraft noise exposed schools lived in high aircraft noise exposed homes (>63 dBA Leq 16hr) and 86% of the children in low aircraft noise schools lived in low aircraft noise homes (<57 dBA Leq 16hr). This justified our choice of primary school children, who live fairly close to their schools as being suitable for the study of day-long noise exposure.

Table 1:

The demographic characteristics of the high and low noise child samples in at baseline(1996) and follow-up(1997): frequencies and proportions

Socio-Demographic Characteristic	**Baseline 1996**	**Baseline 1996**	**Follow-up 1997**	**Follow-up 1997**
Total	**High Noise N=169**	**Low Noise N=171**	**High Noise N=148**	**Low Noise N=127**
Year 4/5	82 (49%)	81 (47%)	66 (45%)	55 (43%)
Year 5/6	87 (51%)	90 (53%)	82 (55%)	72 (57%)
Girls	86 (51%)	85 (50%)	74 (50%)	69 (54%)
Boys	83 (49%)	86 (50%)	74 (50%)	58 (46%)
English	101 (65%)	154 (93%)	90 (66%)	116(94%)
Non-English	55 (35%)	12 (7%) *	46 (34%)	8 (6%)*
Not Deprived	76 (53%)	87 (64%)	68 (53%)	70(63%)
Deprived	68 (47%)	49 (36%) *	60 (47%)	41 (37%)

Note. Total percentages reported are of those known. Missing data are generally a small proportion of the sample, except in the case of social class, socio-economic group and deprivation. * Chi-squared tests were only run on total rows, these items ($\chi2$) $p<0.05$.

Cross-sectional noise effects at baseline & follow-up

Reading Comprehension. Chronic exposure to aircraft noise had no significant effect on reading comprehension in the analyses of the eight schools (see Table 2). However, in the 7 schools, children in the four high noise exposed schools had poorer reading comprehension than children in the three low noise schools at baseline and at follow-up (see Table 2). Sustained attention was entered as covariate into an ANCOVA model to test whether it mediated the relationship between chronic noise exposure and reading comprehension and it did not explain the significant association between noise at school and reading comprehension at follow-up.

Sustained Attention. Chronic exposure to aircraft noise was associated with poorer sustained attention in the analyses of the seven and eight schools at follow-up (see Table 2). A cut-point analysis of sustained attention demonstrated that in analyses of both the seven and eight schools that there was a significantly higher proportion of children with attention problems in the high noise schools. For the 8 schools 48 % of the high noise sample had scores below the cut off compared with 28 % of the low noise sample(χ_2 (1,241)=9.85, $p=0.001$

Noise Annoyance. Chronic exposure to aircraft noise was associated with higher noise annoyance in the analyses of the seven and eight schools at baseline and follow-up (see Table 2).

Table 2

Reading comprehension, sustained attention and noise annoyance mean scores adjusted for age, deprivation and main language spoken in the 4 high-noise schools, the 4 low-noise schools and the 3 low-noise schools (excluding the procedural error school) at baseline(1996) and follow-up (1997).

ognition and erformance utcome	**Four High Noise Schools Mean**	**Four Low Noise Schools Mean**	**Three Low Noise Schools Mean**	**F statistic, degrees of freedom and p-value for 8 schools comparison**	**F statistic, degrees of freedom and p-value for 7 schools comparison**
eading Comprehension aseline	98.48	100.01	102.66*	F(1,241)=0.94 p=0.334	F(1,220)=6.9 p=0.009
ollow-up	100.84	102.19	105.28*	F(1,196)=0.45 p=0.503	F(1,178)=5.0 p=0.027
ustained Attention					
follow-up	8.418	9.01*	8.91*	F(1,201)=8.01 p=0.005	F(1,183)=4.1 p=0.04
Noise annoyance baseline	1.18	0.54*	0.51*	F(1,250)=25.65 p=0.0001	F(1,228)=23.5 p=0.0001
follow-up	1.00	0.58*	0.56*	F(1,206)=9.75 p=0.002	F(1,188)=8.8 p=0.003

* P<0.05 *Note:* Sustained attention was only measured at follow-up

Within-Subject Analyses

Reading Comprehension. In the analyses with both the seven and eight schools after adjusting for baseline 1996 performance, performance in 1997 was significantly different between the high and low noise children (see Table 3 below). However, if further adjustments are made for age, main language spoken and deprivation the difference in reading comprehension performance in both the 7 and 8 schools fails to reach significance (see Table 3 below).

Noise Annoyance. In the analyses of the eight schools after adjusting for baseline noise annoyance (1996), noise annoyance at follow-up (1997) was significantly different between the high and low noise children (see Table 3). This did not remain significant after further adjustment was made for age, deprivation and main language spoken. There was no effect in the seven schools(see Table 3).

Table 3

Within-Subjects ANCOVA models a) adjusting for baseline performance on follow-up reading comprehension and noise annoyance performance and b) fully adjusted for age, main language spoken and deprivation in the 4 high-noise schools, the 4 low-noise schools and the 3 low-noise schools (excluding the procedural error school) in 1997.

Performance at follow-up	**Four High Noise Schools Mean**	**Four Low Noise Schools Mean**	**Three Low Noise Schools Mean**	**F statistic, degrees of freedom and p-value for 8 schools comparison**	**F statistic, degrees of freedom and p-value for 7 schools comparison**
Reading Comprehension Score at follow-up adjusted for baseline performance	100.1	101.9*	103.3*	F(1,225)=4.57 p=0.03	F(1,204)=4.8 p=0.03
fully adjusted	100.8	101.6	103.2	F(1,191)=0.8 p=0.372	F(1,173)=1.2 p=0.266
Noise Annoyance at follow-up adjusted for baseline performance	0.92	0.65*	0.68	F(1,245)=5.42 p=0.02	F(1,222)=3.3 p=0.069
fully adjusted	0.88	0.69	0.69	F(1,204)=2.00 p=0.16	F(1,186)=1.6 p=0.197

* $p<0.05$

4. DISCUSSION

Chronic exposure to aircraft noise was consistently associated with high levels of annoyance. Against the background of previous studies our findings suggest that noise exposure impairs reading comprehension. Moreover, this effect is not substantially confounded by social deprivation or main language spoken and nor was it mediated by sustained attention. These results do not support the hypothesis that sustained attention mediates the effects of noise on cognition in children. The within-subjects analyses indicate that childrens' development in reading comprehension may be marginally significantly adversely affected by chronic aircraft noise exposure. Noise annoyance remains constant over a year with no strong evidence of habituation. Taking all these results together we conclude that our results support the evidence that chronic aircraft noise exposure at school impairs reading comprehension and results in persistent annoyance. Although our results do not conclusively demonstrate that noise presents a significant threat to child health, they do suggest that aircraft noise presents a significant threat to children's reading ability and quality of life. Further investigation of the long-term effects of aircraft noise in larger samples of children is urgently needed.

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ACOUSTIC DETERMINANTS OF AUDITORY DISTRACTION BY IRRELEVANT SOUND

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For some three decades, between the nineteen fifties and the nineteen eighties, the main subject of the study of the effect of sound on performance research was broadband noise. Indeed the main variable of interest was the intensity of broadband noise. There were few, if any, studies on meaningful noise and then only coupled rarely to exploring the effects on performance. Indeed, the main reason for using white noise was to avoid the possiblity that the extraneous noise would capature the attention of the person for reasons connected with meaning. In this decade, by contrast, we have witnessed a marked growth in interest in the effect of irrelevant sound on performance. There have been two main forces behind this growth: the first is that the effects were robust and second, there was the increasing realisation that relatively more of the sound to which people were exposed was verbal and these sounds were not particularly loud. Here the main variables of importance have turned out to be quite different to those of research in the more traditional mould. In addition, the explanatory construct of behavioural arousal has been supplanted by other, more cognitive constructs.

The contemporary study of irrelevant sound has been pursued, primarily, through studying the effects of various classes of sound on short-term memory performance. Generally, two classes of variable have been studied; one relates to the charactersitics of the task and to what makes a particular form of task sensitive and the other relates to the charactersitics of the sound that bring about the disruption. In this short review we concentrate on the acoustic effects and exclude the task effects.

1. THE IRRELEVANT SOUND PARADIGM

Typically, experimental participants undertake a simple memory task, one involving the memory for order of a series of randomly ordered numbers or syllables, for example [1]. Usually, the items to be remembered are known in advance to the participant, only the order is novel. Usually also, these to-be-remembered items are presented visually in a series, and there is also a period when nothing is presented but during which the person is expected to rehearse the items while waiting for a cue to recall the items in order. A person typically undertakes several trials; on some sound is presented while on others there is quiet. The participant is told to ignore the sound and reassured that no test of its contents will take place.

During those trials on which the sound is presented performance is markedly worse, by some 30 to 50 %, than on the quiet trails. The important logical point is that this implies that the processing of sound is somehow obligatory. Furthermore, since the to-be-remembered and irrelevant events are in different modalities, the effect is not one of peripheral masking.

2. THE EFFECTS OF CHANGE

A key feature of the irrelevant sound effect is that change within the auditory stream is an important determinant of the degree of disruption. An auditory sequence made up from repeated tokens (tones or words) is much less disruptive than a sequence made up of different tokens [2]. Subsequent research has been aimed at showing how the relationship between the degree of change and the disruption of performance can be modified.

3. THE EFFECTS OF CHANGES IN INTENSITY

Initially it was thought that any acoustic change in the irrelevant sequence would be sufficient. Subsequent work has shown that this is not the case, and in one very important respect, insofar that changes of intensity seem to have very little impact on the degree of disruption, in other words intensity does not produce a changing state effect. This has been demonstrated experimentally in two ways. One is by changing the level of the irrelevant sound between trials so that the overall level of the sound remains stable but changes when the next trial commences [3]. The other way is to change level from token to token in the irrelevant stream [4]. In both cases change produces no additional disruption relative either to an unchanging token or to quiet. We suggest that this result has important implications for abatement insofar as it suggests that the sound has to be below the threshold of audibility for its damaging effects to be overcome.

4. SEGMENTATION

One way of overcoming the effects of sound without reducing the level to below the threshold of audibility is to capitalise on what is known of the effect of babble speech. If the number of voices arising from a monaural source is increased then so does the degree of disruption. But this is only true up to a point. As the number of voices exceeds about four then the degree of disruption begins to diminish. This trend can be explained by supposing that as more voices are added, the difficulty of segmenting the sound increases. Other studies have been instrumental in suggesting that sudden change at the boudaries of events is important. Slow changes in the pitch of sound produce very little disruption compared to sudden changes [5] (as is the case for legato as opposed to staccato music [6]). Research as yet unpublished indicates an important role for acoustic changes at the onset of sounds, be they tones or speech.

5. STREAMING

To restore the disruptive effects of babble speech containing many voices, we may capitalise upon the fact that unattended sounds are streamed in very much the same fashion as attended sounds. Specifically, the disruptive power of babble with more than four voices can be restored by assigning each voice to a different loudspeaker. The voices are not now masked by each other and the processing of unattended sound resolves them into their component voices on the basis of their location [7].

The ability of the perceptual system to stream sound while it is unattended has proved to be a powerful analytical tool. It can be used to demonstrate that effects of changing state previously thought to be monotonically related to disruption are in fact non-monotonically related. Take the instance of pitch. According to a simple version of the changing state hypothesis the level of mismatch between pure tones in an irrelevant sequence should determine the degree of disruption. Indeed, if we chart the level of disruption in relation to the difference in pitch in a sequence we find it increases monotonically. This result might be taken to imply also that as we add acoustic attributes that vary, the disruption should increase also. For example, if we vary the timbre of a sound (by using sine, square or sawtooth waveforms) then there is more disruption than if the timbre is repeated. If we vary both pitch and timbre together disruption does not increase, in fact it diminishes significantly [8]. Why should this be so given that in other circumstances the degree of change seems to be the primary determinant?

This result can be best understood in relation to what is known about how sequences of sounds are themselves remembered. In a classical series of studies it was demonstrated that memory for an unrelated series of sounds was very poor, seldom exceeding chance levels. When two sounds that were related in timbre, but which were nevertheless distinct from one another were introduced into these sequences memory for the order of events improved dramatically [9]. Generally, if two sounds are different but related, memory for their order is good in that they are variants on the same 'object' or 'voice'. If the sounds are not bound by this object quality then memory for order becomes poor. In our example of adding pitch changes and timbre we can infer that when both attributes changed the tendency for events to cohere is reduced. If this analysis is correct what it implies is that the degree of disruption of unattended sound is predicted from knowing how well the order of those sounds can be recalled when the sound is attended. More abstractly, we would claim that cues to seriation or order in the irrelevant sound is the key determinant of disuption.

This conclusion can be supported in a range of ways. One is to show how the effects of change of pitch can be modulated by streaming. If we alternate two pitches and gradually increase the pitch difference, a listener will experience at first an alternating tone but one which is recognisably a variation of the same perceptual 'object'. However, as the pitch of the sound is increased beyond a certain point, the sequence now results in a fissile percept; typically, the sequence seems to comprise two 'objects' each of which is a repeated pitch. This tendency for fusion to give way to fission as the pitch difference increases can be capitalised upon to demonstrate the interplay of change and streaming.

If we employ a range of pitch difference along a continuum that covers both fusion and fission as irrelevant sound, a non-montonic relationship between pitch difference and performance emerges. That is, as the difference in pitches within the sequence increases, disruption of performance is at first small, but increases gradually as the pitch difference increases. But, when the pitch difference within the irrelevant stream is at or above the level at which fission typically occurs when the sequence is being listened to deliberately, then dirsuption diminishes [8].

That the effect of acoustic factors is modified by the streaming of sound has now been demonstrated in several ways, including auditory restoration [5] and streaming by rate [10]. It is now clear that the extent of disruption cannot be predicted from the description of the isolated events within the irrelevant sequence; rather, the relation between events and the organisational processes they invoke is a crucial determinant of the irrelevant sound effect.

6. CONCLUSIONS

Recently emerging evidence from the study of irrelevant sound has produced a number of findings that have implications noise abatement. The effect of level in this setting is rather small, but change in the acoustic signal (whether that be speech or non-speech) is an important determinant of distraction. Critically, the smaller degree of disruption found with repeated events does not seem to be an effect of habituation [11]. Finally, a range of studies has shown that streaming occurs when sound is unattended; furthermore, the organisational factors illustrate that a process related to the ordering of unattended events seems to impair memory. This work suggests an appreciable threat to efficiency in a range of settings, particularly in offices or control rooms.

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COGNITION, CHILDREN AND EXPOSURE TO TRANSPORTATION NOISE - PATTERNS OF PSYCHOLOGICAL EFFECTS

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1. BACKGROUND

Numerous studies have uncovered associations between exposure to transportation noise and ensuing psychological impairment. Findings suggest deficits from noise exposure on health, psychophysiology, perception, communication, auditory discrimination, annoyance, attention, memory, learning, reading, language skills, intellectual achievement and motivation. Effects have been reported both for chronic and acute noise exposure.

Nonauditory noise effects on children have been critically reviewed by Evans and Lepore [1]. They divided *cognition* into three subtopics: (i) attention and perception, (ii) memory, and (iii) intellectual achievement, and included sections on (iv) mediational processes and (v) methodological concerns

Attention and Perception

With regard to attention and perception they stated that children chronically exposed to noise learn to tune out or ignore auditory stimuli. At least during the first years of noise exposure, children from noisy residential areas appear to be more resistant to auditory distractors. This ability to tune out auditory stimuli has the good advantage of tuning out sounds that are not relevant to task performance, but also the disadvantage of also tuning out meaningful and relevant sounds, such as speech. This can explain why children chronically exposed to noise also suffer from deficits in auditory discrimination. A recent study [2] has corroborated that conjecture in reporting reading deficits for first- and second grade children exposed to chronic aircraft noise. The chronically exposed children also had impaired speech perception, but not sound perception. Impaired speech perception was assumed to partially mediate the noise-exposure -- reading-deficit link.

The Munich study on aircraft noise [3, 4, 5(at this conference)] reported that the close down and opening of airports improved respectively impaired children's language performance. Results from the old airport before it was closed down also indicated that aircraft noise exposed children were satisfied with a lower signal-to-noise ratio in a listening task, as if they had better auditory discrimination. However, the children's auditory discrimination performance was not tested by itself, but screening for hearing impairment showed no difference between aircraft noise exposed children and quiet controls.

Memory

Evans and Lepore [1] stated that although there is little research on children's memory under chronic and acute noise exposure, there seems to be little or no effect on children's short term or working memory. They made an exception when the memory tasks put demanding loads on working memory. In studies published after their review long term recall of a difficult text has been shown to become impaired by transportation noise, both with acute [6] and chronic noise exposure [3, 4, 5].

Intellectual Achievement

In their review Evans and Lepore [1] covered more than twenty studies of noise and intellectual achievements. Their main conclusions, qualified by the often less than adequate methodological rigor in the studies reviewed, included that acute noise exposure appears to have little or no effect on intellectual activities. Chronic noise exposure, on the other hand, has been associated with reading deficits in a clear majority of studies. Subsequent studies have supported and extended that conclusion. The Munich study on aircraft noise [3, 4, 5] reported that the close down and opening of airports improved and impaired respectively children's language performance.

Mediational Processes

In discussing the mediational processes between chronic noise exposure and cognitive deficits Evans and Lepore [1] pointed to several main possibilities, including: (a) noise masking speech (b) noise impairing language acquisition, (c) noise leading to techniques for filtering out auditory sounds, and (d) noise narrowing attention. The alternatives should not be seen as excluding each other, but rather as different main possibilities.

Evans and Lepore concentrated their review and an analysis of what noise does at the cognitive input side, not what noise does to storing and retrieving cognitive material. That is, they did not make explicit assumptions about how noise affects encoding and acquisition in contrast to effects on memory-storing, retrieval and performance. For example, it can be stated that noise affects the quality in which information is stored in memory, even without affecting the encoding or performance phase of that task. The studies referred to above on long-term memory [3, 4, 5, 6] indicated that the amount of text read did not differ between noise exposed and quiet conditions, although memory did. This could imply that attention or encoding did not differ because of noise, but since memory performance was affected the storing or retrieval of the material can be assumed to be impaired by noise.

Methodological Concerns

Many of the studies reviewed by Evans and Lepore [1] lack appropriate methodological controls. Two flaws that are the most common: (i) In cross-sectional field studies there is too often not an adequate match for e.g., socioeconomic and sociodemographic variables. Also, (ii) when children residing in communities that differ in noise exposure are tested for cognitive performance in their regular settings, there is a confound between how much chronic noise exposure may have impaired their abilities and how much the acute noise exposure from their regular settings impair their performance at the cognitive test.

To protect against the first of these short-comings quasi-experimental prospective longitudinal studies with detailed matching are the most wanted. To disentangle the chronic noise effects on cognition and the acute effects on test performance, testing for cognitive abilities should always be performed in a context that is quiet and equal in noise level to the groups compared.

2. TRANSPORTATION NOISE

Effects of transportation noise on children's cognition are important to analyze for several reasons. Firstly, transportation noise is by far the most dominant noise source in modern society. Secondly, the number of studies of noise on children's cognition and school performance are sufficient to permit some preliminary conclusions on what is affected and to what extent. Thirdly, there are theoretical models of attention, memory, and learning to expand on in a finer analysis of the noise effects.

The review provided by Evans and Lepore [1] in 1993 is a good platform for a finer analysis of the effects of transportation noise on children's cognition. By posing a number of conceptually driven specific questions on the effects of transportation noise on children, and by trying to find empirically based answers some advancement can be made in pinpointing the mediating and moderating processes between noise exposure and cognitive impact.

In the next section a limited number of such specific issues are phrased and tentatively answered, mainly with data from [3, 4, 5, 6].

3. SOME SPECIFIC ISSUES

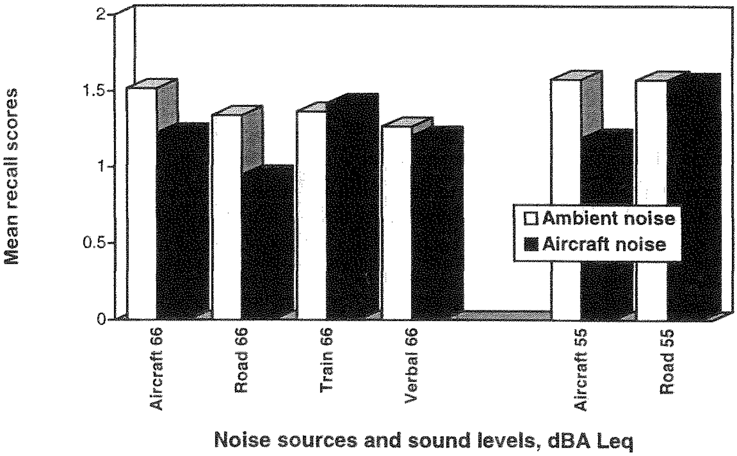

Figure 1. Mean scores on the long-term recall test in the classroom experiments

Are there differences between transportation noise sources in their psychological effects? Surveys of noise annoyance have indicated that at the same physical sound level, aircraft noise is more annoying than road traffic noise, which in turn is more annoying than train noise [7, 8, 9, 10, 11]. In a series of classroom experiments Hygge [6] has reported the same differences between noise sources on the long term recall of a read text. See Figure 1!

A possible explanation of why train noise, in contrast to aircraft and road traffic noise at the 66 dBA L_{eq}-level, did not show any effects on learning is the predictable nature of the train noise, and its low degree of fluctuation. Predictability as an explaining principle of the noise effect may also be extended to the road traffic noise at the 66 dBA L_{eq}-level, but not the 55 dBA L_{eq}-level, since there was no effect of road traffic noise at the lower level. To explain the noise effects at both levels, the predictability principle must be supplemented with something more. It is suggested that in order for the predictability principle to work, a certain noise level, e.g., 60 dBA must be exceeded a substantial fraction of the time.

Are the effects of acute and chronic noise exposure different within and between cognitive functions? Results from the Munich study [3, 4, 5] indicate that for chronic aircraft noise exposure long-term recall and language abilities are more vulnerable to noise than e.g., running memory, and problem solving. From classroom experiments [6] it has been shown that long-term recall, but not long-term recognition, is impaired by acute exposure to aircraft and road-traffic noise. In the review by Evans and Lepore [1] there are indications that reading and language abilities are more impaired by noise than mathematical skills are.

Thus, it seems probable that central processing of language based information is more sensitive to noise impairments than other cognitive processes are, at least with chronic noise exposure, but maybe also with acute noise exposure.

Are reliable noise effects reversible or irreversible? Results from the old and new airports in Munich [5] indicate that some noise effects are reversible, i.e., when the old airport was closed down long-term recall and language abilities improved, while the opposite was true at the new airport.

Are there differences between noise effects at acquisition and performance? This issue in many respects is the same as **Are there differences between noise effects on memory at encoding and retrieval?** That is, they both pose the question of where in a memory-learning chain any noise effects takes place. Is the effect mainly working at the input end, the retrieval end, or in the storing in between? Relevant data are scanty but an argument from above on attention and long-term memory can be reiterated. In [3, 4, 5, 6] there are indications that the amount of text read did not differ between noise exposed and quiet conditions, although long-term recall did. This could imply that attention, acquisition, or encoding did not differ because of noise, but that the storing of the material could have been affected by noise e.g., by interference with the build up of permanent memory traces.

Are there any consistent time-patterns in they way cognitive functions respond to noise? Yes, in the Munich study [5] long-term recall, language abilities, blood pressure and neuroendocrinal levels are significantly sensitive to changes in aircraft noise. Consistent time-patterns between cognitive functions in the onset or offset of noise effects have not yet been looked for, but such analyses are underway.

This issue is related to the issues of **Are there sensitive markers or cognitive functions for the detection of early or strong noise effects?** and **Are there reasons to believe that sensitive markers are interlinked with, mediated or moderated by other psychological variables?** Two examples of alternative causal patterns are given in Figure 2. The examples given are not meant to exhaust the available theoretical possibilities, but are just examples.

In the upper panel, a strict unidirectional time-pattern is suggested, starting with changes in psychophysiological response systems and ending up with changes in quality-of-life measures.

The lower panel suggests another cause-effect chain, more similar to psychological stress theory [c.f. 12], where changes in cognitions are the starting points and changes in psychophysiological response systems the endpoints when the response systems in between have been exhausted.

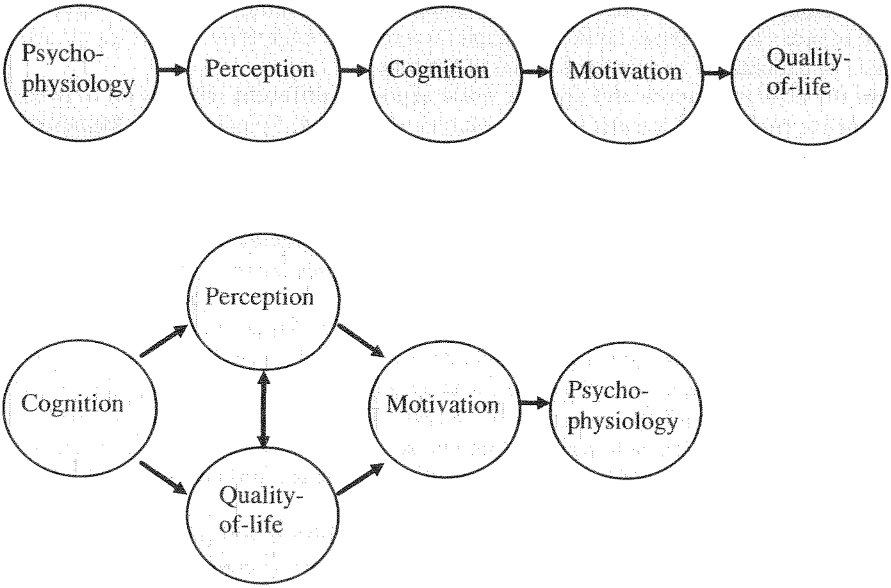

Figure 2. Two examples of alternative causal patterns

However, it has not yet been analyzed whether anyone of these measures are more sensitive than the others or comes ahead in time. To make such analyses it is important to extract a limited set of explicit relationships between the response systems and put them to statistical tests. The extraction of the models to test must rely on psychological stress theory and relevant empirical work. That extraction process has started but is by no means finished.

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NOISE, NEUROTRANSMITTERS AND PERFORMANCE

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1. INTRODUCTION

Much of the previous research on noise has been descriptive [1] and has aimed to provide a profile of noise-induced effects. Explanation of the various effects has been difficult because the different areas of research are often unrelated and the theoretical frameworks have ranged from those concerned with energetics (e.g. changes in arousal), to precise cognitive mechanisms associated with specific phenomena (e.g. the irrelevant speech effect). The present paper considers two types of effects associated with continuos broadband noise and addresses the question of whether there are plausible neurotransmitter mechanisms to account for these phenomena.

The two types of noise effect that I will discuss are two of the areas identified by the late Donald Broadbent and his co-workers. Broadbent [2] discusses the relationship between psychology and physiology. The first point that he raises is that attempts to link physiology and psychology can be disastrous when they are premature. However, he also adds that it would be equally disastrous to go on treating the brain as an abstract entity with no biological reality. Indeed, he concludes that 'behavioural studies and the physiological attack on the brain must go hand in hand'. It is hoped that the present paper presents some evidence of this convergence between neuroscience and performance in noise.

2. NOISE, LOW LEVELS OF ALERTNESS AND LAPSES OF ATTENTION

Much of the research on noise has been concerned with demonstration of detrimental effects. However, there are clear instances in the noise and performance literature which show that noise improved performance. One of the situations where noise improves performance is when alertness is reduced by factors such as sleep deprivation [3]. Sleep deprivation leads to momentary lapses of attention which are manifested in terms of missed signals or occasional very long reaction times. Noise counteracts the effects of sleep deprivation and reduces lapses of attention in sleep deprived individuals.

The above result was initially explained in terms of sleep deprivation reducing alertness and noise increasing arousal to bring the person's state closer to the optimum. Studies have shown that a uni-dimensional approach to arousal is unlikely to succeed and this view is supported by research on neurotransmitter systems. At least five neurotransmitter systems regulate arousal of the cerebral cortex and thalamus. Although a great deal is known about individual neurotransmitters much less is known about their interactions. The first step, therefore, is to consider individual neurotransmitters to determine whether pharmacological challenge of those systems can mimic the effects of noise.

Noradrenaline and Lapses of Attention

The first aim of the present study was to determine whether the increase in lapses of attention in low arousal states could be induced pharmacologically by inhibiting central noradrenaline release using a clonidine challenge. A second aim was to examine whether noise would remove lapses of attention induced by clonidine, and whether idazoxan, an alpha-2 adrenoceptor antagonist, which increases central noradrenaline release, would produce similar effects to noise.

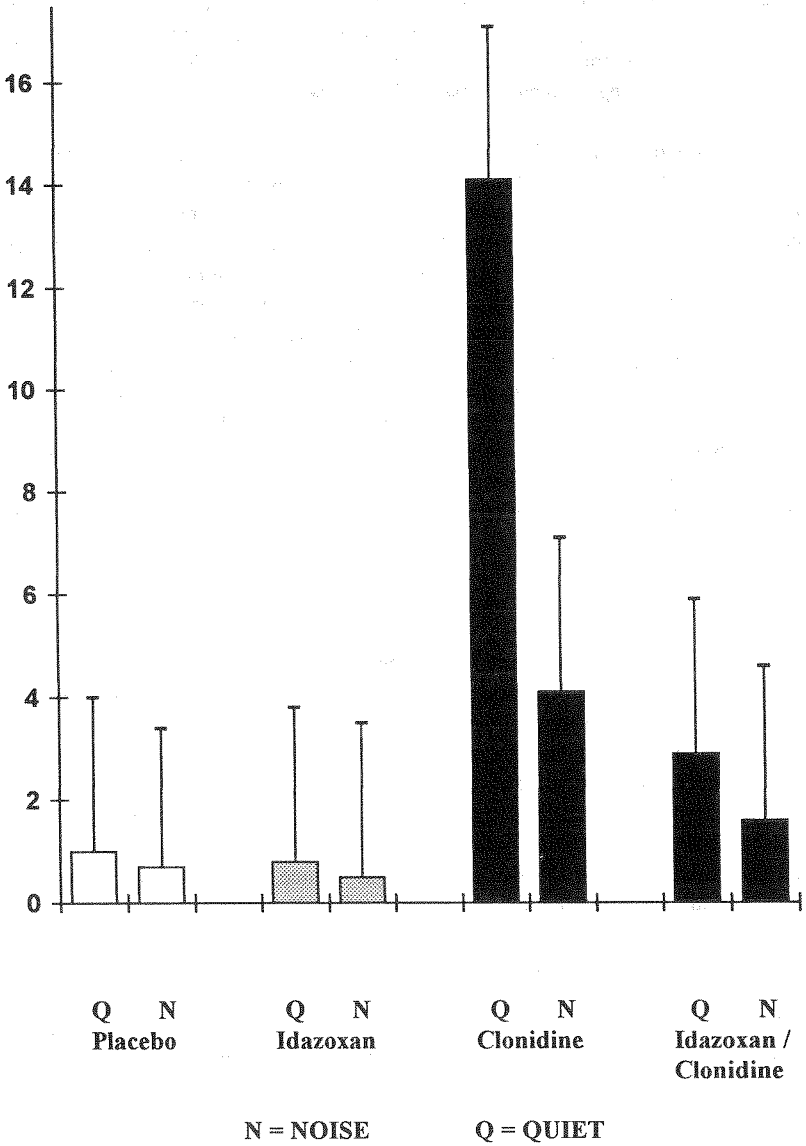
The present study focused on central noradrenaline for several reasons. First, a large body of animal and clinical studies have implicated brain catecholamine pathways in the control of attention [4,5]. Indeed, it has specifically been demonstrated that activation of the noradrenergic neurones facilitates behavioural responses to subsequent sensory cues, which is consistent with a role for this system in sustained attention [6]. Secondly, there is strong evidence that noradrenergic neurones are especially active during high states of arousal, such as those induced by exposure to noise [7].

The clonidine challenge is an established method of testing alpha-2-adrenoceptor function in man [8]. Clonidine is an alpha-2-agonist that in low doses acts pre-synaptically to decrease noradrenergic cell firing and noradrenaline release. Idazoxan is an alpha-2-adrenoceptor antagonist that reverses the functional effects of clonidine and increases noradrenaline release when used alone [9]. The expectation in the present study was that lapses of attention would increase following clonidine challenge, and this effect would be reversed by exposure to noise or by taking idazoxan.

A parallel groups, double-blind study involving challenge with placebo (P), idazoxan (I), clonidine (C) and I+C was conducted. Half of the subjects were tested in quiet (50 dBA) and half were played broadband noise (at a level of 75 dBA) over headphones. Subjects were given a medical examination, a familiarisation session, and then a baseline test followed by 3 post-drug tests. The study was approved by the local Ethics committee and conducted with the informed consent of the subjects. The subjects were 74 males (seven groups of nine subjects and one of eleven), aged 18-35 years. The task considered here was a 2-choice reaction time task involving focused attention and selective response to the letters A or B [10]. Lapses of attention (defined in the traditional way as RT's> 1500 msecs) were recorded. Baseline testing occurred between 9.00 and 10.30, administration of drugs at 10.30, and post-drug sessions at 11.00, 13.00 and 15.00. The drugs were given orally (40 mg idazoxan; 200 micrograms clonidine; the placebo was lactose). Ideally, one would have liked to conduct a dose-response study. This was not practical but as testing took place at the absorption phase, peak and when plasma levels were in decline it was possible to make some assessment of effects of plasma concentration. The doses used were based on previous research and are known to produce significant effects on noradrenaline release in the brain [8,11]. Other measurements were taken during the test session (mood, cardiovascular recordings, saccadic eye velocity, and performance scores of other aspects of attention), the purpose of these being to demonstrate that the experimental manipulations changed alertness.

Figure 1 shows that the number of lapses of attention was markedly greatest in the clonidine, quiet condition. This effect was reversed by idazoxan and noise. An analysis of covariance showed a significant drug x noise interaction ($F_{3,65} = 3.77$, $p<0.05$) and specific comparisons showed that the clonidine, quiet mean was significantly greater than all the other conditions, which did not differ from one another. The effect of clonidine did not changes significantly over the post-drug sessions. These results clearly demonstrate that central noradrenaline is important in maintaining attention. The effect of clonidine was obtained using a low dose which reflects pre-synaptic inhibition of release of noradrenaline [12], a suggestion supported by the fact that it was fully reversed by idazoxan, an antagonist of these receptors. The reversal of the clonidine effect by noise is consistent with the view that increased arousal is associated with noradrenaline release. The results also showed that selective attention was not altered by changing noradrenaline and this makes it difficult to account for noise effects on this function in terms of noradrenergic changes. It should also be pointed out that other neurotransmitter systems may play a similar role and further research is necessary to determine whether they are important in noise-induced performance effects.

Figure (1). Effects of the different drug and noise conditions on lapses of attention (RT's > 1500 msec).
[Scores are the adjusted means from an analysis of covariance.
S.E.s shown as bars]



3. STRATEGIES OF PERFORMANCE IN NOISE

More recent research, usually using moderate intensity noise, has shown that noise influences the strategy used to carry out a task. This may be reflected in several ways but generally there is a reliance of certain types of processing at the expense of other processes (e.g. reliance on well-rehearsed lower levels of processing at the expense of strategies involving behavioural inhibition and mental flexibility). Recent animal work suggests that noise produces neurotransmitter changes which lead to selective dysfunction of the pre-frontal cortex [13]. This could plausibly account for the strategy changes observed in noise, and the main features of the study are outlined below.

Biochemical studies have shown that mild stress increases turnover of dopamine in the pre-frontal cortex (PFC). Spatial memory with a delayed response is dependent on the PFC. The study, therefore, examined the effects of noise and drugs which decrease dopamine receptor stimulation on the spatial memory task and visual pattern discrimination (dependent on the inferior temporal cortex).

Exposure to noise led to impairments on the spatial memory task and this was reduced by drugs which block dopamine receptors (e.g. halperidol) or reduce the noise-induced dopamine turnover (naloxone hydrochloride). This suggests that noise impairs aspects of cognitive behaviour through a hyperdopaminergic mechanism. It is as if the pre-frontal cortex is taken "off-line" to allow more habitual processes to dominate behaviour. This, perhaps, has survival value but may more often be maladaptive in human society and lead to a profile of performance impairments that is consistent with PFC impairments induced in other ways.

4. SUMMARY

The present article has provided two example of the effects of noise on neurotransmitters and performance. Clearly in any particular study it is difficult to know what effects the noise is having on the different neurotransmitter systems. Similarly, it is unclear which effects are specific to noise and which reflect more general stress/arousal effects. The studies do suggest, however, that by combining noise with pharmacological challenges we may gain a better understanding of what the noise is doing to the brain. Indeed, the addition of brain scanning will provide further information on the CNS effects of noise. Once these have been elucidated one can then address the practical implications of such effects.

5. ACKNOWLEDGEMENT

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THE EFFECTS OF NOISE ON MEMORY

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1. INTRODUCTION

The main objective of this article is to present an overview of an experimental study examining verbal- and road-traffic noise influences on memory in high school students. Knowing the details about how different noise sources affect memory, is important practical knowledge about learning environments such as schools, but also a very important key to the theoretical understanding of noise effects in general. The experiment is a platform for future projects about noise effects on memory systems and levels of memory processing at different ages. The study took advantage of representative tasks from the Betula project, a prospective study on memory, health and ageing with 3000 subjects [1]. The battery of memory tasks was supplemented with questions about mood, stress and perceived health. Another aim of the study was to try out focus groups interviews on noise problems in schools.

Theoretical Considerations

Two memory research approaches were of particular interest, the levels of processing view [2] and the memory systems view [3]. The idea of the levels of processing approach is, that the more actively incoming information is processed, the better the long-term recall will be. Tulving [3], on the other hand, separated five but interacting systems in memory; procedural memory, perceptual representation system, semantic memory, primary memory and episodic memory.

2. METHOD

Before setting up the experiment in the laboratory, interviews with teachers and school-children were performed to find out about noise sources relevant to learning in schools. The most often reported bothersome noise source of complaint was verbal noise. Hygge [4] reported that road-traffic noise impaired learning in school-children with 30 % on recall items. Verbal noise and road-traffic noise were therefore chosen for this experiment.

In the Betula project [1] the subjects were tested individually while in the present experiment the tasks were solved individually but three to four subjects were run at the same time. Therefore, some of the tasks had to be revised for the present experiment.

Subjects

A total of 96 subjects took part in the experiment. The subjects, aged 18-20, were students in their final two years of high school. They volunteered and participated in return for payment. Subjects were randomly assigned to one of three experimental conditions: (a) ambient noise (silence) (n = 16 males, 16 females), (b) verbal noise (n = 16 males, 16 females), and (c) road-traffic noise (n = 16 males, 16 females).

Experimental Setting

The study was performed in a chamber (4 x 6 m) in which the air temperature (21°C) and light (900 lux) were controlled. In the noise conditions, verbal- and road-traffic noise were played back through loudspeakers in front of the room. In front of the subjects there was also a computer screen.

Independent Variables

There were three experimental conditions, (a) ambient noise ($\approx$38 dBA L_{eq}), (b) verbal noise: peaks with irrelevant speech with meaning and background noise without any meaning and (c) road-traffic noise. For verbal- and road-traffic noise the equivalent sound level L_{eq} was set to 66 dBA 2 m in front of the loudspeakers. The noise conditions were composed of background noise at 63 dBA and peaks (fast) at $\approx$78 dBA, which occurred intermittently at on the average once per minute. Duration of the peaks were 5.5 - 14.6 s and they occurred at the same points in time for the verbal- and road traffic noise presentations. The noise conditions were set and measured by a sound level meter before the subjects entered at the experimental room.

Tasks and Procedures

1) Self-report affect circumplex measures [5] (5 min). At the beginning of the experimental session and in silence, the subjects filled in the questionnaire. Perceived stress and mood were rated on a Likert-scale with 5 points. In all there were 48 items.

Tasks with both encoding and performance in verbal -, road-traffic - or ambient noise. 2) Search and memory task (SMT) [5] (6 min). According to Tulving [3] primary memory demands attention. Subjects were presented with lines of letters for five target letters given at the beginning of each line. They were asked to memorise the given targets and search through the given line only once, and draw a line through any target found. Each line contained 59 letters, 0-4 of which were targets. In this way attention was measured.

3) Reading a text during 15 min about an ancient culture. The text was a revision of the text used by Hygge [4] in class-room experiments. In order to prevent the readers from using their knowledge about the actual culture, certain nouns and names were replaced by imaginary nouns and names. Recall and recognition were tested later in the experiment both in road-traffic noise and silence (to control for context-dependency, see below).

4) Face and name encoding for later test of intentional and incidental learning in episodic memory (6-7 min). The task was revised from the Betula project [1]. Subjects were presented with 16 colour pictures of faces of 10 years old children. Each picture

was presented for eight seconds on a computer screen. Together with the presentation of each picture, a made-up first name and family name were presented. The subjects were instructed that they later would be tested for recognition for the family name.

5) Enacted sentences with and without enactment - encoding (5 min). There were two lists with different sets of 16 sentences each. For one of the lists the encoding was with enactment and for the other one without. Half of the subjects in all conditions were given the enacted list first. The subjects were instructed to try to remember the sentences. Each sentence was presented on a computer-screen for eight seconds. The enactment procedure was done by self-performing without any real objects [6]. In the Betula study there were verbal instructions and the enactment was done with real objects [1]. Episodic memory with and without a motoric component were tested.

6) Word fluency [1]. There were three different tasks. The first task was to generate as many words as possible with the initial letter A. The second task was to generate five-letter words with the initial letter M and the third task was to generate as many names of professions with the initial letter B. Each task was done during a period of one minute. General knowledge in the semantic memory was tested.

7) Word comprehension [1]. The subjects were presented with a list of 30 target words and next to each word there were five other words presented. Among these five words there was one synonym to the target word. This task, which was tested the general knowledge semantic memory, was allotted for seven minutes.

8) Word-stem completion [1]. The subjects were presented with word-stems and was asked to say the word that came to mind. Perceptual priming in PRS was tested for six minutes.

9) Search and memory task [5] (6 min). Replication of task 2.

Performance on the following tasks was performed in silence for all subjects. 10) Self-report affect circumplex measure [5](5 min). Perceived stress and mood were rated on a Likert-scale with 5 points. In all there were 48 items.

11-12) Free recall of the sentences encoded with and without enactment (no 5 above). The subjects' task was to generate as many as possible of the sentences encoded earlier. Four minutes were allotted for this task. Immediately after the free recall test there was a cued recall test. There were eight category names presented for the subjects, and they were instructed to recall as many nouns from the sentences as possible from each category for three minutes. Episodic memory with different cues was tested, the first task with a motoric component and the second with a semantic cue.

13) Recognition test of first and family name (no 4 above). Revised from the Betula study [1]. Presentation of 24 faces and names. Twelve were target faces and names and 12 were distracter faces and names. Target and distracter faces appeared one by one for 15 s on a computer screen in a random order. The faces were first presented without the names. The subjects' task was to decide if they recognised the face from the earlier presentation or not. Immediately afterwards the same face appeared with four different name combinations. If the subjects recognised the face in this second presentation they were instructed to choose one of the name combinations. Episodic memory was tested with recognition for faces and names. Incidental and intentional memory was tested with recognition for first and last names.

14) Cued recall of the sentences encoded with and without enactment. Revised task from the Betula study [1]. The subjects were presented a phrase, on a computer-screen,

with the verb from the earlier presentation of sentences. The task was to fill in the missing noun in the phrase. In all there were 32 phrases and each phrase was shown for eight seconds. Episodic memory with a semantic cue was tested.

15) Test of recall and recognition encoded during task 3 revised from Hygge [4] (5 min).

Performance in road-traffic noise. 16) Continued test of recall and recognition from task 3 revised from Hygge [4] (5 min) in road-traffic noise for all participants to control for context-dependency learning.

After the experimental sessions. 17) Demographic variables were taken, e.g., gender, age, education level, self-rated health and grade point in English, Swedish and maths.

Focus Groups Interviews

To get a broader perspective of students' experience of noise, focus groups interviews were performed after the experimental sessions with four informants in each group (N=16). A general interview guide with a set of issues decided in advanced was used. The issues were composed from four themes: knowledge/information, emotions, strategies/behaviour and a perceptual theme. These themes covered three different environments: the experimental situation, the school environments and future changes.

Preliminary Results

Analyses of data from the experimental study have started. Preliminary results show that verbal noise is more demanding for attention compared to the ambient noise condition. The focus groups interviews support this result. In the future analyses, the importance of attention on the performance of memory systems will be further investigated.

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The study was performed in a chamber (4 x 6 m) in which the air temperature (21°C) and light (900 lux) were controlled. In the noise conditions, verbal- and road-traffic noise were played back through loudspeakers in front of the room. In front of the subjects there was also a computer screen.

Independent Variables

There were three experimental conditions, (a) ambient noise (≈38 dBA L_{eq}), (b) verbal noise: peaks with irrelevant speech with meaning and background noise without any meaning and (c) road-traffic noise. For verbal- and road-traffic noise the equivalent sound level L_{eq} was set to 66 dBA 2 m in front of the loudspeakers. The noise conditions were composed of background noise at 63 dBA and peaks (fast) at ≈78 dBA, which occurred intermittently at on the average once per minute. Duration of the peaks were 5.5 - 14.6 s and they occurred at the same points in time for the verbal- and road traffic noise presentations. The noise conditions were set and measured by a sound level meter before the subjects entered at the experimental room.

Tasks and Procedures

1) Self-report affect circumplex measures [5] (5 min). At the beginning of the experimental session and in silence, the subjects filled in the questionnaire. Perceived stress and mood were rated on a Likert-scale with 5 points. In all there were 48 items.

Tasks with both encoding and performance in verbal -, road-traffic - or ambient noise. 2) Search and memory task (SMT) [5] (6 min). According to Tulving [3] primary memory demands attention. Subjects were presented with lines of letters for five target letters given at the beginning of each line. They were asked to memorise the given targets and search through the given line only once, and draw a line through any target found. Each line contained 59 letters, 0-4 of which were targets. In this way attention was measured.

3) Reading a text during 15 min about an ancient culture. The text was a revision of the text used by Hygge [4] in class-room experiments. In order to prevent the readers from using their knowledge about the actual culture, certain nouns and names were replaced by imaginary nouns and names. Recall and recognition were tested later in the experiment both in road-traffic noise and silence (to control for context-dependency, see below).

4) Face and name encoding for later test of intentional and incidental learning in episodic memory (6-7 min). The task was revised from the Betula project [1]. Subjects were presented with 16 colour pictures of faces of 10 years old children. Each picture

was presented for eight seconds on a computer screen. Together with the presentation of each picture, a made-up first name and family name were presented. The subjects were instructed that they later would be tested for recognition for the family name.

5) Enacted sentences with and without enactment - encoding (5 min). There were two lists with different sets of 16 sentences each. For one of the lists the encoding was with enactment and for the other one without. Half of the subjects in all conditions were given the enacted list first. The subjects were instructed to try to remember the sentences. Each sentence was presented on a computer-screen for eight seconds. The enactment procedure was done by self-performing without any real objects [6]. In the Betula study there were verbal instructions and the enactment was done with real objects [1]. Episodic memory with and without a motoric component were tested.

6) Word fluency [1]. There were three different tasks. The first task was to generate as many words as possible with the initial letter A. The second task was to generate five-letter words with the initial letter M and the third task was to generate as many names of professions with the initial letter B. Each task was done during a period of one minute. General knowledge in the semantic memory was tested.

7) Word comprehension [1]. The subjects were presented with a list of 30 target words and next to each word there were five other words presented. Among these five words there was one synonym to the target word. This task, which was tested the general knowledge semantic memory, was allotted for seven minutes.

8) Word-stem completion [1]. The subjects were presented with word-stems and was asked to say the word that came to mind. Perceptual priming in PRS was tested for six minutes.

9) Search and memory task [5] (6 min). Replication of task 2.

Performance on the following tasks was performed in silence for all subjects. 10) Self-report affect circumplex measure [5](5 min). Perceived stress and mood were rated on a Likert-scale with 5 points. In all there were 48 items.

11-12) Free recall of the sentences encoded with and without enactment (no 5 above). The subjects' task was to generate as many as possible of the sentences encoded earlier. Four minutes were allotted for this task. Immediately after the free recall test there was a cued recall test. There were eight category names presented for the subjects, and they were instructed to recall as many nouns from the sentences as possible from each category for three minutes. Episodic memory with different cues was tested, the first task with a motoric component and the second with a semantic cue.

13) Recognition test of first and family name (no 4 above). Revised from the Betula study [1]. Presentation of 24 faces and names. Twelve were target faces and names and 12 were distracter faces and names. Target and distracter faces appeared one by one for 15 s on a computer screen in a random order. The faces were first presented without the names. The subjects' task was to decide if they recognised the face from the earlier presentation or not. Immediately afterwards the same face appeared with four different name combinations. If the subjects recognised the face in this second presentation they were instructed to choose one of the name combinations. Episodic memory was tested with recognition for faces and names. Incidental and intentional memory was tested with recognition for first and last names.

14) Cued recall of the sentences encoded with and without enactment. Revised task from the Betula study [1]. The subjects were presented a phrase, on a computer-screen,

with the verb from the earlier presentation of sentences. The task was to fill in the missing noun in the phrase. In all there were 32 phrases and each phrase was shown for eight seconds. Episodic memory with a semantic cue was tested.

15) Test of recall and recognition encoded during task 3 revised from Hygge [4] (5 min).

Performance in road-traffic noise. 16) Continued test of recall and recognition from task 3 revised from Hygge [4] (5 min) in road-traffic noise for all participants to control for context-dependency learning.

After the experimental sessions. 17) Demographic variables were taken, e.g., gender, age, education level, self-rated health and grade point in English, Swedish and maths.

Focus Groups Interviews

To get a broader perspective of students' experience of noise, focus groups interviews were performed after the experimental sessions with four informants in each group (N=16). A general interview guide with a set of issues decided in advanced was used. The issues were composed from four themes: knowledge/information, emotions, strategies/behaviour and a perceptual theme. These themes covered three different environments: the experimental situation, the school environments and future changes.

Preliminary Results

Analyses of data from the experimental study have started. Preliminary results show that verbal noise is more demanding for attention compared to the ambient noise condition. The focus groups interviews support this result. In the future analyses, the importance of attention on the performance of memory systems will be further investigated.

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AUDITORY DISTRACTION AND MEMORY: THE ROLE OF STREAMING

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INTRODUCTION

A substantial body of research has shown that background noise interferes with performance, at least for some tasks and for some sounds [1]. By their mere presence task-irrelevant sounds may be detrimental to performance on a wide range of tasks but the disruptive effect is more robust and marked on memory tasks that involve seriation [2]. In the typical irrelevant sound paradigm, to-be-remembered items are presented visually, and while the visual recall task is being undertaken, irrelevant sound is played. Participants are asked to ignore any sound they hear and are reassured that they will never be required to report any feature of it. This paradigm has been instrumental in investigating practical issues like the impact of background noise on work efficiency as well as theoretical issues such as the role of attention in memory and the extent to which unattended stimuli are processed.

Some characteristics of the irrelevant sound effect are well established: i) the level of intensity of unwanted sounds does not matter since levels as low as 45 dB(A) produce an effect [3]; ii) non-speech sounds such as tones and musical streams markedly impair serial recall [4]; and, iii) irrelevant sound disrupts serial recall markedly if the sound changes in composition (stimulus-mismatch), but the disruption is less if the sound is repeated [5]. Empirically, this increased disruption was shown to result from a mismatch between immediately successive tokens [6]. The degree of disruption seems to be related to the degree of stimulus-mismatch within the irrelevant stream rather than on the phonological similarity between relevant and irrelevant stimuli [7].

However, evidence from recent findings suggests that perceptual organisation of auditory events may in part determine the effect of mismatch. For example, the organisational factor of streaming by spatial location has been shown to modulate the irrelevant sound effect [8]. Streaming refers to the outcome of perceptual processes responsible for integrating auditory tokens into coherent wholes. One typical example of stream formation is the phenomenon of fission whereby sequences of alternating sounds (e.g., right/left location), separated by a marked difference, tends to be heard as two distinct streams when presented rapidly enough. In the context of the irrelevant sound effect, spatial location can be used to transform a changing state sequence into unchanging sequences; disruption is marked when three syllables are presented from one location, but not if each of the same three syllables is assigned to the left, centre or right auditory location [8]. When effective streaming induces the fission of one changing stream into two or more steady streams the degree of disruption is reduced. The boundary between fusion (the process of binding sound tokens together) and fission (splitting a stream into two or many streams) appears to be dictated by a principle of coherence [9]; sounds similar in terms of their location, pitch or loudness tend to bind together as coming from one source. The current study seeks further evidence that organisational factors like streaming might govern the effect of mismatch by manipulating pitch separation.

The impact of streaming by pitch on the irrelevant sound effect is tested by contrasting a sequence for which perceptual fission is very likely to occur with a sequence for which fission is unlikely. The choice of pitch difference and rate of presentation, used to construct the auditory stimuli, was based on Van Noorden's well-known streaming parameters for non-speech stimuli [10]. He found that sequences are always integrated for pitch separation below three semitones and for separation of 10 semitones the most likely outcome is a two-stream percept. The critical test of interest in the current work is the effect of streaming on the degree of disruption by irrelevant sounds, more specifically the contrast between irrelevant sounds organised in one changing stream and those organised in two distinct unchanging streams.

METHOD

Participants. 18 students volunteered to participate in the experiment in return for course credit. All reported normal hearing and vision.

Apparatus and materials. Lists for serial recall comprised random orderings of the nine consonants *f, k, l, m, q, r, s, t, and v*, were presented on the screen of an *Apple Macintosh*. For the irrelevant sound, pure tones were generated to 16-bit resolution at a sampling rate of 22.5 kHz, using *Sound Edit Pro* software. These tones were edited to last 100 ms. The test sequences used as irrelevant sound were constructed in the format of a two-pitch gallop (a series of tones going from low-pitch (L) to high-pitch (H) presented in the form of LHL_LHL, when integrated, gives the impression of a galloping rhythm). Three different arrangements were constructed: a two-frequency gallop pattern (LHL_LHL) with a pitch separation between high and low tones of roughly 2 semitones, a two-pitch gallop pattern with a much larger frequency separation (10 semitones), and a pattern in which one single tone was repeatedly played. The lower tone was 500 Hz. For all three sequences there was 20 ms silent gap between successive tones. For each arrangement, a recording of approximately 12-minutes duration was created.

Design and procedure. The three auditory conditions just described (gallop, fission and steady control), were contrasted in a repeated-measures design. There were 15 trials per condition, 45 trials in all. Conditions were presented in blocked fashion, which was counterbalanced within a Latin square design. Participants had to perform a typical serial recall task. When the consonants had been presented there was a 10-sec delay after which participants were prompted to write down their response on an answer sheet. The irrelevant sound was played continuously throughout the 15 trials of one condition (during presentation, rehearsal and recall phases of the task). Sound was played via a DAT tape. In all, the experiment took some 35-min.

RESULTS AND DISCUSSION

Percent serial recall errors in relation to auditory conditions (pooled over serial positions and blocks) are shown in Figure 1. The main results indicate that gallop is more disruptive than the steady control and crucially 'fission' seems to be less disruptive than 'gallop'. An ANOVA with serial position (9 levels), auditory conditions (3 levels) and block of trials (3 levels) was performed on the error data. Two of the main effects were significant: auditory condition, $F(2, 34) = 3.32$, $p < .05$, and serial position, $F(8, 136) = 55.86$, $p < .001$. All other effects were not significant ($Fs \approx 1$). Planned comparisons performed on the main effect of auditory condition revealed that the contrast between steady and gallop was significant, $F(1, 34) = 4.83$, $p < .05$, and so was the critical contrast between fission and gallop-pattern, $F(1, 34) = 5.11$, $p < .05$. The contrast between steady and fission was not significant $F(1, 34) = 0.02$, $p = .95$.

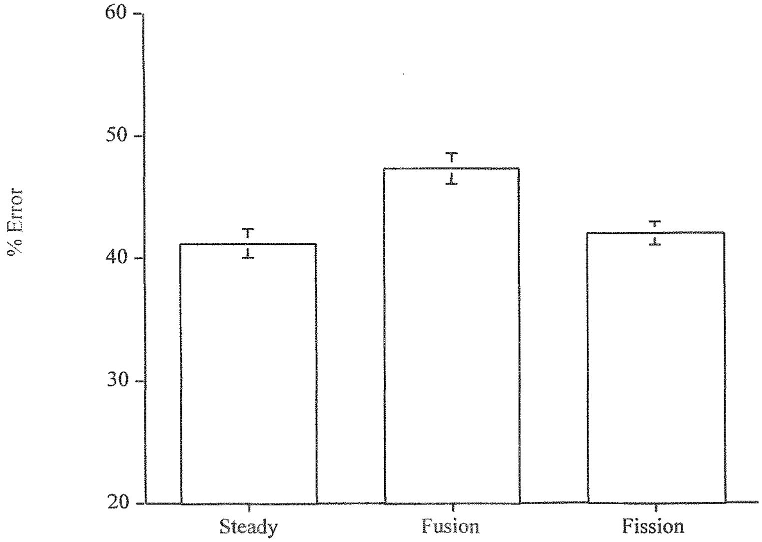

Figure (1) Percentages of serial recall errors pooled over serial positions in relation to auditory conditions. Error bars are based on standard errors.

For a given fast rate of presentation, a sequence of alternating tones loses its disruptive potency when the between-tone pitch difference is large enough. The results suggests that very great pitch difference between alternating tones may induce the formation of two distinct streams each containing one repeated tone. The gallop-pattern, which, according to Van Noorden's streaming parameters, form one single stream of changing tones, produced significant disruption relative to both the fission and the steady-state conditions. This experiment reinforces the view that mismatch alone cannot account for the disruptive effect of irrelevant sound; the effect is modified by streaming.

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EFFECTS OF ACUTE AND CHRONIC TRAFFIC NOISE ON ATTENTION AND CONCENTRATION OF PRIMARY SCHOOL CHILDREN

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1. GROWING UP IN NOISE

There are some indications that children who grow up in noisy environments compared to quiet areas might be disadvantaged; especially if the acquisition of language and reading [2; 3] are concerned. Some other studies [4; 5; 6, 7] have shown that in the presence of acute noise cognitive performance, like memory functions, are restricted. The aim of this study is to explore whether chronic noise exposure will influence the reactions in acute noise as it should be expected if the children tackling with the noisy environments develop coping strategies. This is the reason why the children who took part in the study were tested in quiet as well as in noise. Tests were chosen which reflect upon attention and concentration serving as a basis for appropriate execution of cognitive operations. 76 children aged between 8 and 10 years, half of them living for at least two years in the busy city centre (CC) and the other half living for the same time in a quiet suburb (QS) of Düsseldorf, were tested. The two groups were matched for age, sex, number of siblings, and the level of education of their parents.

Noise Measures

24-hour noise measures were taken in front of the homes of each of the participating children.

Table 1. Frequency distribution of sound levels Leq dB(A) as measured outside of the participants homes. Day = averaged over time between 6 a.m. and 10 p.m., Night = averaged over time between 10 p.m. and 6 a.m. Range of level classes: 5 dB.

		Midpoints of level classes (dB)							Median
		45	50	55	60	65	70	75	
City Centre	Day			3	6	4	12	13	69.6
	Night		7	4	6	13	8		63.1
Quiet Suburb	Day		5	32	2				54.2
	Night	24	13						46.8

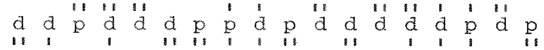
Average sound levels (Leq) were calculated separately for day (6 a.m. to 10 p.m.) and night (10 p.m. to 6 a.m.) time. The median sound levels were 69.6 dB (day) and 63.1 dB (night) in the City Centre and 54.2 dB (day) and 46.8 dB (night) in the quiet area. The distribution of the measured sound levels are given in table 1.

2. PROCEDURE

The children from both areas were tested twice, always on the same weekday at the same time at intervals of one week. In one session, they were tested in quiet ambient-noise condition, in another while exposed to traffic noise at 65 dB(A) as measured at the ears of the test persons. The background noise was recorded at a distance of 12 m from a busy highway. The testing took place in a mobile laboratory which was placed near to the homes of the children. The mobile lab was put at our disposal by the Landesanstalt für Arbeitsschutz in Düsseldorf. Care was taken that the ambient noise and the climatic condition inside the laboratory were the same regardless of its stand. A cross-over design was used with half of the children in each area during their first session tested in quiet and the other half tested while exposed to the traffic noise. Test instructions to each of the tests applied were repeated until the reactions on short test sequences confirmed that the instructions were clearly understood. The order of test presentation never changed.

Tests applied
The tests used were always applied in the order as listed below:

1) the d2 test (about 5 min) is a paper and pencil test [1] which requires the subjects, while under time pressure, to inspect 14 lines of 47 symbols and to mark all "d" characterized by two little lines placed above and/or below (see example below). For each line 20 s are allowed. Dependent measures are the performance index (number of correctly minus incorrectly marked items) and the range of performance (maximum minus minimum number of inspected items per 20-s interval).



2) a colour-discrimination test (about 5 min) following the Stroop paradigm. A button has to be pressed if the colour in which a colourname appears on a screen is congruent with the written colourname; and another button if colour and colourname fall apart. Dependent measure is the difference in the reaction times (RT) as the time elapsed between the occurrence of the colournames and pressing either one of the buttons. RT is usually longer when colour and colourname are incongruent.

3) the Go/Nogo-test [8] which requires immediate pressure on a reaction key (go) as soon as a "x" appears on the monitor; but to restrain from action (nogo) when a "+" appears. Dependent measures are the averaged reaction times for correct responses. About 5 min are given to complete the test.

4) **a visual vigilance task** [8]. The subjects are to watch the movements of a small square grid presented on a computer screen. The grid moves alternately up and down every second, except for rarely irregularly interspersed breaks where it remains on its position for another second. The subjects were instructed to press a key as soon as an irregularity in movement was detected. Measure is the reaction time averaged over the 8-min test period.

3. RESULTS

Multiple analyses of variance (MANOVA) with 2 areas x 2 experimental backgrounds as independent variables were conducted for each dependent variable. The results which gained statistical significance are given below. In addition, separate analyses of variance were calculated with the variable area replaced by either the median dichotomised day- or night-time sound levels.

Effects of Acute Noise Load

When tested in acute traffic noise, all children regardless of their home area performed better with shorter reaction times in the discrimination task, F(1) = 5.23, $p < 0.025$, and showed a change in direction to a more consistent performance in the vigilance task, F(1) = 3.37, $p < 0.07$, as shown in Fig. 1.

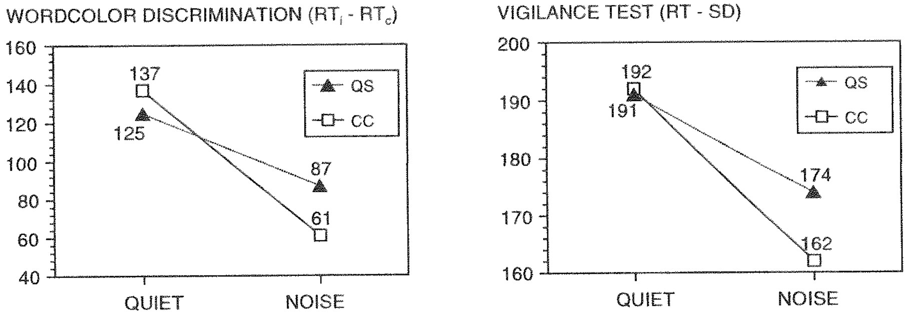


Figure 1. Averaged performance for children living in the CC (open squares) and in the QS (filled triangles) in quiet and while exposed to traffic noise of 65 dB. Left panel: Discrimination time for wordcolour discrimination (reaction time for inconsistent minus reaction time for consistent cases) Right panel: Vigilance test, performance consistency expressed in terms of standard deviation of RT to critical cases as measured during the 8-min test intervals.

Effects of Chronic Noise Load

In the d2 test, as shown in Fig. 2, the overall performance of the children living in quiet areas was better, F(1) = 2.91, $p < 0.09$, and more consistent, F(1) = 6.37, $p < 0.01$, during the time course of the test than the performance of those children living in noisy areas. The differences in overall performance are more pronounced when related to the sound levels measured during night-time, F(1) = 5.32, $p < 0.02$. Reaction times measured in the Go/Nogo-test of the children living in the quiet area were quicker, albeit not statistically significant, F(1) = 2.12, $p < 0.15$, if the children living in different areas are compared. When based on the day-time levels, however, statistical significance, F(1) = 4.11 $p < 0,04$, is reached.

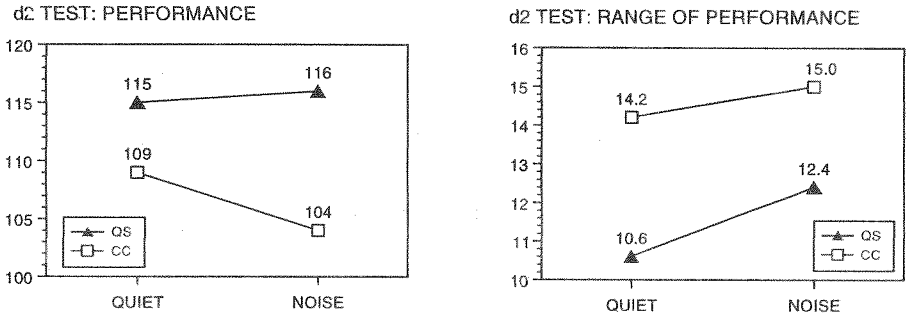


Figure 2. Performance in the d2 test. Left panel: performance index (number of correctly minus incorrectly marked items). Right panel: range of performance (maximum minus minimum number of inspected items per 20-s interval).

4. DISCUSSION

The finding that performance of the discrimination and vigilance task are improved in noise points on the activating property of sound either due to enhanced arousal, or caused by increased effort in order to overcome the compound working conditions. The performance in the d2 test, which to a high degree requires sustained focused attention and concentrative power, is worse for children living in the noisy area. The observation that this effect is more pronounced when related to the night-time sound levels leads to the assumption that the concentration deficits are caused by a lack of sufficient sleep for the children who presumably need to invest more fatiguing effort to meet the daily demands than children living in quiet areas. In this study no indications of coping strategies were found. This may be due to the age of the children as other studies [5; 6] showed that with increasing time living in noisy environments the coping strategies may change.

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THE EFFECTS OF TRAFFIC NOISE ON PHYSIOLOGICAL RESPONSES, TASK PERFORMANCE AND PSYCHOLOGICAL RESPONSES

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1. Introduction

This study aims to experimentally evaluate the effects of noise on physiological response, task performance and psychological response using commonly persisting noise in urban environment. The test was concerned with road traffic noise and railway noise. The equivalent continuous A-weighted sound pressure level (LAeq) was used as the rating value of fluctuating noise.

2. Methods

2.1. Facility description

The test room was adapted as a living room in order to make the situation as realistic as possible. Inside it was furnished with a easy chair and a table. Two loudspeaker systems were located on the floor, one in each corner.

The sound level in the room was monitored by means of a 1 inch B&K microphone that was located 1.0 m above the floor.

Four different type of noise sources used here are characterized such as road traffic noise, railway noise, and digitally emulated white noise. [Fig.1. -Fig.4. and Table 1.]

2.2. Subjects

In the first experiment, 16 males and 4 females (20 - 24 years of age) were involved. 6 males and 4 females were randomly selected for the second experiment.

2.3. Work and Procedure

Pulse Graph (device for measuring heart rate; PROA-4A2, SEIKO) was used to determine the physiological effects of noise in experiments. Psychological measures and performance tests were also carried out.

1) 1st experiment

In order to examine the effects of noise on daily life following experiments were carried out. Before everything, Pulse Graph was fitted to the subject sitting in a

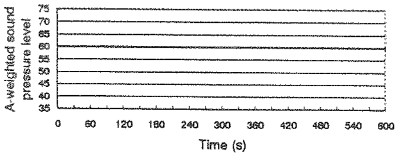

Fig.1. White Noise

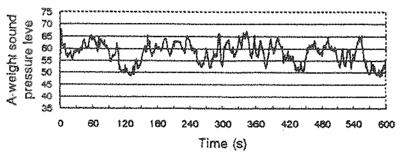

Fig.3. Road 2

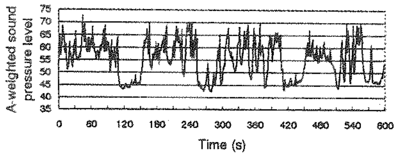

Fig.2. Road 1

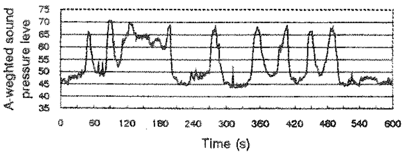

Fig.4. Railway

Table.1 Statistic of noise (Modulated Leq 60dB(A))

	White Noise	Road 1	Road 2	Railway
Lmax	60.0	72.4	67.7	70.7
L10	60.0	64.8	63.5	66.3
Leq	60.0	60.1	60.0	60.0
L50	60.0	59.2	59.2	51.2
L90	60.0	52.1	44.5	45.2
Lmin	60.0	48.4	43.4	43.4

test room, and the subject was given oral instructions about the purpose of the experiment and procedure. Firstly, some questionnaire and tasks were given to subject in the room under background noise. Then the sounds were generated and the same procedure was repeated.

2) 2nd experiment

To evaluate the adaptability to noise, following experiments were carried out two weeks after the 1st experiment. Pulse Graph was fitted to the subject as done in the 1st experiment. The subject was exposed to noise for five minutes and then the same tasks were given. After five minutes interval, the same procedure was reported.

3. Results and Discussion

3.1. First Experiment

3.1.1. Physiological Response

It analyzed in the correlation between the number of the heartbeats, which was measured in 4 seconds interval and the noise level in 4 seconds. As a result, it found that there was a subject where correlation is happened to see only to the railway noise. This shows that there is a subject who is fluctuating with the heartbeat reacting to the noise level change.

3.1.2. Task Performance

As a result of the T-test, it found that the reaction time became long when noise is exposure background noise. [Table 2.] However, there was not a significant difference in the influence over the average reaction time by the different type of the noise. In other words, it seems that effect to consideration is larger when fluctuation of noise is larger and when it is smaller, its effects are little.

3.1.3. Psychological Response

The impression of noise is shown in Fig.5. The Railway noise is most badly evaluated and Road 1 noise is following. There are little differences of effect from Road 2 and white noise. Estimating nuisance in daily life of subjects is shown in Fig.6. In this result, high evaluation is given to Road 2 noise. This shows that the evaluation changes with the level fluctuation and the noise types even if it is equivalent in LAeq.

Table 2. The results of T test (Response time average)

	BGN	White Noise	Road 1	Road 2	Railway
BGN		-3.5510 *	-2.3440 *	-2.6589 *	-4.2019 *
White Noise			-0.5892	-0.2203	-1.4695
Road 1				0.4552	-0.6567
Road 2					-1.2021
Railway					

*: $p < 0.05$

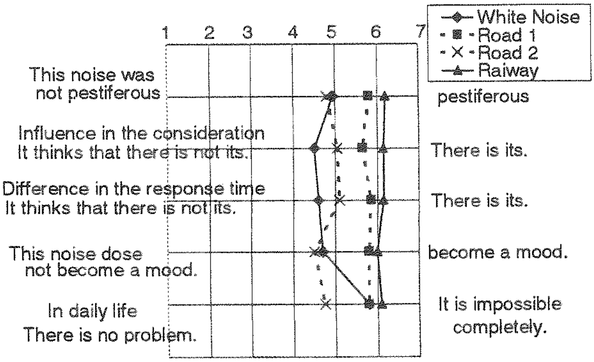

Fig.5. Vote about impression of noise
(1st experiment)

3.2. Second Experiment

3.2.1. Physiological Response

In 2nd experiment, it found that there was not a subject where correlation is happened. For four type of LAeq 60dB noise, which was used by this experiment, the effect to exert on the average heartbeat of the noise wasn't seen.

3.2.2. Task Response

As a result of T test between 1st experiment and 2nd experiment, it found that that significantly severed in Railway became ($t=3.06, p< 0.05$). This shows that the 2nd experiment gets for the response time to be shorter than the 1st experiment. Among these, the noise that the change of the response time was the biggest was the time of Railway and the noise that the change of response time was the smallest was the time of Road1. From above, it thinks that there was an effect excellent to the adaptation under the railway noise exposure.

3.1.3. Psychological Response

When comparing between Fig.5. and Fig.6., it seems that impression of annoyance is reduced when duration times become long. Oppositely, impression for Road 1 and White Noise become undesirable.

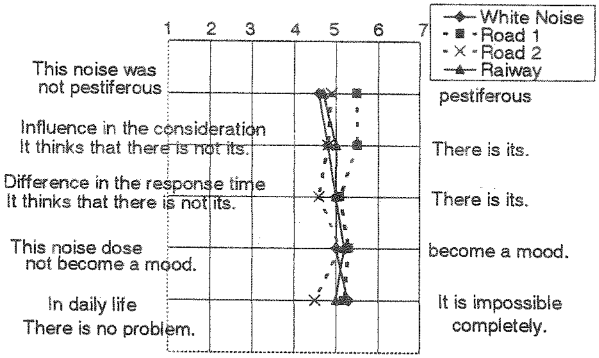

Fig.6. Vote about impression of noise
(2^{nd} experiment)

4. Conclusion

Numerous laboratory studies have been carried out to investigate the relation between traffic noise and annoyance with special reference to the number of noise event. In this study two experiments were carried. The aim is to investigate the effects of familiar noises with a moderate sound level of 60 dB LAeq on physiological responses, task performance and psychological responses.
The results are as follows:
1. The effects of traffic noises on physiological response, task performance and psychological responses relate to the range of level fluctuation and whether the noise event is predictable or not.
2. Railway noise is easy to adapt because the event of railway noise is predictable.
3. Psychological responses fluctuate with the length of noise exposure.

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INTERIOR NOISE EXPOSURE AND READING READINESS AMONG PRESCHOOL CHILDREN

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1. BACKGROUND

There is a considerable amount of literature documenting the adverse effects of noise on school-aged children [1]. Academic achievement, in particular reading skills, are vulnerable to the effects of chronic noise exposure. A possible intervening mechanism linking noise and reading is delay in language acquisition [2]. In addition, young children chronically exposed to noise suffer motivational deficits associated with learned helplessness [1]. The primary objectives of the present study are 1. to investigate the relation among noise, language acquisition and subsequent ability to read, and learned helplessness during the pre-reading period among preschoolers; 2. rather than investigate external transportation noise sources (e.g., aircraft, trains, vehicles) as in prior studies, to examine poor interior acoustics. In order to meet these two objectives we were able to take advantage of a naturally occurring experiment afforded by the acoustical renovation of a day care center that had unacceptable poor acoustic qualities.

Children begin acquiring language skills that relate to reading before they begin formal reading instruction. There appears to be a developmental hierarchy in the way children learn to read. In order to be able to read, children must first learn to recognize the letters of an alphabet and comprehend that letters when put together form words. Children also must learn the symbolic nature of words, that words can be labels for things, feelings, and thoughts. Furthermore, children must learn the relation between the sounds of speech and the way those sounds are represented in the printed word. Children need to have practice, therefore, in both seeing words and hearing words [3].

To date, there have not been any studies that examine the relation between noise and prereading skills in preschool children. Other researchers have found that chronic noise negatively affects children as young as four years old, but often the consequences are not evident until third, fourth or fifth grade [4, 5]. This study investigates the relation between noise, language acquisition, and prereading skills among preschoolers. It also examines potential motivational consequences of noise exposure.

2. METHOD

Design

A cohort model was used in this study. Measures were taken in year 1, the noisy condition, and in year 2 after the installation of sound absorbent panels in the classroom ceilings. The classrooms in the day care center had ceilings in excess of 12 feet high and in some cases walls separating classrooms did not extend to the ceiling so noise could travel between classrooms. There were few soft surfaces in the classrooms as well. Testing was done in March and April of each year.

Participants

Ninety children participated in the study; 48 in the first year and 42 in the second year. There were 36 boys (18 in each year) and 54 girls (30 in year one and 24 in year two). All of the children were in the preschool (3 and 4 years old) or pre-kindergarten (4 and 5 years old) classes. The mean age for children in year 1 was 54 months and for year 2, 56.5 months. A t-test for independent samples indicate a significant age difference between year 1 and year 2 (t= -1.99, df=88, p=.049). Class sizes were 17 to 18 children in the preschool classrooms and 23 in the pre kindergarten classrooms with two teachers in each room.

The children in year one and year two were from similar socioeconomic backgrounds. T-tests for independent samples indicate no significant differences for family annual income (mean range $50,000 - $60,000, t=.45, p=.656) or for parents' educational level. Mean number of years of schooling completed indicate that both mother and father either attended or graduated from college (mothers, t= -1.08, p=.285; fathers, t= -1.46, p=.151).

Procedure

Children were tested on three cognitive prereading measures: 1) number and letter recognition, 2) letter-sound correspondence, and 3) rhyming. For the first measure children were asked to identify several letters of the alphabet, point to the number that represented their age, and recognize simple words such as 'mama'. In the second measure children were asked to identify letters in the alphabet by the sound of the letter in a spoken word, i.e., 'b' in 'belt'. For the third measure children were asked to identify from among three words the word that rhymed with the target word, e.g., 'which word rhymes with pet - net, barn, hand.' The measures were excerpted from two standardized tests, the TERA-2 (Test of Early Reading Ability, 2nd Edition) [6] and the MRT6 (Metropolitan Readiness Tests, 6th edition) [7]. Each child was also rated by the classroom teacher on a language scale that consisted of four items: 1) ability to understand when spoken to, 2) amount of age-appropriate language used, 3) use of sentences, and 4) ability to make himself or herself understood by others.

A helplessness measure was also used in the study. Helplessness was induced by exposure to an unsolvable jigsaw puzzle. Time spent trying to solve a subsequent solvable puzzle was the index of helplessness.

Noise levels were determined by placing a decibel meter (B & K model #2236) in each classroom for a total of four hours. The meter was placed in an open area of the classroom on a book case or shelf out of the reach of children. The meter was placed in the classroom during different activities throughout the day when the children were awake.

3. Results

In the second year, a t-test for independent samples indicate that after the installation of sound absorbent panels, classrooms were significantly quieter (Leq dBA : t (88) = 26.69, p=.000; peak dBA: t (88) =13.42, p=.000) (see Table 1).

Table (1)
Noise Levels

	Average Decibel Level	**Peak Decibel Level**
	M (std. dev.)	M (std. dev.)
Year 1	75.92 (.51)	95.50 (1.37)
Year 2	70.90 (1.19)	89.26 (2.87)

Children performed better in the quieter condition on two of the cognitive measures. Controlling for age, scores were significantly higher in the quieter condition on the measure of prereading skills requiring recognition of numbers, letters, and simple words (f (1, 86) = 3.81, p=.054). As compared to the noisier classrooms, children in the quieter condition were given higher ratings by their teachers on the language scale (f (1, 87) = 6.44, p=.013). No significant differences were found for the rhyming measure (f (1, 87) =.11, p=.743) or the letter-sound correspondence measure (f (1, 85) =1.72, p=.193). (see Table 2).

Table (2)
Cognitive Measures

	Recognition-letters numbers, words	**Lang.Scale**	**Rhyming**	**Letter-Sd Corresp.**
	M *	M **	M *	M *
Year 1 (n=48)	1.44	4.54	1.31	1.57
Year 2 (n=42)	1.30	4.02	1.28	1.60

*1=correct, 2=incorrect
** 1=adequate, 2=could use help, 3=definitely needs help

No significant differences were found on the initial puzzle between the noisy and quiet conditions. The mean time spent on this puzzle before giving up was 2.07 minutes. However, children in the quieter classrooms (M=1.86 minutes) solved the second puzzle significantly faster than their noisy cohort (M=2.43 minutes), (t (88) =3.88, p=.052).

4. Discussion

Chronic exposure to high interior noise levels negatively impacts preschool children's language and prereading skills. There were significant differences on one standardized index of prereading skills directly administered to the children and on the teacher's subjective rating of children's use of language. This research is unique in it's focus on interior acoustical elements of a building as opposed to external noise sources such as airports, trains, or truck traffic. Acoustical problems can more easily be corrected than site problems once construction is completed. However, as demonstrated in this study with the installation of sound absorbent panels, such renovations may not always completely solve the problem. The Acoustical Society of America states that many architectural consultants do not acknowledge the impact of proper acoustics on student learning and academic achievement. [8] Designers must give greater attention to the acoustical features (i.e., shape of rooms, height of ceilings, finishes, adjacencies) of facilities used by young children.

There appears to be a link between interior chronic noise levels and prereading skills in preschool children. Children's use of, and understanding of, language is poorer in loud classrooms. Additionally, one of the earliest and most fundamental of prereading skills, letter and number recognition, is adversely affected. As in previous research with older children [2], the critical role of language in acquiring reading skills is disrupted by loud noise. To our knowledge this is the first study to uncover evidence of possible linkages between chronic noise exposure and pre-reading skills. Children who live or attend day care in noisy settings may suffer in the development of reading skills. Previously attention to the adverse cognitive impacts on reading has been limited to primary school children. We also provide evidence that there may be adverse motivational consequences of chronic noise exposure among preschoolers.

This study and earlier work by the authors [2] is cross sectional. Therefore, developmental trends in language and reading skills can only be implied. Additional longitudinal work is need to confirm the linkages uncovered in this research.

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NOISE, CAFFEINE AND PERFORMANCE

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1. BACKGROUND

Exposure to noise often produces physiological signs of stress [1], negative mood changes [2] and impairments of sustained attention [3]. It is important to determine which factors modify these effects and the main aim of the present research was to determine whether caffeine exacerbates these effects. A number of studies suggest that caffeine is capable of increasing the effects of stressful situations [4]. However, other research [5] has not been able to provide any evidence of interactive effects of caffeine and stress.

The present study examined this issue with emphasis being placed on the following. First, the effects of a relatively low dose of caffeine (1.5 mg/kg body weight) were examined. This is representative of levels typically ingested in a single beverage in real-life. Secondly, a range of functions were examined to determine whether may caffeine/noise effects are observed in subjective mood, cardiovascular function and objective measures of performance. Realistic noise was used as the potential stressor.

2. EXPERIMENT

METHOD

A between-subjects design was used with different groups being allocated to one of the noise/quiet x drinks conditions. Prior to the experiment subjects were practiced at the tasks. A pre-drink baseline session took place and volunteers then consumed their drink. Post-drink testing occurred one hour later. The caffeine manipulation in the coffee was carried out double-blind.

Participants. The participants were 106 members of the Health Psychology Research Unit subject panel (49 female, 57 males; mean age = 21.2 years, s.d = 3.4 years). They were given both written and verbal information about the nature of the study and signed a consent form following this.

Thirty-three were assigned to the caffeinated coffee condition, thirty-eight to the decaffeinated coffee condition and thirty-five to the juice condition. Fifteen volunteers in the caffeinated condition, nineteen in the decaffeinated condition and sixteen in the juice conduction were exposed to noise while completing the performance tests.

Cardiovascular function. Blood pressure and pulse were measured at the start of the session followed by the mood assessment and the performance tests. A final measurement of pulse and blood pressure was then made at the end.

Mood. This was measured using 18 bi-polar visual analogue scales (e.g. Drowsy-Alert, Tense-Calm) presented on the screen of an IBM compatible computer.

Repeated-digits Vigilance Task. Three-digit numbers were shown on the screen at the rate of 100 per minute. Each was normally different from the preceding one but occasionally (8 times a minute) the same number was presented on successive trials. Volunteers had to detect these repetitions and respond as quickly as possible. The number of hits, reaction times for hits, and false alarms were recorded. The task lasted for 3 min.

Nature of the drinks. Participants were given 150 ml of one of the following drinks: orange juice; decaffeinated instant coffee; caffeinated coffee. In the caffeinated coffee condition caffeine tablets were added to decaffeinated coffee (1.5 mg.kg body weight).

Nature of the noise. A recording of industrial noise, irrelevant speech and music was played at a level of 75 dBA through headphones. The noise was played throughout the post-drink testing session. In the quiet condition volunteers just wore the headphones while performing the tests.

PROCEDURE

Prior to the test session volunteers completed questionnaires measuring their personality and normal eating and drinking habits. They then completed a familiarisation session where they practiced the tasks. On a separate day they completed a baseline session and were then given their assigned drink. They had been told prior to this that they would be given either caffeinated coffee, decaffeinated coffee or fruit juice (with no caffeine). One hour after completion of the drink they started the second test session.

RESULTS

Analyses of covariance were carried out with the baseline data as covariates. The between subject factors were noise/quiet and drinks.

Main effects of noise.

Mood. Subjects exposed to noise reported that they were more anxious (as revealed by a number of scales, e.g. Tense/Calm, Troubled/Tranquil, Contented/Discontented) both soon after the noise was switched on and at the end of the session. This effect is shown for the pre-performance test Tense/Calm ratings in Figure 1 (noise effect: F 1,99=15,61, $p<0.001$).

Cardiovascular measures. There was no effect of noise on the pre-test cardiovascular measures. However, by the end of the test session subjects exposed to noise had significantly higher diastolic blood pressure (F 1,99=5.66, $p<0.05$).

Repeated digit vigilance task. Performance of this task was impaired by noise. This was only observed at the end of the task (performance in the first minute being enhanced by noise), which is again consistent with previous results, and which led to noise x time on task interactions for both hits and false alarms (Hits: Noise x time on task - F1, 195 = 3.93, $p<0.05$). False alarms: Noise x time on task - F1, 195 = 3.26,$p<0.05$). The effects of noise on this task are shown in Table 1.

Figure 1. Effects of noise on Tense/Calm ratings (Scores are the means. S.D.s shown as bars. Possible range of scores = 1.50, with low scores relecting greater tension)

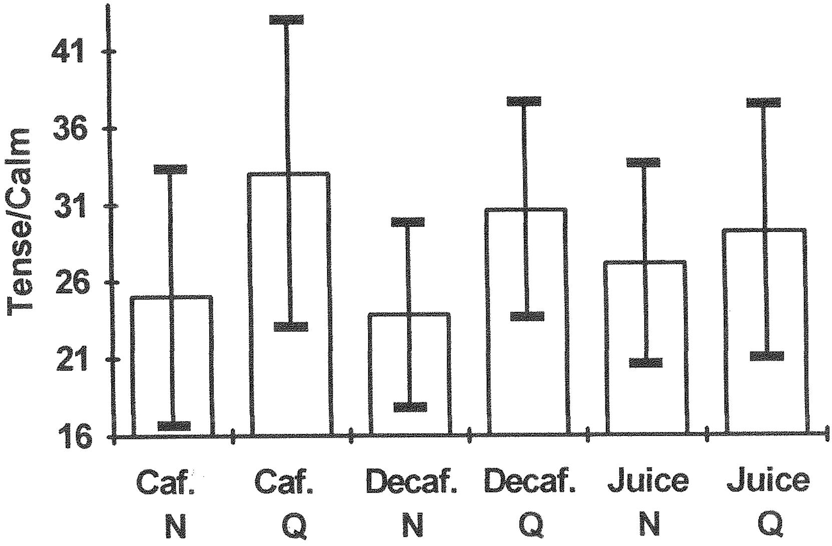

Table 1. Effects of noise on hits and false alarms in the repeated digits task for minutes 1 and 3 (Scores are the means, S.D.s in parentheses. Maximum score for hits = 8)

	Caffeine Noise	Caffeine Quiet	Decaf Noise	Decaf Quiet	Juice Noise	Juice Quiet
Hits						
Minute 1	5.93	5.33	5.89	5.47	6.12	5.84
	(1.71)	(1.71)	(1.52)	(1.50)	(1.74)	(1.71)
Minute 3	4.06	4.33	3.74	4.76	4.38	4.53
	(1.98)	(1.84)	(1.82)	(1.30)	(1.63)	(1.71)
False alarms						
Minute 1	0.87	0.72	0.95	1.35	1.06	0.89
	(0.74)	(0.75)	(0.85)	(1.32)	(1.12)	(1.33)
Minute 3	1.27	0.83	1.00	0.94	1.50	1.00
	(1.16)	(1.15)	(1.15)	(1.02)	(1.97)	(1.10)

None of the effects of noise were modified by caffeine. Similarly, there was no evidence of main effects of caffeine.

DISCUSSION

The present study was designed to investigate whether a low dose of caffeine increased negative effects of having to perform in a stressful environment. Stress was manipulated by playing realistic noise to half the subjects and this was at a level that would be encountered in many jobs and environments. The noise increased anxiety and diastolic blood pressure and also led to a decline in the ability to sustain attention. However, the results showed that there was no evidence that caffeine increased these negative effects of noise. Overall, this suggests that a single dose of caffeine typical of that consumed in real life will not increase the effects of acute stress.

The present study has demonstrated that the present paradigm provides a useful method of examining stressful effects of moderate intensity noise. Further studies can now consider a range of possible moderators of these effects.

ACKNOWLEDGEMENT

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EXTENDING THE IRRELEVANT SOUND EFFECT: THE EFFECTS OF EXTRANEOUS SOUND ON PERFORMANCE IN THE OFFICE AND ON THE FLIGHT DECK

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1. INTRODUCTION

The effects of background sounds on task performance are of great relevance to the study of efficiency at the place of work, whether the work is undertaken in the office or on the flight deck of an aircraft. A number of laboratory studies have shown large, consistent and replicable disruption of performance, despite participants' consciously trying to ignore the background sound.

Early studies established key features of this disruption by irrelevant speech, among them that the degree of disruption was not dependent on the meaning of the sound [1,2,3]. However, recent research has found that the effect is not confined to speech, since the effect can be found with tones [4] or pitch glides [5]. Thus, it is now referred to as the 'irrelevant sound effect'.

2. KEY FEATURES OF THE IRRELEVANT SOUND EFFECT

Most notably, the effect of irrelevant speech on serial recall is independent of intensity; the disruption is roughly the same whether the sound level is equivalent to a whisper [48dB(A)] or a shout [76dB(A)]. This is true whether the level is varied between trials or within trials [6].

The meaning of sound is also not an important determinant of disruption. A number of studies, using serial recall tasks, have shown that speech in a language a person does not understand leads to disruption [1,7]; and that the effect is roughly the same as for narrative English for English speakers [3]. Although studies on the effect of meaning on more complex cognitive tasks have been inconsistent, the weight of evidence suggests that the disruption is independent of both meaning and intensity.

A model to account for the disruption by background sounds assumes that, in the process of reading, material in written form is transformed into phonological code, a code that is based on the sound of the material rather than its appearance or meaning [2]. This set of codes conflicts in memory with phonological codes resulting from privileged access of speech to phonological memory. This model suggests a mechanism in which the degree of disruption is proportional to the phonological similarity of items from two sources. Thus only background speech can show disruption.

However, the model based on the phonological similarity between the two sound streams remains controversial. Effects may be found with non-verbal memory tasks and with non-verbal irrelevant sounds (e.g. spatial memory tasks with no verbal component [8], and random tones [4]). These studies suggest that some factor other than phonological confusion is responsible for the disruptive effects observed.

Overall, these results suggest that tones and speech are equipotent, which confounds any account based on the similarity of the visual and auditory material. Instead, some simple analysis of the auditory stream, insensitive to the gross acoustical differences between speech and steady-state tones, serves as the basis for disruption. This simple analysis underpins the 'Changing State' hypothesis put forward to account for these results [9].

The Changing State hypothesis argues that to disrupt serial recall, the 'irrelevant' sound stream has to show an appreciable acoustic variation (in all but intensity) from one segmented entity to the next, rather than the assumption that the sound has to be "speech-like" [9]. A necessary precursor to changing state must be some means of segmenting this sometimes physically continuous signal into its component units. If the onset of a sound is masked, such as in a speech babble, the effects of disruption are rather small. Sounds that do not contain sharp transitions in energy, such as continuous pitch-glides, therefore show reduced levels of disruption.

3. IMPLICATIONS FOR THE OFFICE ENVIRONMENT

The practical implications for the deleterious effects of extraneous sounds are clear. Extraneous sound is increasingly common in a range of work environments, such as open-plan offices, aircraft cockpits and various kinds of command and control centre. If irrelevant speech impairs performance on tasks involving primary memory, then job performance may be affected adversely.

A small number of studies have attempted to research the effects of background noise in open-plan office environments [7,10]. Consistent with many observational studies conducted after the introduction of open-plan offices in the 1960s, these results highlight people's susceptibility to disruption from extraneous background noise, even when they are not attending to the noise. Typically, the results showed that both speech and office noise (without speech) could disrupt performance on the memory for prose and mental arithmetic tasks, and that the effect was independent of the meaning of the irrelevant speech.

The finding that nonspeech sounds, such as telephones and printers, can cause as much disruption as irrelevant speech sounds is of particular interest [7]. Clearly, the finding that both speech and nonspeech sounds cause disruption presents problems for the phonological similarity account, but goes some way to support the Changing State hypothesis. In addition, this has clear implications for office work, particularly with the increasing trend by corporations to move toward open-plan offices. The performance of office workers is likely to be affected not only by conversations of their co-workers but also by the office equipment they have to use. Office planners need to find ways of reducing subjective noise levels, for example by providing adequate partitioning and sound insulating materials. Alternatively, they could consider introducing a continuous noise that serves to mask not only the background speech but also the equipment noise, so that these sounds become less distinct from one another [11].

4. IMPLICATIONS FOR THE FLIGHT DECK

The shift from the physical to mental that has characterised work in commerce has been paralleled in many military tasks, among them flying. Technological advances in military aviation have allowed a greater number of manual tasks in the cockpit to be delegated to automated systems, leaving the pilot to engage in a variety of cognitive activities. The widespread use of automated systems in aviation has also increased the amount of extraneous sound in the cockpit. Indeed, the auditory modality has been seen as a relatively under-utilised communication channel providing an effective alternative to the visual modality. Thus, in addition to the ambient aircraft noise and voice communications within and between aircraft, the amount of sound in the cockpit has been increased by auditory messages from automated systems. However, not all the sound is relevant, and it is not always timely.

The effects of extraneous cockpit sound on aircrew performance have been examined [12]. The experimental scenario required participants to attend to an incoming radio message containing navigation information (i.e. longitude and latitude), briefly retain the information in memory, and then write it down. The results showed that memory for longitude and latitude information was severely disrupted (up to 60%) when extraneous background speech was presented concurrently, compared to performance in quiet or with ambient aircraft noise. Indeed, no disruption to recall performance by ambient aircraft noise was found. Such findings are consistent with the Changing State hypothesis, in that the changing-state speech sounds cause more disruption than the comparatively steady-state ambient aircraft noise.

These results have a number of implications for the design of cockpits, in particular the timing of auditory events with concurrent seriation-based tasks (i.e. those that require the order of information to be maintained in the correct order). It is possible, for example, that an auditory warning for a relatively minor event may cause errors in entering co-ordinates into navigation, or weapon delivery systems, with potentially serious results. One way of overcoming this difficulty is through the active management of speech and sound on the flight deck. Digital storage allows the possibility of suppressing or postponing non-critical audio signals during critical phases of the flight.

5. CONCLUSIONS

The study of irrelevant sound has illuminated a number of key features of the way in which selective attention breaks down. Sound appears to have obligatory access to the mind; even when attention is directed elsewhere, sound is recorded and processed (if only to a rudimentary level) by the brain. From the practical viewpoint, the fact that this disruption does not depend upon the loudness of the sound has very important implications for noise abatement in settings as diverse as the office and the flight deck.

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VOCAL LOADING AND PREVALENCE OF VOICE DISORDERS AMONG DAY CARE CENTER PERSONNEL

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1. INTRODUCTION

In clinical practice, persons working with children in day care centers are most often seen patients seeking treatment for voice disorders. The acceptance of voice disorders of these persons as occupational disease is not invariably established practice in our country. This is due to the lack of reliable evidence of the occupational risk factors for voice disorders in these professions. On the other hand, when the risk factors are better known and eliminated, the care of the professional voice disorders succeed with higher probability and prevention becomes possible.

2. MATERIALS AND METHODS

The prevalences of vocal symptoms and voice disorders were studied among 262 persons in 27 day care centers with a questionnaire and performing a clinical examination to separate functional and organic voice disorders. Special interest was paid on finding organic changes associated with high vocal loading. Clinical examination included assessment of voice quality using GRBAS categories and 100 mm long visual analogue scales, and an indirect laryngoscopy.

Risk factors for voice disorders are several, but the most obvious ones are speaking loudly long times without proper breaks. High speech level is needed when background noise levels are high, and this, again, is associated with the large group size of the children and poor acoustics of the rooms. Therefore RASTI-values in quiet rooms (n=178) and background noise levels during activity were measured in 51 rooms. To measure vocal loading of individual persons (n=51), a method to measure speaking time and voice levels in background noise was developed and applied.

3. Results

Prevalence of vocal symptoms. The 2-year prevalence of vocal symptoms is presented in table 1 and compared to prevalences in other professions. The prevalence of the symptoms among these other professions has been studied earlier using the same questionnaire [1]. The 2-year prevalence of the vocal symptoms among persons working with children in day care centers is 35%. The most frequent symptom was the feeling that voice tires easily, whereas aphonia was the most uncommon symptom. The symptoms among day care center personnel are far more frequent than among any other professional group.

Table 1. 2-year prevalence of vocal symptoms (%) among day care center personnel compared to some other professions with high voice demands.

Symptom	Persons in day care centers n=262	Students, future teachers n=226	Teaches n=478	Nurces n=95	Military trainers n=321
Voice tires easily	23	14	9	4	5
Hoarseness	19	10	4	2	2
Voice breaks	9	5	3	2	2
Aphonia	1	0	0	0	0
Difficulty in being heard	10	5	2	1	0
Pain around larynx	14	10	4	2	3
Any of the symptoms	**35**	**22**	**12**	**7**	**9**

Prevalence of functional and organic voice disorders. The findings (diagnoses) based on clinical examination and the questionnaire study is presented in table 2. As persons with functional voice disorder were defined those who had symptoms once a week or more often and who did not have any organic findings in vocal cords. On the other hand, those with organic voice disorders had some organic changes in vocal cords found in the traditional indirect laryngoscopy.

There was about the same amount of functional and organic voice disorders. 17 per cent of the disorders were organic changes unambiguously associated with vocal loading. Laryngitis may be caused by several factors one of which may also be vocal loading.

Table 2. Prevalence of functional and organic voice disorders among day care center personnel. (n=262)

Finding	**Prevalence (%)**
Functional voice disorder	**35**
Organic voice disorder	**36**
- Laryngitis	19
- Noduls	6
- Polyps	1
- Minor changes	10

Vocal loading. Vocal loading consist of the speech level one uses and the time one has to speak during working day. The speech levels of individuals and the duration of speaking during working day is shown in fig 1. Mean speech level was 78±2 dB ($L_{Aeq,\ 30\ cm}$) and ranged from 74 to 85 dB. The speech level exceeds the level one needs in quiet speech situation where listener is at a close distance. Speaking time was mean 40±10 % of the working day (min 20%, and max 63%). This seems a large proportion of the day. However, according to our knowledge, there is no reference data concerning speaking time during working days in different professions.

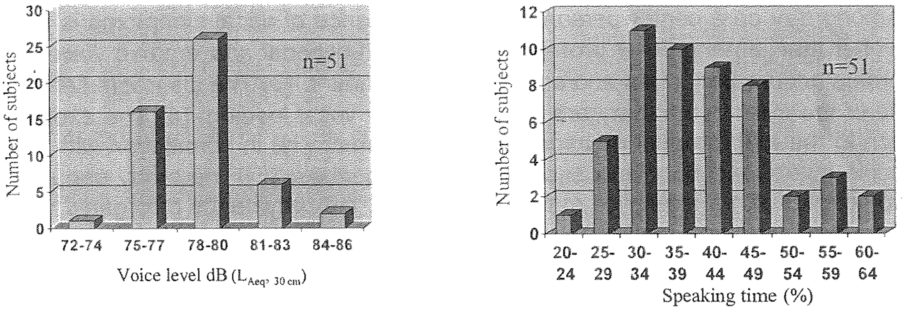

Fig. 1 Speech levels and speaking time of day care center personnel. Speaking time is presented in per cent of the total measurement period. n=51.

Background noise levels and acoustics in rooms. The mean background noise level was 68±3 dB (L_{Aeq}). Background noise levels exceed 20-30 dB the level at which one has to start to rise her/his voice to be heared. There were only 12 rooms where the mean RASTI-value was 0.85 or higher and in as many as 58 the mean RASTI-value was lower than 0.75. For rooms where background noise levels are high, and the listeners are children from 1 to 6 years old, the RASTI-values seem to be poor.

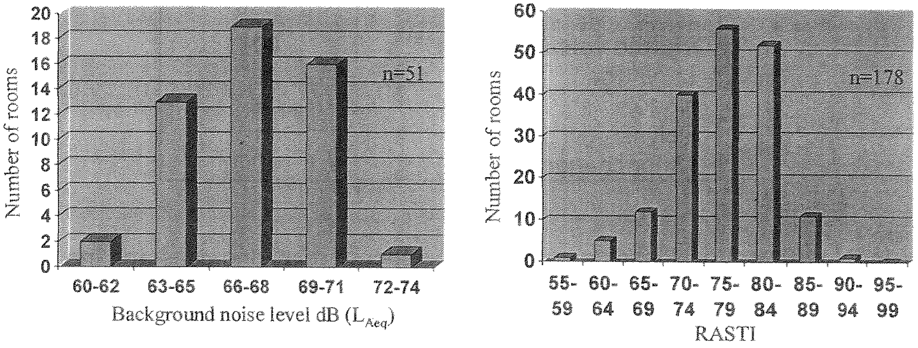

Fig 2. Background noise levels during working day (n=51) and RASTI-values in 178 rooms.

4. SUMMARY

Among day care center personnel: [1] Prevalence of vocal symptoms is high, higher than among other professions, [2] the functional and organic voice disorders occure very often and about in equal amount. [3] The disorders seem to be of the quality, that they are associated with vocal loading. [4] The explanation to the high amount of voice disorders seems to be in connection with high noise levels and poor acoustics in day care centers. [5] The study shoud be completed with a reference material to find out the prevalence of organic voice disorders and vocal loading in other professions.

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DISSOCIATIVE EFFECTS OF TRAFFIC NOISE ON IMPLICIT AND EXPLICIT MEMORY: RESULTS FROM FIELD AND LABORATORY STUDIES

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1. INTRODUCTION

An overview of the literature regarding the effects of noise on performance shows that the concept of noise covers an abundance of different types of auditory stimulations and measurements of performance [1]. Noise leads to decreasing memory performance, if the tasks are complex, if items are presented peripherally, and if the tasks are strongly dependent on semantic processing [2]. These studies of memory under the influence of noise have traditionally relied on tests such as free-recall, cued-recall, and recognition. A common feature of these memory tests is that they make explicit reference to a specific learning episode.

Since the early seventies, however, greater attention has been paid to experimental situations in which information that was encoded during a learning phase is subsequently expressed without conscious recollection. These memory procedures are termed 'implicit memory' [3]. Typical instructions of implicit memory are to complete graphemic fragments or word stems, and to produce examples of categories of previously read words. The 'implicit' or 'priming effect' is the facilitation of previously read or performed items ('old') in relation to 'new' items.

In several studies dissociative effects of implicit and explicit memory were observed. In a recent experiment, it was demonstrated [4] that mild divisions of attention reduce category cued-recall (explicit memory task) but not conceptual priming (implicit memory task). Strong divisions of attention, on the other hand, reduce the performance on *both* tests and eliminated priming.

In accordance with models of implicit memory [5], it could be expected that only explicit memory tests would be significantly influenced by the manipulation of complex traffic noise in the sense of a *mild* form of divided attention, whereas implicit memory tests would not.

The present study explored these assumptions in two experiments. The first experiment was embedded in the Munich Airport Noise Study to test memory effects with children in the presence of chronic *and* acute aircraft noise. The second experiment was a replication study in the laboratory with adults.

2. THE MEMORY TESTS

All experiments and comparisons of the implicit memory tests were based on the same material and procedure. One conceptual implicit (word production) and two conceptual explicit memory tests (free-recall and cued-recall) were developed.

MATERIALS

From each of eight categories (e.g., a piece of furniture, a fruit, a part of the human body), five common examples were selected (German norms [6]) so that these 40 category examples formed the target items for the experiments. The material consisted of two lists of 20 randomly presented items (five examples x four categories) for each participant. The label from each category was used as a cue for the priming test and for the cued-recall test.

GENERAL PROCEDURE

Subjects were tested individually. They were instructed to read 20 items and to rate their preference for each word. Three unrelated words were practised before the target items. During the study phase the acute noise conditions were manipulated. After a retention interval of five minutes (for each experiment with different tasks) the subjects were given a priming test, followed by a free-recall and a cued-recall test. The priming test instructions advised the subjects to produce eight exemplars from each of the eight presented category labels, one at a time, as quickly as they could. Four of the eight categories were always the ones from which the study items were drawn ('old' items), the other four had not been presented before ('new' items). The probability to produce new items provided a measure of baseline performance for word production. After the word production, a free-recall test was given. It was the first time that a memory test was mentioned. The experimenter asked the subjects to reproduce all the items from the study phase, and wrote down the items in the order of reproduction (necessary for clustering measures). Finally, the participants were shown the four category labels from the items encoded in the study phase with an explicit memory instruction (cued-recall). Notice that the material to produce or reproduce was the same for all three memory tests, only the instructions differed.

3. EXPERIMENT I: THE MUNICH AIRPORT NOISE STUDY

In the Munich Airport Noise Study [7] the framework of psychological stress was employed as a model to conceptualise human responses to suboptimal environmental conditions such as chronic aircraft noise [2].

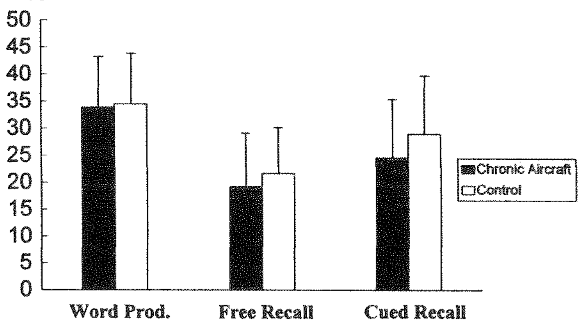
Before the closure of the old Munich Airport (Muenchen-Riem) in May 1992 and the inauguration of the new airport (Franz-Josef Strauss Flughafen), children were divided into one experimental (noise exposed) and one control group at *both* airports. The experimental design was a four group quasi-experiment with repeated measurements in three waves (1991/92, 1992/92 and 1993/94). On two days, 393 children, aged 9-12 years (wave 1), were tested individually in 1.5 hr sessions in a sound-attenuated movable laboratory. The data and results which are to be reported here are selected from wave 3, and are only related to the implicit memory tests. Furthermore, two comparisons will be presented: 1. Children exposed to chronic aircraft noise at the new airport (EXPnew, N=111) vs. children from control areas (CONnew, N=110, new airport), and 2. A selected sample of children from the two control areas (new and old airport) under acute noise (N+, N=43) vs. a control group (N-, N=43).

EFFECTS OF CHRONIC AIRCRAFT NOISE

Method. Children from the noisy areas (M=62 dB(A) L_{eq}, peak=73 dB(A)) and from rural control areas (M=55 dB(A) L_{eq}, peak=64 dB(A)) performed in the implicit memory test at the end of the second day, as described above. During the study phase one half of the children were confronted with 80 dB(A) L_{eq} (peak=83 dB(A)) fluctuating aircraft noise over headphones, the other half encoded the 20 items under silent conditions.

Results. The important results of the 2 (AREA: exposed vs. not exposed) x 2 (ACUTE NOISE: yes vs. no) x 3 (TEST: word production, free-recall, cued-recall) analysis of covariance (sociodem. controls) with repeated measurements on the last factor are the following: the overall performance of the word production was M_{WP}=34.15% [baseline 20.50%], for free-recall M_{FR}=20.46% and for cued-recall M_{CR}= 26.73%. A posthoc 'TEST-by-AREA' interaction was significant (F(1, 203)=4.71, p<.05): children from exposed areas performed the cued-recall worse than the controls (M_{EXPnew}= 24.56%, M_{CONnew}= 28.93%), whereas differences in the performance of word production were marginal (M_{EXPnew}=33.84 [baseline=20.43%], M_{CONnew}=34.46% [baseline =20.82%]). It seems that chronic aircraft noise affects explicit memory tests but not implicit memory tests (see Fig. 1). The significant priming effect ($M_{PRIMDIFF}$= 13.14, F(1, 214)=227.26, p<.01), however, was unaffected by the factors AREA and/or ACUTE NOISE (all F's<1).

Fig. 1: Chronic aircraft noise and implicit memory
- Results from children (N = 221) -

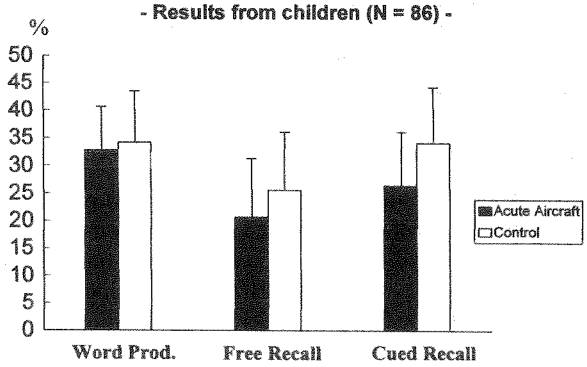


EFFECTS OF ACUTE AIRCRAFT NOISE

Method. In order to analyse 'pure' memory effects induced by acute laboratory noise, without confounders by the actual or former chronic aircraft exposure, exclusively children from the control areas were selected. The two control areas (one rural and one from the control area Munich City) were posthoc equated by age, gender and school education.

Results. The 2 (ACUTE NOISE: yes vs. no) x 3 (TEST: word production, free-recall, cued-recall) analysis of variance (controlled by CITY: yes vs. no, as a factor) showed an interesting pattern of results (see Fig. 2).

Fig. 2: Acute aircraft noise and implicit memory
- Results from children (N = 86) -



The *effects* of chronic and acute noise conditions revealed the same direction: the implicit memory test was, in contrast to the cued-recall, not influenced by acute noise ($F(1,82)=4.46$, $p<.05$; word production: $M_{N+}=32.79\%$ [baseline=21.74%], $M_{N-}=34.18\%$ [baseline=22.09], cued-recall: $M_{N+}=26.39\%$, $M_{N-}=34.06\%$). Once again, the observed overall priming effect ($M_{PRIMDIFF}=11.57\%$) was not affected by the noise factor (here ACUTE NOISE ($F<1$)).

4. EXPERIMENT II: THE LABORATORY REPLICATION STUDY

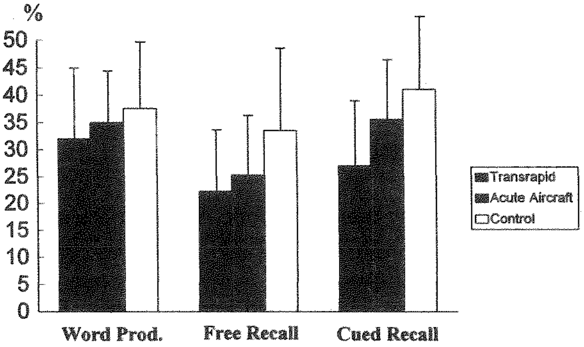
METHOD

The experiment took place in a sound-attenuated laboratory in the University of Oldenburg. Sixty subjects ($M_{AGE}=25.0$ years; 29 men and 31 women) were divided into three groups. Twenty subjects encoded the stimulus material in silent conditions, 20 subjects under fluctuating aircraft noise, the same noise source (80 dB(A) L_{eq}) was used as in the experiments above, and the third group encoded under noise conditions of the German high speed train 'TRANSRAPID'. The recordings were taken at a distance of 100 m and the speed of the train was 412 km/h. The L_{eq} in the laboratory was 80 dB(A), with a peak of 86 dB(A); the duration of each noise episode was 14 sec with a break of 8 sec. between each episode. Noise was presented over loudspeakers (ELAC EL-141 S).

RESULTS

Simple main effects were significant (see Fig. 3): subjects who encoded under TRANSRAPID noise showed decreased performance on the free-recall test, compared to the control group ($M_{TRANS}=22.25\%$, $M_{AIR}=25.25\%$, $M_{CON}=33.50$; $F(2, 57)=3.92$, $p<.05$; *Scheffe*). This effect was mediated by a significant decrease in clustering [8]: noise led also to a decreased amount of clustering ($F(2, 57)=4.36$, $p<.05$), the amount of clustering led to an increased memory score (*Beta*=.46, $T=4.02$, $p<.01$), and by controlling clustering, the former significant influence of noise on the free-recall score was no longer significant ($F(2, 57)=1.57$. $p>.10$).

Fig. 3: Acute traffic noise and implicit memory - Results from adults (N = 60) -



Subjects who encoded during TRANSRAPID also showed decreased memory performance concerning the cued-recall (M_{TRANS}=27.00%, M_{AIR}= 35.50%, M_{CON}=41.00%; *F*(2, 57)=6.10, *p*<.01; *Scheffe*). Priming was also significant (*F*(1, 57) =60.16, *p*<.01), but the ACUTE NOISE-by-PRIMING interaction showed a tendency (*F*(2, 57)=2.76, *p*<.10): the difference 'old - new items' (Primdiff) was reduced in the TRANSRAPID condition in contrast to the aircraft and control condition (M_{TRANS}=8.25%, M_{AIR}=12.50%, M_{CON}=17.75%). Recent conducted experiments concerning the noise source TRANSRAPID strengthened this pattern of result: in the condition TR-300/25 (300 km/h, recording distance 25 m) priming was eliminated ($M_{Primdiff}$=6.75, *t*(20)=1.98, *p*>.05).

5. GENERAL DISCUSSION

The main hypothesis of three experiments was confirmed: it was demonstrated that discontinuous traffic noise leads to reduced memory performance if the instructions were explicit, so that the nature of the effects induced by traffic noise on implicit and explicit memory are dissociative.

Potential explanations for this pattern of result may be that chronic noise induced cognitive coping strategies in terms of 'learned divided attention' as adaptations to suboptimal environmental conditions. Acute traffic noise as a mediator of complex information (e.g., 'Where does the noise come from?') may disrupt processes of encoding in the test phase [9], so that deteriorations in the explicit tests occurred. Implicit memory tests do not rely as heavily on the mobilisation of cognitive resources during encoding so that priming was less affected by the noise presentation. The small amount or the elimination of priming in the TRANSRAPID conditions, however, could be interpreted to mean that this noise source leads to a stronger division of attention, because of the steep rise time of level [10].

Future research should attempt to use more specific noise material, e.g., recordings of traffic noise in more natural settings, a broader set of stimulus material, and the development of additional implicit memory instructions, e.g. perceptual implicit memory procedures, such as word stem completion. Furthermore, the question of parallel or dissociative effects of traffic noise on implicit and explicit memory must be clarified.

ACKNOWLEDGEMENTS

Thanks are due to many students from Munich and Oldenburg for their help in running the experiments, to Matthias Vormann for his help in calibrating the noise material, and to the Umweltbundesamt Berlin for the TRANSRAPID tapes.

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CHILDREN'S MISBEHAVIOURS AROUND U.S. AIRFIELDS IN THE RYUKYUS

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1. INTRODUCTION

Children in their nature demonstrate misbehaviours more or less. But some factors in their living environment can raise the frequency of misbehaviours. Hattori et al. [1] pointed out aircraft noise was one of the factors reporting that the children around Komatsu Airport in Ishikawa Prefecture showed significantly higher rate of misbehaviours than that of the control.

The authors conducted a survey around U.S. airfields in the Ryukyus and found the significant relationships between children's misbehaviours and aircraft noise exposure.

2. METHOD

The questionnaire on children's misbehaviour bases on that developed by Kodama et al. [2]. It consists of 92 questions regarding "biological function", "social standard", "physical constitution", "movement habit" and "character". The questionnaires were delivered in nursery schools and kindergartens in the areas with WECPNL over 75 around Kadena and Futenma U.S. airfields in the Ryukyus. The children living around Kadena airfield were divided into four groups according to WECPNL at their residences of under 75, 75, 80, and over 85 and those around Futenma airfield into three groups of WECPNL of under 75, 75 and 80.

The subjects were male and female preschool children (3-6 years old), whose parents and caregivers or teachers answered the questions. The respondents were only explained that the survey was conducted for the sake of the health care of preschool children and did not know that the questionnaire was related to aircraft noise. The numbers of valid answers were 1,580 from the noise-exposed groups (915 around Kadena and 665 around Futenma), and 308 from the control group, which is located in the southern part of the main island having scarce aircraft noise exposure.
Table shows the numbers of valid answers stratified by WECPNL and age.

Table. The numbers of valid answers.

		WECPNL									
		under 75		75		80		over 85		Total	
Age	Ctrl.	K	F	K	F	K	F	K	F	K	F
3	48	15	70	43	36	35	20	60	0	153	126
4	79	30	109	88	61	71	27	91	0	280	197
5	106	32	77	127	117	104	65	113	0	376	259
6	75	9	28	37	39	28	16	32	0	106	83
Total	308	86	284	295	253	238	128	296	0	915	665

K : Kadena F : Futenma

3. RESULTS AND DISCUSSION

The responses are analysed by means of cluster analysis and 17 clusters are obtained. These clusters are named (1) cold symptom, (2) skin problem, (3) headache-stomachache, (4) excretory problem, (5) language problem, (6) eating problem, (7) habitual problem A, (8) habitual problem B, (9) injury-sickness, (10) interpersonal tension, (11) passive inclination, (12) fearsome inclination, (13) fatigue inclination, (14) adherence-anxiety, (15) emotional instability, (16) aggressiveness-disobedience, and (17) complaint-discontent.

Multiple logistic regression analysis is conducted taking the each of cluster score as the dependent variables and "dose of noise exposure", "age", "sex", "size of family", "birth order", "mother's age at birth", "father's job", and "mother's job" as the independent variables.

As is shown in Figure 1, it is found that the clusters showing the linear relation between the logarithm of odds ratio and WECPNL are "cold symptom", "headache-stomachache", "eating problem", "passive inclination" and "emotional instability" around Kadena, and "cold symptom", "eating problem", and "passive inclination" around Futenma.

To put the above tersely, children living around airfield and habitually exposed to aircraft noise are likely to have the following inclinations: they easily catch cold, have a poor appetite, and take a long time to make friends.

4. CONCLUSION

From the results, it would be safe to say that the aircraft noise exposure is a factor in increasing the number of the preschool children's physical and mental misbehaviours.

5. ACKNOWLEDGMENTS

The authors wish to express their gratitude to Okinawa Prefectural Government for its support in carrying out this study.

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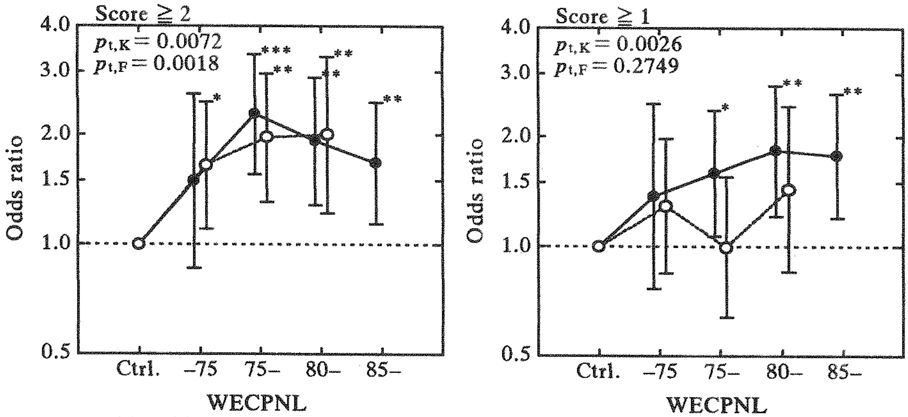
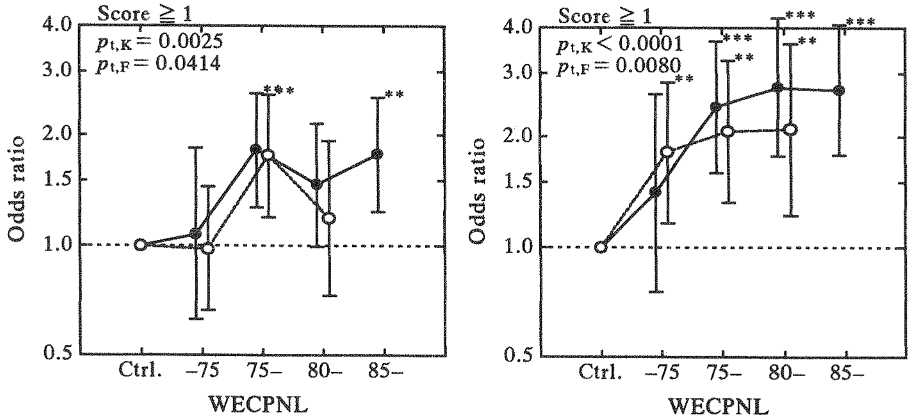


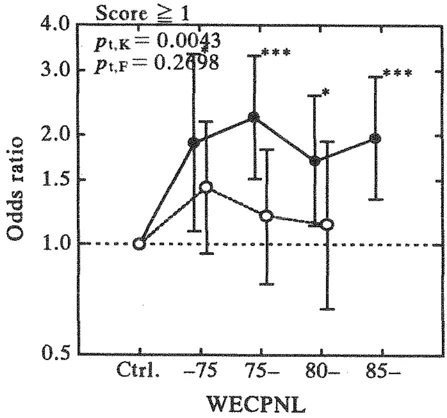
(a) cold symptom

(b) headache-stomachache



(c) eating problem

(d) passive inclination



(e) emotional instability

Figure 1. Odds ratio vs. WECPNL

●—● : Kadena ○···○ : Futenma

I : 95% confidence interval

p_t : significance probability of the linear relation between the logarithm of odds ratio and WECPNL.

Asterisks : significance levels in odds ratio between each noise-exposed group and the control group.

(*: p<.05, **:p<.01, ***:p<.001)

EFFECTS OF HEARING TASKS ON VISUAL INFORMATION PROCESSING IN BRAIN: ANALYSIS OF VISUAL EVOKED POTENTIALS

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1. INTRODUCTION

Visual evoked potential (VEP) [1] is one of the indices that reflect visual information processing in the brain. VEP is a potential that occurs in the central nervous system after the input of a visual stimulus into the eye, and is measured easily using electrodes put on the scalp. As it is a physiological index, visual information processing can be estimated without verbal evaluation by means of analysis of VEPs.

When a person sees a visual information under usual situation, he also hears an auditory information at the same time. Generally, a person manages both visual and auditory information processing at a time. It is supposed that the visual information processing becomes a different thing from the usual processing if it goes on while auditory information is attended to. For example, visual information processing may be interrupted when auditory information processing is prior to it in the brain. To investigate this issue, visual information processing when a hearing task is added to subjects is discussed by means of measurement and analysis of VEPs in the present research.

2. EXPERIMENT

Method

A white circle presented on a display, of which visual angle was 1.5 degrees, was used as a visual stimulus. The intensity of a visual stimulus was 15, 45, or 133 cd/m^2. In one trial, 40 visual stimuli of one intensity were repeatedly presented to the center of a subject's visual field through the display for central vision that was placed 1.5 m distant from the subject's eye, or to the periphery of his visual field through the display for peripheral vision that was placed 0.8 m higher than the display for central vision was. Subjects were instructed to concentrate on looking at the white circle on the display for central vision under condition-A, and to carry out hearing task during the trial without looking away from the white circle on the display for central vision under condition-B.

The hearing task under condition-B required a subject to evaluate the duration of auditory information that was presented intermittently to him through a loudspeaker. Pink noise of 50 dB(A) was used as an auditory information, and its duration was 1.2, 1.5, or 1.8 s. The subject had to evaluate the duration of each auditory information by pushing a key. Subjects saw visual stimuli on the display for central vision under each task condition, but their attention was paid to auditory information under condition-B while it was given to visual stimuli under condition-A.

Twelve subjects (male = 10, female = 2) participated in the present experiment. Each subject experienced 12 trials that consisted of all the combination of visual fields where stimuli were presented, intensities of visual stimuli, and task conditions (A or B). Trial orders were balanced among subjects. During each trial of each subject, brain waves were measured from Cz (vertex) after international 10-20 system. Sound pressure level of background noise was adjusted to 30 dB(A) using pink noise. Luminance of background where visual stimuli were presented was 5.5 cd/m^2, and illuminance on the seat where a subject sat was 270 lx. Under condition-B, presentation of auditory information did not synchronized with the rise of a visual stimulus.

Results

First, eye movements were observed through video monitor and electrooculogram [1] using electrodes put around subject's eyes. They were also examined through eye-camera after the experiment employing two subjects. Observation of eye movements reveals no obvious saccade nor lateral eye movement that occurs when a person meditates. The results support the fact that subjects looked at visual stimuli repeatedly presented on the display for central vision under condition-B.

Prior to the analysis, VEPs were obtained from each trial of each subject. Measured brain waves were averaged thirty times with the rise of visual stimuli to obtain VEPs. Brain waves that were measured when the subject's eyes were closed for their blinks were excluded from the averaging. Averaged VEPs were filtered digitally by low pass filter that was adapted to the frequency character of VEP. Figure 1 shows an example of VEP. After obtaining VEPs, latencies of two obvious peaks that were observed within 300 ms from the input of a visual stimulus (Figure 1) and the peak-to-peak amplitude were measured. The peaks are named N (negative peak) and P (positive peak) in the present paper.

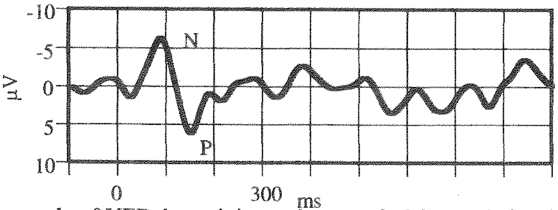

Figure (1). An example of VEP that originates in central vision and visual stimuli of 133 cd/m^2 under condition-B from one subject. Each stimulus was presented at 0 ms. The upper side of vertical axis shows negative value of amplitude after usual electroencephalogram.

Figure 2 shows the mean value of latencies and amplitude under each condition. VEPs that result from peripheral vision are so small that some peaks are not identified. Therefore, further analysis can not be attempted, however some tendencies can be seen in these figures. They show the tendencies that the latencies on central vision are faster than those on peripheral vision, and that the amplitude on central vision becomes larger than that on peripheral vision.

On the other hand, as VEPs that originate in central vision are fully large, few peaks are

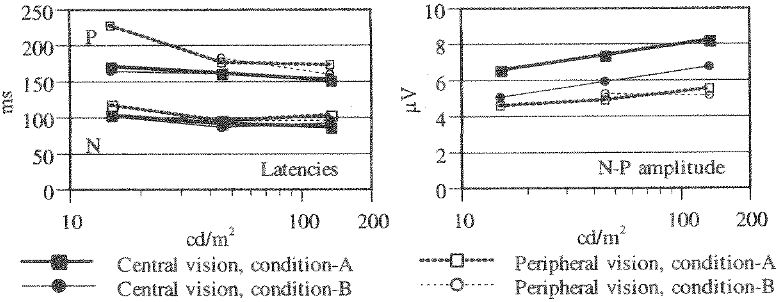

Figure (2). Results of the experiment. Mean values are plotted. The peaks of VEP that results from peripheral vision and visual stimuli of 15 cd/m^2 under condition-B are not identified from most of the subjects.

Table (1). Results of ANOVA.

	N latency	P latency	N-P amplitude
Intensity	**	NS	*
Task	NS	NS	**
Intensity × Task	NS	NS	NS
Subject	*	*	**

NS: not significant *: $p<0.05$, **: $p<0.01$

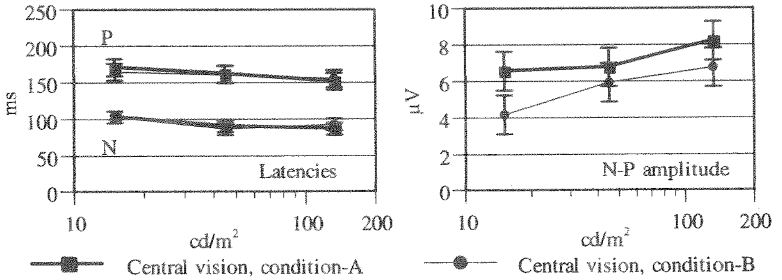

Figure (3). Results of the experiment, especially on the central vision. Mean values are plotted and error bars show the 95% confidence interval.

not identified. Therefore, 2-way analyses of variance (ANOVA) are performed for each latency and amplitude under the condition of central vision. The independent variables are stimulus intensity and task condition. Table 1 summarizes the results of ANOVA. The analyses reveal main effects of stimulus intensity on the N latency and the N-P amplitude, and a significant main effect of task condition on the N-P amplitude. These results reflect that the N latency becomes fast and the N-P amplitude becomes large with increase of stimulus intensity, and that the N-P amplitude decreases when visual stimuli are looked at with much attention to the hearing task (Figure 3).

3. DISCUSSIONS

As the latency of VEP reflects the processing speed of visual information in the brain and its amplitude corresponds to the quantity of neural response to the visual information, the results on the differences of VEPs between central and peripheral vision indicate that visual information processing that originates in central vision goes on faster than that of peripheral vision, and that larger perceptual response occurs in central vision than in peripheral vision. Besides, the results of ANOVA on central vision suggest that visual information processing is diminished when auditory information processing is prior to it in the brain, even if visual information is processed in central vision. It implies that interruption of visibility happens when a person gives attention to what he hears while looking at some visual information. The results also show that this phenomenon takes place regardless of the stimulus intensity. These interpretations on the results of the present experiment are appropriate, as they correspond to what people experience under usual situation.

The most considerable point is that the evidence that visual information processing is interrupted in the primitive stage of the central nervous system when a person's attention is paid to hearing is obtained. According to the results and suggestions, when a system that intends to transmit information to a person visually is planned, sound environment where the system exists should also be considered so as not to interrupt the visual information transmission. It is possible that the existence of auditory information that tends to attract a person's attention disturbs the proper visual transmission, however successfully the visual transmission system is designed.

4. CONCLUSIONS

According to the reports concerning the effects of attention on VEPs, VEP to unattended stimulus becomes small like the present results [2], [3]. In those reports, attention has been controlled within the same sense. The present research confirms that this phenomenon occurs when attention is managed among different senses.

Moreover, the previous researches have suggested that perception of sound is diminished when a person carries out a visual-related task [4], [5]. In addition, the results of the present research show that perception of visual information is also diminished by the existence of an auditory-related task. However, it has been reported that simultaneously presented auditory and visual information are perceived separately when they are attended equally [6], [7]. To examine these results, further studies concerning the relation between sound and human from the viewpoint of multi modality and attention will be necessary.

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NOISE, CENTRAL NORADRENALINE AND LAPSES OF ATTENTION IN A CATEGORIC SEARCH TASK

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1. BACKGROUND

It is well-established that noise can lead to improved performance when alertness is reduced, as by sleep deprivation [1]. Low arousal is associated with very long response times or failures to respond [2] and noise removes this effect. Arousal is regulated by several neurotransmitter systems and noradrenaline is one of the most important. Brain noradrenaline is involved in the control of attention [3] and it has been shown that activation of noradrenergic neurons facilitates responses to subsequent target stimuli [4]. Noradrenergic neurons have also been shown to be highly activated during high states of arousal such as those induced by exposure to noise [5].

States of low arousal can be mimicked using clonidine [6]. This drug, an α-2-adrenoceptor agonist, in low doses acts presynaptically to decrease noradrenergic cell firing and noradrenaline release. A state similar to sleep deprivation is produced and this is associated with increased lapses of attention [7]. It was predicted that exposure to noise would remove these lapses of attention induced by clonidine. If this was the case then it would appear plausible to suggest that at least some of the effects of arousal changes produced by noise reflect effects occurring in the noradrenergic system.

2. METHOD

A parallel-groups double blind study was conducted involving challenge with placebo, idazoxan, clonidine and idazoxan and clonidine. Idazoxan is a selective α-2-adrenoceptor antagonist and it was predicted that this would block the effects of clonidine.

Broadband noise was played over headphones and half of the volunteers were exposed to noise at an intensity of 50 dBA (the quiet condition) and other at a level of 75 dBA (the noise condition).

Volunteers were given a medical examination, familiarised with the procedure and then carried out a baseline session followed by administration of the drug and then 3 post-drug tests (30 mins, 150 mins and 270 mins after drug administration). The study was approved by the local ethical committee and carried out with the informed consent of the participants (74 males, aged 18-35 years).

3. DRUG CONDITIONS

DRUGS

The drugs were given orally : 40 mg idazoxan; 200 microg clonidine. The placebo was lactose.

NATURE of the task

Categoric Search Task. This task was developed by Broadbent et. al [8] to measure aspects of selective attention and choice reaction time. Each trial started with the appearance of two crosses in the positions 2.04 or 5.20 degrees apart. Volunteers did not know which of the crosses would be followed by the target. The letter A or B was presented alone on half the trials and was accompanied by a digit (1-7) on the other half. Again the number of near/far stimuli, A versus B responses and digit/blank conditions were controlled. Half of the trials led to compatible responses (i.e. the letter A on the left side of the screen or letter B on the right) whereas the others were incompatible. Responses which were either the same (repetitions) or different (alternations) from the previous one. Volunteers were given ten practice trials followed by five blocks of 64 trials. In each block there were equal numbers of near/far conditions. A or B responses and equal numbers of the four distractor conditions. The nature of the previous trial was controlled.

Interest here focuses on the long reaction times which were used as indicators of lapses of attention (defined as RT's > 1500 ms).

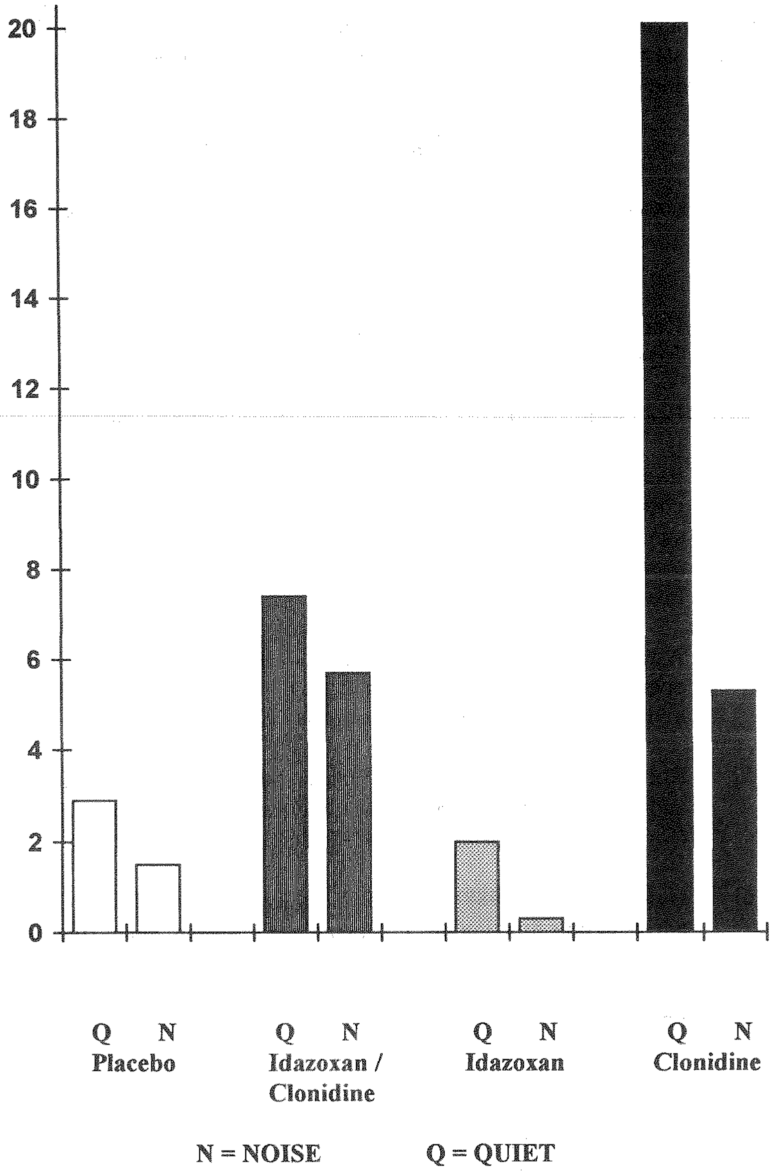
5. RESULTS

Figure 1 shows the mean number of long RT's in the various conditions. If one first considers the quiet conditions one can see that clonidine produced a dramatic increase in long responses. Idazoxan had no effect on its own but did reduce the magnitude of the clonidine effect. In the noise conditions there was a similar pattern except that noise clearly reduced the effect of the clonidine. Analyses of co-variance, with the baseline data as covariates, and the post-drug scores as dependent variables revealed a significant main effect of drug conditions ($p<0.0001$), main effects of noise ($p<0.05$) and a significant interaction between noise and drug conditions ($p<0.05$).

6. DISCUSSION

The results from the present study show that noise can reverse the effects of reduced alertness. Clonidine led to an increase in lapses of attention and this was reversed by idazoxan. These two drugs alter noradrenergic function and it is reasonable to suggest that lapses of attention seen in low arousal states reflect this.

Figure 1. Effects of the different drug and noise conditions on lapses of attention (RTs > 1500 msec) in a categoric search task. Scores are the adjusted means from an analysis of covariance.



It is now important to determine which other effects of noise reflect changes in central noradrenaline. Other research by our group suggests that selectivity in memory and attention does not change when drugs affecting the pre-synaptic receptors and subsequent noradrenaline release are given. This leads to the view that the effects of noise on performance will involve many different neurotransmitter systems. Noradrenaline changes can account for effects of noise in low alertness situations and it is now important to determine other mechanisms underlying effects of noise.

7. ACKNOWLEDGEMENT

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A CROSS-CULTURAL STUDY OF THE EFFECTS AND AFTER-EFFECTS OF NOISE

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1. BACKGROUND

There has been little previous research on whether there are cross-cultural differences in the effects of noise. This was investigated here by comparing the effects and after-effects of noise exposure on mood and performance of Turkish and British students. This was done using the 'adaptive cost' paradigm developed by Glass and Singer [1] and used more recently be Evans and colleagues.

Tafalla and Evans [2] examined whether negative effects of noise can be masked by compensatory effort, which then leads to a physiological cost. The results confirmed that few negative effects of noise on performance are observed when motivation to perform well is high but this increased effort has a psycho-physiological cost.

Evans, Allen and Tafalla [3] examined combined effects of noise and stress on performance, blood pressure and motivation to continue with insoluble puzzles after the noise had been switched off. The noise/high stress condition led to the greatest increase in blood pressure and also the least time on the insoluble puzzles.

The present study used the adaptive cost model to examine whether students in Turkey and the UK responded differently during and after expose to noise. In addition, the volunteers were subdivided into those with high and low levels of perceived stress. Measurement of mood, performance, cardiovascular functioning, effort and motivation meant that it was possible to consider many ways in which cross-cultural differences could manifest themselves.

2. EXPERIMENT

METHOD

Pre-study screening: One hundred volunteers from Turkey and the UK were given the perceived stress scale [4]. This allowed identification of 24 high stress volunteers and 24 low stress. These 48 volunteers then participated in the study.

Study design. The study involved 3 sessions. In the first baseline measurements were recorded with no noise. In the second session the noise manipulation was carried out. In the third session there was no noise, the aim being to determine whether any after-effects of noise exposure were present.

Nature of the noise. Continuous free-field white noise was used and the sound level of the noise condition was 85 dBA.

Performance tasks. The Norinder mental arithmetic task [5] was used to study direct effects of noise. After-effects were examined using solvable and insoluble puzzles [6].
Cardiovascular function. Blood pressure and pulse were recorded at various stages of the experiment.
Mood ratings. Mood was rated using bi-polar visual analogue scales [7]
Effort. Volunteers rated the effort they put into the task and how demanding they found the task. This was done using 7-point scales with 1 representing low effort/demand and 7 maximum effort/demand.

PROCEDURE

Baseline: [in quiet]	Norinder task (10 minutes) Mood/effort rating Blood pressure/heart rate
Noise condition:	Norinder task (10 minutes) Mood/effort rating Blood pressure/heart rate Norinder task (10 minutes) Mood/effort rating Blood pressure/heart rate
After-effects:	Feather figures Mood/effort rating Blood pressure/heart rate

RESULTS

Baseline. Analyses of variance distinguishing country and stress level were carried out on the baseline data. The English students completed significantly more items in the Norinder task ($p<0.01$), were more accurate ($p<0.01$) and rated the task more demanding ($p<0.01$). In addition, they had higher systolic blood pressure ($p<0.05$) and lower heart rate than the Turkish students..

The high stress groups felt more anxious than the low stress groups ($p<0.01$) but there were no interactions between country and stress level. This is shown in Table 1.

Table 1 Stress effect on anxiety and sociability ratings at baseline
(high scores = low levels of anxiety and high levels of sociability)

	TURKEY		ENGLAND		
	Low stress	High stress	Low stress	High stress	
	mean/sd.	mean/sd.	mean/sd.	mean/sd	F's/d.f.s/P's
Sociability	43.67 11.11	35.67 10.04	39.50 7.08	32.58 6.43	8.46/1,44/p<0.01
Tense	20.92 5.30	15.50 5.42	18.67 4.76	16.08 4.30	7.80/1,44/p<0.01

Acute effect of noise. Analyses of covariance, with the baseline data as covariates, showed that the Turkish students performed the task more quickly and felt less tense than the English group, There were no main effects of level of stress or country x stress interactions.

Insoluble figures. There were no significant effects of country or stress level on the time spent on these figures.

3. DISCUSSION

The main aim of this study was to determine whether any differences between countries would emerge in relation to the crucial variables relating to the adaptive cost model. However, the major difference was found at baseline which may reflect the different familiarity with these types of assessment in the two countries. Alternatively, features of the present study, such as the intensity and type of noise may have been responsible for the failure to find differences. Indeed, most of the previous studies of the adaptive cost model have used very loud conglomerate noise. It is certainly plausible that the effect of type of noise is far greater than any cross-cultural differences that might exist, or, indeed, than the individual differences in levels of perceived stress.

Research on occupational stress has shown that there are differences between Turkey and the UK [8]. However, these appear to be largely due to different exposure to stress rather than different responses to it. The present results are consistent with such an interpretation.

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DIVER AVERSION TO THE DURATION OF UNDERWATER LOW FREQUENCY SONAR

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1. INTRODUCTION

Underwater low frequency sound pollution is increasingly present in the marine environment. These far ranging frequencies created by military sonar, oceanography research, oil exploration, and super tankers raise the risk of ensonification of recreational divers. This study attempts to identify the effects of sound duration and sonar signal types on self-reported diver aversion and body vibration. Our primary hypothesis states that aversion scores will increase as the duration of sound increases.

2. METHODS

Subjects

Seventeen male and nine female recreational SCUBA divers volunteered for participation. All volunteers were United States Military active duty or reserve personnel with civilian diving certification. Prior to sound exposure all subjects demonstrated normal in-air low frequency auditory thresholds. Subjects were determined medically qualified to dive if no absolute contraindication was elicited by medical exam or history in accordance with the Recreational Scuba Training Council's Medical Examination Guidelines [1]. The protocol was reviewed and approved by the Committee for Protection of Human Subjects at Naval Medical Research and Development Command.

Experimental Design

Diving was conducted in an acoustically transparent 2.5 x 2.25 x 1.25 m tank suspended in a 91 x 61 x 12 m anechoic pool. Subjects adopted a prone position 1 m below the surface. All subjects wore standard issued equipment, which included a mask, deflated buoyancy compensator, regulator, single tank and a full 3-mm neoprene wetsuit with booties but without gloves or a hood. Water temperature surrounding the diver was maintained between 21.1-27.8 °C. A J15-3 sound transducer was located 4 m directly below the diver's head. Sound presentations consisted of three signals: 100 Hz pure tone (PT), 30 Hz hyperbolic sweep up (HU), and 30 Hz hyperbolic sweep down (HD) (7-second sweep with 100 Hz center) at a sound pressure level of 136 dB re. 1μPa at the diver's head (maximum spatial SPL variation over the divers' location was 1.3 dB). The duration of sound exposures was 7 s, 14 s, 21 s, and 28 s with a 50% duty cycle between sound presentations. All sound exposures were presented twice and randomized for signal and duration. Sound exposures greater than 7 s were repeating units of the original 7-second signal. The subjects were informed of the potential minimum and maximum sound duration but were unaware of the frequency or sound pressure level (SPL).

Measurements

On an underwater console, subjects rated aversion to the sound on a Borg 10-point category-ratio scale [2] and recorded the subjective presence or absence of body vibration. Respiratory rate was visually determined by regulator bubble exhaust. A total of 10 steady-stream bubble exhausts were timed and converted to breaths per minute. Respiratory rate was measured for each subject within the first and last 10 minutes of the dive. Statistical analyses used repeated measures analysis of variance to determine the effect of sound duration or signal on aversion. Chi-squared and dependent t-test were used for analysis of vibration and respiratory rate, respectively.

3. RESULTS

Our study population's age, height and weight were (mean ± S.D.) 32 ± 7 years, 173 ± 10 cm, 77 ± 14 kg, respectively. Median length of diving certification was 8 years (range, 1–25); median number of completed dives was 30 (range 1–2,000). The percent representation of female was 35% compared to 22% in the Diver's Alert Network database (unpublished). There was no significant difference between male and female subjects' aversion ratings ($p>0.40$)

Mean aversion ratings for the signals PT, HD, and HU were 1.56, 1.60, and 1.61, respectively (ratings fall between "very slight" and "slight"). There was no significant difference in aversion ratings among the three signals ($p>0.15$). Vibration was reported in 99% of all presentations. There was no significant difference in reported vibration among the three signals or the four time durations ($p>0.50$). Aversion rating for all three signals was (mean ± S.D.) 1.6 ± 1.4 (deviation between "none" and "moderate"). Again, there was no significant difference in mean aversion ratings for 7 s, 14 s, 21 s, and 28 s presentations: 1.52, 1.61, 1.65, and 1.56, respectively ($p>0.50$). However, there was a slight but statistically significant increase in mean aversion ratings from the first presentation to the second 1.37 vs. 1.53, respectively ($p<0.005$). Furthermore, there was a significant decrease in the mean breathing rate from 9.4 breaths/minute to 8.6 breaths/minute between the first ten minutes and last ten minutes of the dive ($p=0.016$).

4. DISCUSSION

For most sound, loudness is the predominant variable affecting aversion [3]. However, for frequencies below 100 Hz, vibration and resonance of anatomical structures are the dominant variables affecting aversion [4]. In air, for sound durations shorter than a second, the perception of loudness increases with duration whereas at durations longer than a second, loudness is perceived to remain the same or decrease [5]. There were no statistically significant effects of duration or signal characteristics on mean aversion ratings. Furthermore, wetsuited divers universally reported sensations of body vibration during exposures; yet, the duration of vibration also appears to have no effect on aversion at the levels tested. Although very little is understood about underwater aversion to sound these findings support results from in-air sound-duration studies and our previous findings for these sonar signals at various frequencies and sound pressure levels [3,6]. The power of our study was capable of detecting less than a 0.75 change on the rating scale for a 5% chance of either a type I or II error. Therefore, we do not believe that our sample size had a significant effect on findings. Interestingly, we did find a small but significant increase in aversion with the second sound presentation despite a significant slowing in respiratory rate. One might expect the opposite to have occurred with aversion ratings remaining the same or decreasing due to habituation [3]. We believe this finding can be explained by the decreased respiratory rate resulting in fewer bubbles around the head and ears. Since bubbles can create either an auditory masking or sound barrier effect depending on SPL and frequency [7], fewer bubbles would result in greater perceived loudness or actual SPL. We conclude that exposure to this frequency and sound pressure level is well tolerated by a majority of informed divers. In particular, increasing the duration of underwater sonar signals at 100 Hz from 7 seconds to 28 seconds does not increase diver aversion ratings.

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