Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Noise and Health from different perspectives

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PACS: 43.50.Qp

ABSTRACT

In the past 30 years and over research has documented the long term health effects of noise for some distinct outcomes, exposure-response relations are now available and this increasingly facilitates the calculation of the total burden of disease due to noise. Annoyance, sleepdisturbance, cognitive and cardiovascular effects have been identified as the main consequences of chronic noise exposure, primarily transport related. For all outcomes further finetuning is still feasible and necessary. Noise and health research has typically been oriented on single sources, single exposures and single health outcomes, with a main focus on noise control. Recently, more integrated and contextual approaches have come forward, in which the health effects of combined noise sources or the combined effect of air- and noise pollution are studied. Another example of an integrated approach is the so called soundscape approach, which is strongly contextual, pays more attention to acoustical quality and the balance between positive and negative aspects of the acoustical environment and the potential restorative function of areas with wanted sound. This approach is still in its infancy especially where effects on health and well being are concerned. There is ongoing debate about which noise metrics are most suitable to predict health effects, especially in relation to sleep disturbance, and the effects of low frequency noise. Additional measures may also be necessary in order to describe acoustical quality at the microlevel in the context of perception, behaviour, social cohesion and the restorative effect of areas with a high acoustic quality. This paper reviews the state of the art of "classic" studies on noise and health and discusses some new approaches and their potential to enhance further understanding of differential health effects of noise. Finally some research needs are put forward which can map the health effects of noise produced by new technologies.

INTRODUCTION

Transport related noise is an ever increasing problem as a result of continuing urbanisation and accompanying growth in mobility. Nighttime exposure is also excpected to increase due to the 24 hour economy. The long term effects of transport noise are now reasonably well described for several health outcome and dose response relations have been established for them [1] [2] [3] [4] [5] [6] [7]. Based on these, currently a report is being finalised by WHO on the noise related burden of disease, which will be presented at this conference by Dr. Schwela. These findings pertain primarily to transport related noise and A-weighted mean noise levels (expressed in L_{Aeq}, L_{dn}, L_{night}) are the prevailing noise metrics used. There is ongoing debate whether these metrics are suitable for the effects on sleepdisturbance and e.g the health effects of low frequency noise. Recently, more integrated and contextual approaches have come forward, in which the health effects of combined noise sources or the combined effect of air- and noise pollution are studied. Another trend is the soundscape approach [8] [9] which is not primarily oriented at effects on health. The meaning of sound and its context are key concepts, as is acoustic quality. These concepts link potentially with health when the restorative function of areas with high acoustic quality are taken into consideration. Howvere evidence for the beneficial health effects of these areas is however still lacking and the mechanism by which this could work needs to be described in more detail. This paper summarises the evidence on noise related health effects including health effects of low frequency noise and combined exposures. New approaches are discussed in view of their potential to enhance our understanding the differential health effects of noise and finally some future research directions based on them are presented

NOISE AND HEALTH

Chronic exposure to noise in the residential as well as work situation can lead to a range of health effects which are usually subdivided in well-being effects (annoyance and sleepdisturbance) and clinical effects such as hearing damage and cardiovacular diseases.

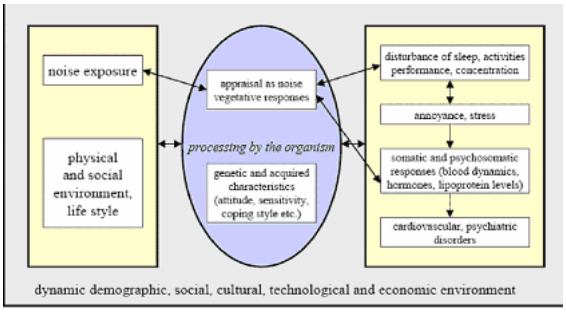

Figure 1: Conceptual Framework Noise and Health [10]

Figure 1 shows the potential mechanisms by which noise can lead to health problems. The model is based on a publication of the Netherlands Health Council [10] and is one of the prevailing approaches to noise and health based on a cognitive stimulus response model. The model assumes that most effects are a consequence of the appraisal of sound as noise. It is generally assumed that stress responses play an important role in the process by which environmental noise leads to health effects. However sound can also directly lead to physiological responses. Noise exposure is associated with annoyance, sleep disturbance and activity disturbance and stress-responses. These effects are at the base of so called instantaneous effects such as blood pressure increases and increased secretion of cortisol, responses which are considered as riskfactors for cardiovascular diseases and mental pathology. Responses are partly dependent on the noise characteristiscs (frequency, intensity, duration and meaning) and partly on non-acoustical aspects such as context, attitude, expectations, fear, noise sensitivity, and coping strategies.

Taking (variations of) this approach as a point of departure, research in the past decades has shown that there is sufficient evidence for the development of hearing damage (at extremely high noise levels) as well as for continuous effects on annoyance, sleep disturbance, and mixed evidence regarding hypertension and ischeamic heart disease ([6] [7]. There is also growing evidence for effects on cognition and reading performance in children [3] [4] [5]. There is no or weak evidence for immune system effects and no evidence for a direct relation with mental health [1] [11]. Below these effects will be described in more detail.

Annoyance

It is now widely accepted that annoyance is an endpoint of environmental noise that can be taken as a basis for evaluating the noise-impact on exposed populations. For example, the Environmental Noise Directive (END) in Europe [12] recommends evaluating environmental noise exposures on the basis of estimated noise annoyance, in addition to evaluation on the basis of estimated sleep disturbance. In his ICBEN 2008 review [13] Gjestland concludes that only a few new annoyance studies have been performed in the past years and that most recent studies have been performed in Asia. The ISO standard for annoyance has facilitated the comparison of annoyance data across studies. Factors such as noise source, exposure level and time of day of exposure only partly determine individual annoyance responses. Many non-acoustical factors such as the extent of interference experienced, ability to cope, expectations, fear associated with the noise source, noise sensitivity, anger, and beliefs about whether noise could be reduced by those responsible influence annoyance responses [14]. Generalised exposure-effect associations have been established for the effects of different noise sources on annoyance responses [reviews: 15] [16]. Where the dose response relation for road traffic noise seems rather stable, there is growing evidence that the generalised curve for airtraffic noise is not tenable and in need of an update [17] [18] [19]. Only a few studies addressed the annoyance response in children. Based on the RANCH study it was concluded that children's annoyance can be measured in a reliable and valid way by means of a questionnaire. Exposure-response curves can be derived but are shaped somewhat different to those found in adults with higher levels of severe annoyance at the low end of the noise scale and lower levels at the high end [20].

Sleep disturbance

A distinction can be made between self reported sleep disturbance - which can be interpreted as night time annoyance- a well-being aspect- on the one hand, and physiological sleep disturbance with insomnial-like symptoms or consequences on the other hand, which can be considered as a (Ill-) health effect. There is sufficient evidence [14] [21] [22] [23] that nighttime transport noise leads to acute effects such as physiological response, arousal, awakening, sleep stage changes, and the amount of total sleep. It also leads to after effects such as self reported sleep disturbance, reduced performance in the daytime and cognitive effects. However, what the long term health effects at cognitive, physiological, emotional level and behavioural level (performance) are of these instantaneous and short term effects of noise on sleep, is still unclear and hypothetical. According to the WHO [14] there is nevertheless consensus about the biological plausibility that short term sleep disturbances form a long term health risk. There is sufficient evidence that chronic sleep disturbance is related to self reported overall sleep disturbance, insomnia-like symptoms, as well as increased medication use. For CVD type effects and depression (and other diseases) no such relation can be established based on current evidence. However, in particular night time noise exposure is considered to be a risk factor for CVD [23]. Recently a relation was established between disturbed sleep and risk of type 2 diabetes [24]. There is ongoing debate regarding the appropriate noise metric to be used to assess sleep disturbance. From current evidence it is clear that different indicators of sleep disturbance are related to different noise metrics and a combination of L_{Aeq}, L_{max} and SEL might be preferable. An association between L_{Aeq} and L_{night} has been established for subjective sleep disturbance, motility and awakenings, whereas single event levels, L_{max} and the number of events (combined with levels) are more predictive of instantaneous and short term effects of arousal, cardiovascular responses, sleep stage shifts etc. The additive value of limit values above L_{night} is currently being analysed by TNO and RIVM on the data of a large sleep study [25] which was carried out around Schiphol airport. In 2009 the Nighttime Noise Guidelines were published [14]. Despite the many uncertainties, the document has suggested standards for the noise metrics for sleep disturbance, the effects to consider, the dose response relationships to apply and the threshold levels to be used in preparing nighttime noise policies. Threshold levels, L_{night}, outdoors have been proposed ranging from:

- 30 dB(A) of no effect,
- 30-40 dB(A) some effects, but within acceptable limits, except for vulnerable groups,
- 40-50 dB(A) where the effects are considerably increased and for vulnerable groups one could speak of severe effects, and

- over 55 dB(A) where one could speak of a serious public health problem, with potential cardiovascular risk.

There is no evidence as to whether these limits are applicable to any country, and specifically to Asia. Studies from Asia are scarce and studies which have been reported (e.g. from Korea or Japan) were strongly epidemiologically oriented. WHO recognises that these limit values might not be realistic to achieve in many places in the world, when noise levels are considerably higher and has therefore formulated interim target values of 55 dB (L_{night}, outdoor) and 40dB (L_{night}, outdoor) respectively.

Physiologal and cardiovascular effects

Recent studies into the effect of noise on endocrine reactions such as cortisol and catecholemines, show variable results which are hard to interpret [26]. Davies and van Kamp [7] have suggested that several factors that influence the variability seen in endocrine response to noise stimulation, including timing or measurement, type of stressor, controllability, individual response characteristic and individual psychiatric sequalae, should be considered in future studies.
Several reviews [6] [27] [28] [29] have suggested that noise exposure is associated with blood pressure changes and ischemic heart disease. The biological plausibility of the hypothesis of the effects of noise on the cardiovascular system is high and assumes that noise acts as a stress factor and as such has the potential of directly and indirectly causing disease [28]. The associations are weak for blood pressure changes and hypertension and somewhat stronger for ischemic heart disease [30]. For hypertension as well as ischeamic heart disease proposed threshold values [2] [10] range between LAeq levels of 65-70 dB outdoor environmental noise exposure. Recent meta-analyses partly confirm the conclusion of WHO showing that the results of the studies investigating the association between road- and aircraft noise exposure and cardiovascular disease converged. The effects are systematically more robust for airtraffic noise than road traffic noise. No definite conclusions can be drawn regarding the exposure-effect relations nor the possible threshold values. Restricting is that cardiovascular effects have only been investigated in a limited set of populations (middle-aged men). Since some studies regarding hypertension were cross-sectional no final interferences can be made about causality and long term effects. Besides study design it is also relevant whether exposure and outcome have been assessed objectively. However after adjustment for reporting bias, it is unlikely that ill health or noise sensitivity lead to noise exposure, so in most case there is rather the risk of underestimating the effect. The meta-analyses on ischemic heart disease refer to prospective cohort and case control studies, in which new and objectively diagnosed cases were detected over the study period, exposure was objectively assessed independently of disease incidence and therefore enable more definite interferences [27] [28].

Since 2000 a number of high quality studies have been finalised and addressed many of the past concerns of study design, power, analytical approach, exposure assessment and outcome classification [7]. Results of studies of noise and blooodpressure among children show inconsistent results across noise sources and studies [31] [7]. Key issues for future studies indentified [7] are these inconsistent effects in children as far as cardiovascular effects are concerned, as well as vulnerable groups and gender differences. Exposure assessment should also be further improved and improved harmony in the measutrement of cardiovasculare endpoints is warranted (eg diagnosed versus self reported hypertension). And finally systematic adjustment for confounding factors is also advised.

Mental health

Recent reviews on noise effects and mental health [1] [11] concluded that there is no direct association between environmental noise and mental health, in both adults and children. Noise annoyance is consistently found to be an important mediator. Evidence for an effect of noise on psychological health suggests that for both adults and children noise is probably not associated with serious psychological ill-health but may affect quality of life and well-being. Conclusions from cross sectional evidence should be treated with caution since poor mental health might go together with a negative evaluation of the environment or a larger susceptibility to noise in general. It is recommended that in future studies a clearer distinction should be made between (diagnosed) mental health effects, medically unexplained symptoms, self-reported health and well-being/ quality of life. Also a more contextual approach to this field is advised with attention to both vulnerable groups and vulnerable locations and the beneficial effect of the availability of areas with high acoustic quality for both.

Cognitive effects

Studies into the cognitive effects of noise have been performed primarily in schoolchildren. During the last 30 years, a limited number of studies investigated the effects of long-term exposure to air-, rail-, and road traffic noise among primary school children. Cognitive effects were found on (comprehensive) reading, attention, problem solving and memory [1] [4] [5]. The evidence for an association between noise and cognitive functioning was strongest for exposure to noise from air traffic. In general it is concluded that mainly performance on the more complex tasks was affected.

The recent large scale RANCH study, which compared the effect of road traffic and aircraft noise on children's cognitive performance in the Netherlands, Spain and the UK, found a linear exposure-effect relationship between chronic aircraft noise exposure and impaired reading comprehension and recognition memory, after accounting for a range of socio-economic and confounding factors [4]. No associations were observed between chronic road traffic noise exposure and cognition. Neither aircraft noise nor road traffic noise affected attention or working memory. A 5dBA_{Leq16} increase in aircraft noise exposure was associated with a 2 month delay in reading age in the UK and a 1 month delay in the Netherlands [4]. This association remained after adjustment for aircraft noise annoyance and cognitive abilities including episodic memory, working memory and attention. It is not yet fully clear what the longer term effects are on cognitive functioning. Preliminary results of a follow up uf the RANCH study on the UK sample have shown that the effects are perisistent over a 6 year period [32]. Most children still lived in the noisy area. Also within the framework of the RANCH study the neurobehavioral effects of road traffic and aircraft noise exposure in 553 primary schoolchildren living around Schiphol Amsterdam Airport was investigated making use of an automated test [5]. Effects of *school* noise exposure were observed in the more complex parts of the switching attention test: children attending schools with higher road or aircraft noise levels made more mistakes. Several mechanisms have been described in the literature to explain these findings and include direct effects, teacher and pupil frustration, learned helplessness and impaired attention.

It has also been suggested that learning deficits are mediated through lack of attention, which is used as coping mechanism to deal with unwanted sounds [1].

Health effects of Low Frequency Noise

Low frequency noise (LFN) is sound with a long wave length and is usually defined as noise under a frequency of 100 Hz. Noise with a frequency under 20 Hz is referred to as infrasound. Due to its characteristics LFN can carry far and the direction of LFN is often hard to determine. LFN can relate to a broad range of sources and it is often very hard to define the source and as stated above the direction. Potential sources are transport (rail, road, air), navigation, industry and wind turbines. Diesel motors as well as freight traffic contribute to LFN and regarding rail especially the marshalling activities produce LFN. Also in and around the dwelling there are often several sources of LFN present such as air conditioners, ventilation systems as well as refrigerators. People who are disturbed by LFN often describe LFN as a *hum* or experience it as a pressure (in the head) and vibrations in the body.

Important effects of LFN described in the literature [33] [34] are annoyance, loss of concentration and sleepdisturbance. Also reported are health symptoms such as hearing loss, vertigo, balance problems and physiological effects on breathing, heart rate, BP and cortisol levels. Occupational exposure to high levels of infranoise have been reported, but not for daily levels of exposure. Results from experiments into the effect on hearing loss, vertigo and balance are inconclusive, due to differences in design, frequencies, and sources making a comparison difficult. The number of studies available into the physiological effects of LFN is limited. Results are often based on one single study and the noise frequencies vary strongly between studies Most of the effects cannot be distinguished from the physiological effects associated with "normal" noise. Exception is the so called vibro-acoustic disease, a disorder characterized by a combination of neurological, respiratory and cardiovascular symptoms. This disorder is not generally accepted and very hard to diagnose. Available results are exclusively derived from occupational studies and animal studies. Finally, it is not clear from the available evidence which aspect(s) of low frequency noise cause the physiological effects as yet.

Combined exposures

As Stansfeld concluded in his Euronoise paper [35] the joint effects of noise and air pollution are increasingly being examined with a need for greater consideration of moderating factors in noise research.

There are indications that exposure to air pollution is associated with effects on the cardiovascular system [36] [37]. Since people in urban areas often are exposed to both air pollution and noise, the effects on the cardiovascular system could be attributed to both exposure types. Epidemiological data linking cardiovascular disease prevalences with traffic-related air pollution and transportation noise are scarce [36], but recently several large studies have addressed the combined effects of noise and airpollution. Kluizenaar [38] studied the so-called GLOBE cohort (Eindhoven, Netherlands) of over 18.000 people. Noise exposure (road traffic) air pollution were estimated making use of the URBIS model. The primary exposure indicator was the distance of the dwelling to the road (within 200 m), PM10 and L_{den}. Primary outcome measure was the incidence of hospital admissions for CVD. The association between noise and incidence of CVD disappeared after adjustment for exposure to PM10. The association between road traffic noise exposure and self-reported use of antihypertensives, only held for subjects aged 44 and 54 and only at noise levels > 55 Lden) after adjustment for air pollution (expressed in PM10). Results of the so-called cancer cohort [37] which contains 120.000 people was aimed at testing the hypothesis that the association between air pollution due to road traffic with mortality (CVD) is mediated or moderated by noise exposure. Results showed that cardiovascular mortality was associated with traffic intensity. The mortality was highest in areas with noise exposures over > 65 dB. However after adjustment for black smoke and traffic intensity the effect of noise was reduced. The association between black smoke and mortality did not change after adjustment for noise. Since traffic intensity is also an important indicator for noise levels the change in the exposure response relation between noise and CV mortality is disputable.
The Hyena study [39], an EU funded multi centre study, looked into the combined effects of aircraft noise and road traffic noise on cardiovascular disease, in particular hypertension. The number of participants was 4800 aged 45-70 living around six EU airports. Results indicated that long-term exposure is associated to excess risk of hypertension, primarily from night time aircraft noise, moderated by day time road-traffic exposures as well as several coping behaviours (closing windows etc) [40].
Finally, a Swedish study [41] looked into the combined effect of long term exprore to road traffic nosie and airpollution and Myocardial Infarction. Results suggest a longterm effect of noise on increased risk for MI. Effect modification by airpollution was not strong.

There is also increasing attention for the possible cognitive effects of air pollution. In 2008, the first epidemiological study investigating the effects of air pollution on children's cognitive functioning was presented [42]. The long-term concentration of black carbon particles from mobile sources was associated with decreases in cognitive test scores among 202 primary school children living in Boston. It is hypothesized that particles move to the brain tissue where they might cause oxidative stress and inflammatory reactions. Since children in urban areas often are exposed to several environmental exposures simultaneously, it is possible that the associations found in our study could also be attributed to traffic-related air pollution and not to road traffic and aircraft noise exposure. Conversely, the effects found in the studies investigating the relation between air pollution and cognitive functioning could also be attributed to noise exposure. More research is necessary to disentangle the effects of traffic-related air pollution and noise exposure. Currently secondary analysis on the RANCH data [43] matched with airpollution data for the Dutch sample is addressing this topic.

NEW APPROACHES

Recently, two major trends are visible in thinking about and studying environmental noise. Firstly more integrated and contextual approaches have come forward, in which the health effects of combined noise sources or the combined effect of air- and noise pollution are studied. Examples of this approach were already described above. In view of the limited space in this paper, we refer to Knol [44] and Knol and Staatsen [45] for a more detailed description and examples of integrated measures. Here we would like to focus on the soundscape approach, another integrated and contextual approach, which is gaining ground. More attention is hereby given to acoustical quality [8] [9] of micro environments and the balance between positive and negative aspects of the acoustical environment and the potential restorative function of areas with high acoustic quality. This approach is still in its infancy in particular where the relation with long term effects on health and well being are concerned. In the noise and health studies which were summarised above, environ-

mental noise and specifically transport noise is consistently being considered as pollutant, a partly unavoidable waste product, an aversive stimulus which can lead to a negative responses. This stimulus response approach is at the base of current noise research and policy where the emphasis lies on threshold levels, norms and interventions aimed at reducing negative health effects. The exclusive attention for physical noise metrics is shifting towards meanings and the role of context in reactions and perceptions of acoustic environments [8] [9]. The soundscape approach describes the acoustical environment more broadly as a resource and not merely as a waste product and shifts the focus from the physically measured levels of exposure towards the meaning of the sound heard and the role of context in shaping human perception and experience of the acoustical environment.

Table 1 : Noise control approach versus the soundscape approach [source Brown, 2010]

Noise control approach	Soundscape approach
Concerns sounds of discomfort	Concerns sounds of preference
Measures integrated sounds (Leq)	Differentiates between sound sources (wanted unwanted)
Manages by reducing levels	Manages by wanted sounds masking unwanted sound
Sound as a waste	Sound as a resource

Although this approach [see table 1] takes the meaning of sound into account by making a distinction between wanted and unwanted sounds and stressing the match between the soundscape and its context, often geographically defined, its focus is still highly acoustical. One aim of this approach is soundscape planning such as the protection and creation of varied soundscapes not overshadowed by one noise source (e.g. transport related noise). In order to understand and explain how soundscapes develop and are maintained within a social and cultural context it is worthwhile studying the driving forces behind them. In the context of noise and health it is also important to understand the pathway by which these meanings lead to well-being and health via restoration. Against this background we developed a provisional conceptual working model (Figure 2), which takes the societal and personal needs (with noise as a consequence) as a point of departure and includes the behavioral effects in the model in parallel with health effects, while accounting for the influence of the spatial distribution of noise over societal groups.

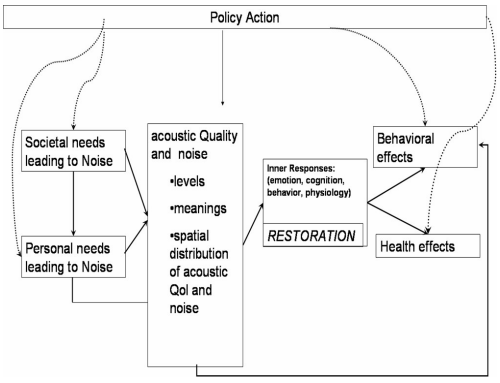

Figure 2: Provisional framework on societal aspects of noise

Meaning and Context

The meaning people give to sounds and noise or to an exposure context strongly influences their reactions and accompanying health effects. Human noise can be considered as a product of behavior, which in its turn is a consequence of human needs. As a result of these needs people produce sounds and expose themselves to sounds with a meaning. These meanings can be negative and positive, they are partly generic, partly culturally defined and they change over time. As said before, the noise control approach has been focused exclusively on the negative aspects and meanings of noise. But in order to understand the driving forces behind noise it is important to study the positive aspects as well. Bijsterveld [46] investigated 1084 expressions about noise in literary sources archived in the framework of the World Soundscape Project (WSP). The primary focus was on historical aspects and the worldwide change in acoustic environments in the cause of time. Bijsterveld studied different remarks and expressions in the literature regarding (the meaning) of noise for the period between 1875-1975 pertaining to mechanical noise. Based on this, a division was made between 'intruding', 'frightening, 'sensational' and 'comfortable'

Based on an extensive literature review [47] [and to be published elsewhere] we showed that people have a whole range of motives to produce noise: a need for sensation and excitement, control of identity, control over the esthetics of- a noise environment (soundscape), a sense of belonging, maintaining working rhythms and motivation, expression of revolt/rebellion, power, perceived company or accompanied solitude, in and exclusion of groups (commercial or safety motives), and defense/imposing behavior.

With regard to acoustic quality several dilemmas exist: the need of control in one person expressed in e.g. car use can lead to a lack of control /learned helplessness in the other: the meaning for producer is completely different from that of the receiver. Likewise the noise of a rebel, freedom fighter is sensational/comfortable for the producer but threatens the receiver. This phenomenon might be for example at the base of extremely high annoyance scores for mopeds and scooters in inner city areas. Moreover the effects of the need to control ones own soundscape appears to manifest itself at different scale levels. At individual/micro level people are nowadays highly capable to control the private soundscape because this can be bought e.g. noises of household equipment, but also mobile phones and MP3 players. However as a consequence noise can increase at higher scale levels e.g. by increased car use, disturbance form MP3-players and mobile phones in public spaces and transport. Another consequence could be a kind of indifference towards soundscapes outside the personal/micro space. If people are disturbed and annoyed they can at any time retreat into their own sounscapes. It has e.g. been shown that people turn up noise levels of their i-pods in reaction to high environmental noise levels , eg in the metro. This behavior is also referred to as *accompanied solitude*, indicating substitution of direct experience by technologically transferred experiences [48]. This phenomenon was first described by Adorno [49] attributing this to a need to substitute (a sense of) community, which often is lacking in modern society. A third issue concerns the manipulation of soundscapes as a means to include or exclude people deliberately: e.g. the use of *muzak* to attract certain groups and repulse others or high frequency noise which is being used to chase young people away (the so called Mosquito). Noise regulations do not exist for such soundscapes and the phenomena described also fall outside the realm of noise planners.

So, at all levels a sense of control on the one hand and a sense of helplessness on the other play a key role. From the stress literature there is ample evidence that learned helplessness is related to a range of health problems. There is also evidence that learned helplessness is linked to socio-economic status. That noise plays a part in this has also been shown, but its exact influence is hard to determine. This is partly due to a lack of studies and partly to an accumulation of psychosocial and physical stressors which makes it hard to pinpoint the specific role of noise. Thinking in terms of acoustical quality sheds a different light on the spatial and demographic distribution of noise. The local orientation of the soundscape approach seems quite fit to study the acoustical quality in deprived areas and groups as well as at sensitive locations (e.g. school environments) and thus has the potential to contribute to the field of social health inequalities. It would be worthwhile to study these mechanism in more depth in the future.

Auditive aspects

Mean A weighted noise levels are par excellence fit to map long term health effects. In order to describe acoustical quality at the microlevel additional measures may be necessary especially when related to perception, behaviour, cohesion and the restorative function of the environment. These approaches are still in its infancy and evidence for the disciminating effects on reaction and health effects is still limited. Based on the available knowledge it could be hypothesized that these additional measures (Lmax, SEL and spectral analysis) are better related to the perception of noise and could play an important role in the further study of both social and health effects of noise. Different dimensions play hereby a role: the function of an area, the time dimension and noise as waste or resource. Current policy takes the residential situation as a point of departure. This is justified since people spent on average 16 hours at home and it has been shown that for most people a quiet home is crucial and home is seen as the most important place to relax and restore from daily hassles, but when other functions are considered the current approach may be too limited. Besides function there is the aspect of time. Current policy is aimed at chronic exposures and long term effects. The soundscape approach is aimed at location specific acoustical quality and its immediate effects on peoples' perception and wellbeing. The long-term effects of access to high acoustic quality areas needs to be studied in more depth. Lastly the distinction between noise control and soundscaping is an important dimension. The shift from decibels to meanings and context offers important cues for future research and policy.

Research into the soundscape of "quiet areas" has shown that people appreciate sounds of water, nature sounds and humans sounds above mechanical sounds [8] [50]. There is some indication that certain areas contribute to restoration. Often it is assumed that this is related to aspects as quiet and green, but evidence is still limited and insight in the mechanisms needs further attention.

Most studies address [51] [52] [53] the restorative effects of natural recreational areas outside the urban environment. The question is whether natural areas within and in the vicinity of the urban environment contribute to psycho-physiological and mental restoration after stress as well. Does restoration require the absence of urban noise? Beside the immediate restorative effects, there may be long-term effects of access to environmental amenities in the immediate living environment. Dutch cross-sectional studies [54] [55] found that residents in green neighbourhoods report a better general health. Do natural environments (micro/macro) positively influence long-term general health and well being, and which environmental aspects are important?

CONCLUSIONS

A summary of existing evidence shows that some distinct health effects of environmental noise and transport noise in particular are now well documented. Dose response relations are available for those and a (careful) start can be made to calculate the noise related burden of disease. The health effects of low frequency noise are still highly anecdotal, while the number of sources of LFN might be increasing especially in view of energy saving measures. Insight in the combined effect of noise and airpollution is growing although not yet conclusive. The 6th framework project ESCAPE which is currently investigating the combined effects of noise and air pollution in nine European cohorts as well as a Canadian study of Davies and coworkers will shed new light on this topic in the years to come. Issues for future research which came forward include: the tenability of generalized exposure response relations regarding annoyance in specific in relation to aircraft nosie, the long term effects of sleep disturbance including the risk of diabetes type 2, harmonization of measures regarding CVD, conceptual issues in relation to mental health outcomes, and the robust but limited evidence on cognitive effects of noise in children and its long term consequences. Future research needs in the noise field will also be mapped by the EU framework programme European Network on Noise and Health (ENNAH- http://www.ennah.eu/). It has been noted that detailed studies on the added value of additional noise metrics based on maximum levels, number of events and duration are worthwhile pursuing.

Two major trends were discerned in the noise field 1) towards a more integrated approach of environmental stressors and 2) towards a more contextual approach of acoustical quality (the soundscape approach). Both approaches offer important starting points for future noise and health research. A model was presented which takes human motives to produce and receive sounds as a point of departure. Apart from noise levels, the meaning and distribution of sounds (geographical as well well as demographical) are key concepts as well as the effects on social behaviour and health. Based on an extensive literature study into needs and motives on the one hand and social effects on the other it was concluded that at all levels a sense of control plays a key role. The challenge in fiuture research is to include this sense of control and its counterpart, a sense of helplessness alongside motives and meanings. Only understanding the way in which environments with a high acoustic quality work, will enhance the design of good urban soundscapes, which stimulate people to spend more time outside and in company with other people and potentially recuperate from daily stressors. Meanings of noise are complex and the noise issue is in essence a battle about meanings and this plays at different scale levels (neighbour noise, noise in public spaces, around mainports etc etc). A topic which also needs further attention is that people tend to create their own soundscapes and thus control over their own soundscapes by using certain equipements, using mobile sound technology or travelling in a so called 'soundbubble'. If this form of coping with unwanted sound is not taken into account it might result in an underestimation of the health effects of environmental sound or one could falsely conclude that the acoustical quality of outside spaces is not so important any longer because people have ways to create their own noise barrier.

ACKNOWLEDGEMENTS

I gratefully acknowledge the contribution of Jeroen Devilee, Eveline Maris and Elise van Kempen to parts of the new work summarized in this paper. I also would like to thank Danny Houthuijs and Wolfgang Babisch for their valuable comments on a previous version of this paper.

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