SOME ISSUES IN NOISE-INDUCED SLEEP DISTURBANCE

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ABSTRACT. Research using the sleep polygraph to monitor sleep has indicated the main noise parameters related to sleep disturbance and the preferred noise metrics to be used. Evaluation and prediction of population statistics of noise-induced sleep disturbance due to noise has begun, using methods of detecting sleep disturbance more suited to large population testing. This work must continue if adequate guidelines for environmental noise control for the prevention of sleep disturbance are to be developed. Equally, the need for concurrent basic research on the effects of noise on sleep and health must not be lost sight of.

1. INTRODUCTION

The problem of sleep disturbance by noise has long been recognised in Australia. The 1971 report of the (Australian Parliament) House of Representatives Select Committee on Aircraft Noise (HORSCAN) stressed the need for research into the effects of aircraft noise on sleep and rest, particularly that of shift workers and older people [1].

In spite of this early recognition of the importance of sleep research in the assessment of the effects of aircraft noise on people, such research has not been well supported here. Exceptions have been some studies on possible health effects of noise during sleep [2,3,4], and a laboratory study on traffic noise and sleep [5].

Justification for noise effects research in Australia has mainly been that it should lead to the development of standards and regulations for noise control. The question of regulations and standards on noise and sleep has not yet been properly discussed in Australia, and so there is no agreement yet on the preferred aims of this research. The main alternative aims appear to be the following:

- to provide methods for predicting sleep disturbance per se (however that is defined);
- to find out whether or not there are harmful consequences of noise- induced sleep disturbance for health and/or daily functioning;
- to enable planners to avoid complaints about noise from, for example, airports and roadways;
- all of the above.

The aims agreed on will influence the choice of methods used in the research. In this paper the main methods for measuring sleep are outlined. Fortunately, perhaps, for the Australian community, many studies have been carried out elsewhere in the world which have yielded valuable information for the assessment of the effects of noise on sleep. Some results from that research are presented. Some possible health issues are also considered.

2. METHODS OF MEASURING SLEEP DISTURBANCE

2.1. The Sleep Polygraph

The sleep polygraph records continuous electro-encephalograph (EEG) activity, eye movement and muscle tone overnight. These data are used to classify sleep into various 'stages'.

With the possible exception of effects of noise on sleep latency (time to fall asleep after lights out) and on total time spent overnight in Slow Wave Sleep (SWS) in young people, results of research on noise effects on total time in the various stages of sleep have been inconsistent [6]. Reasons for this are not hard to find. There is normal variation between people in the duration of sleep and its various stages, and variation between nights in the same people. Individuals differ in their susceptibility to disturbance of sleep by noise. Substantial numbers of subject/nights are needed to obtain reliable results, but the costs of using the sleep polygraph in large population studies are prohibitive.

Reliability aside, it has never been clear what the implications of noise induced changes in overnight sleep architecture were for people, largely because the biological and psychological functions of the various sleep stages were unknown [7].

Polygraphic indicators of responses to individual noise events in the form of changes in sleep stage, body movement, arousal and awakening are much more repeatable measures than measures of e.g. total slow wave sleep (SWS) overnight [5]. The latter are, however, essential for studies of possible health effects and their mechanisms.

2.2. Actimetry

Actimetry records arousals and awakenings (activity) by means of accelerometers (actimeters) worn on the sleeper's wrist. Validated as measures of arousal/awakening against the sleep polygraph, actimetry has recently been used to monitor sleep disturbance in large numbers of people exposed to aircraft noise while sleeping in their homes [8, 9].

Actimeters are 'objective' (independent of subject bias), cheap and convenient, and have minimal effects on sleep, factors which make them the technique of choice in the study of noise-induced arousals in large populations. Disadvantages are that they are limited to detecting arousals (do not reveal sleep stage changes) and may not indicate how long the subject remains awake if they are lying quietly. This precludes their use if the aim is to assess sleep disturbance in terms of sleep stage changes, or if research is aimed at finding what aspects of sleep other than number of arousals may be related to health or daytime functioning.

Fidell et al. [9] found that while overall the correlation between actimetric measures of disturbance ("motility") and indoor A-weighted sound exposure level (ASEL) of individual noise events was relatively high, correlation with measures of behavioural awakening (button-pressing) was less than might have been expected. This may be a defect of the behavioural awakening method rather than actimetry.

2.3. Behavioural Awakening

Reliable results have been found by asking the subject to indicate all awakenings by pressing a button connected to a bedside computer [10].

This method has a great deal of face validity in that it can hardly be questioned that the subject is awake for each button-press. It may have a higher (noise) threshold than other methods of sleep monitoring. Unlike brief EEG arousals, it is easily recalled the next day and should correlate highly with public complaints about aircraft and traffic noise.

One disadvantage of the method as a basis for standardisation is that it may underestimate brief awakenings, especially from the 'deeper' stages of sleep (SWS), because of the degree of sleep inertia present at these times.

Another disadvantage is that subjects may give biassed responses or unconsciously provide results which they believe are 'desired' or expected by the experimenter. An important question, not yet investigated, is the relation of noise-induced sleep disturbance to subjects' general noise sensitivity and their attitudes to the sources and controllers of noise (airlines, road transport authorities etc.). Attitude and noise sensitivity have been shown to be powerful modifiers of annoyance due to noise [11] and, because auditory scanning of the environment and perception of the meaning of sounds continues during sleep [12, 13] could affect sleep disturbance as well. Research on this issue requires that the method of sleep monitoring be (and be seen to be) as objective as possible.

As with actimetry, button-pressing cannot record how long subjects remained awake after arousal.

3. RESEARCH RESULTS

3.1. Noise Characteristics and Metrics Related to Sleep Disturbance.

Laboratory and field research has established the following (see [6] for review):

- intermittent noise is more disturbing than continuous noise of similar average energy;
- the probability of sleep disturbance is related to the maximum levels of single noise events (such as that due to truck passbys and aircraft flyovers);
- single event noise levels are best measured in LAmax or ASEL;
- the likelihood of sleep disturbance due to noise events is related to the 'emergence' of noise events (roughly, the difference between LAmax and ASEL of noise events and background noise level);
- total sleep disturbance is related to the number of single noise events during the night. The form of this relationship is not clear and may depend on which measure of sleep quality is used as the outcome variable.

3.2. Sleep Disturbance - Dose/Response Curves

Several authors have collated the results of a number of studies and developed dose/response curves of probability of arousals and awakenings, and sleep stage change (from 'deeper' to 'lighter' stages of sleep) as a function of LAmax or ASEL of noise events.

A review and analysis by Pearsons et al [14] showed that dose/response curves derived from laboratory and field studies are dramatically different, probably because people sleeping at home in familiar surroundings were much less sensitive to disturbance by noise than when they slept in the laboratory. This suggested that much of the variation between various published synthesised curves was due to pooling data obtained in the laboratory and in the field in varying proportions.

It was also clear that sleep stage change was much more sensitive to noise than arousals/awakenings in both laboratory and field studies. The curve for sleep stage change from field studies was very similar to that of laboratory studies of arousal/awakenings. Three field studies of aircraft noise and sleep disturbance, using actimetry and/or behavioural awakening as the response measure, have been reported since this review was written, broadly confirming the dose/response curve for arousal/awakening developed by Pearsons et al. from previous field studies [8, 9, 10].

3.3. Prediction Of Chronic Noise-Induced Sleep Disturbance

Passchier-Vermeer [15] developed a calculation method which permits the number of aircraft overflights to be increased if the level of individual overflights is reduced. In her method the probability of sleep stage change and arousals/awakenings (based on work by Pearsons et al., [14] and Horne et al. [8]) were a linear function of the number of noise events overnight and the ASEL of these events, but she combined these measures of individual noise events overnight in an LAeq, and the limit of permissible exposure was set in LAeq. For example, if a maximum permissible LAeq overnight of 27 dB is set, then (in terms of percentage awakenings) the worst case (most arousals or sleep stage changes) consistent with this value is 5 aircraft noise events per night, all with indoor ASEL values of 64 dBA. This is calculated to induce an average of 13 aircraft noise-induced awakenings per person per year in an average population. Fewer aircraft with higher levels than 64

ASEL (up to a maximum permitted level), or a greater number of aircraft flyovers with lower noise levels, will lead to fewer awakenings. Similar calculations for sleep stage change showed a much greater number of sleep stage changes overnight and over one year than arousals/awakenings.

3.4. Outdoor/Indoor Noise Attenuation

Estimates of noise-induced sleep disturbance require indoor noise levels, but environmental noise assessment necessarily entails outdoor noise measurements. The available data on outdoor/indoor noise attenuation are quite inadequate to estimate indoor noise levels.

Finegold et al. [16] refer to the US Environmental Protection Authority's (USEPA) "average house noise reduction" as 17 dB for windows open and 27 dB for windows closed. The influence of noise spectrum and other variables [17] on outdoor/indoor attenuation make it unlikely that these values will be accurate for all environmental noise sources.

Passchier-Vermeer [19] assumed outdoor/indoor attenuation of 15 dB with single glazing (presumably windows closed) and 25 dB for double glazing. For regulatory purposes she stated that 15 dB was appropriate. However she later indicated that Netherlands' night time aircraft noise regulations specified that sound insulation be determined for windows in the "ventilation position" (partly open). For this window position the attenuation was given as 22 dBA for landings and 20.5 dBA for take-offs. For windows fully open the attenuation is lessened by 5 dBA [15].

Carter, Ingham and Tran [17], in a study of traffic noise in a Sydney suburb, found that the average attenuation depended on which noise metric was used, and whether the window was closed or partially open (up 20 cm), the latter probably corresponding to Passchier-Vermeer's "ventilation position". The mean attenuation values in dB (windows partially open) were:

Metric:	LAeq	LAmax	LApk	LA90	LA10	LA1
Attenuation:	17.05	17.35	17.2	13.39	17.77	17.63

For windows closed the attenuation values (in dB) were:

Metric:	LAeq	LAmax	LApk	LA90	LA10	LA1
Attenuation:	21.52	23.08	21.11	12.05	23.72	23.72

USEPA attenuation values for open windows and Carter et al.'s [17] data for partially open windows are somewhat similar but since the latter were determined for traffic noise they may not be appropriate for aircraft noise [cf. 16]. On the other hand the Netherlands' [15] regulatory figures (20.5 and 22 dB) may well be appropriate for aircraft noise and apartment buildings, but not for single storey dwellings.

The magnitude of variations in estimates of outdoor/indoor attenuation are significant in the context of noise reduction achievable by quieting aircraft and motor vehicles, buffer zones for airports, and sound barriers near roadways. Further field work on noise and sleep should take every opportunity to increase information on bedroom outdoor/indoor noise attenuation values and their determinants.

3.5. The Context: Non Noise-Induced Awakenings

Fidell et al. have consistently argued that in studying noise-induced sleep disturbance, cognizance should also be taken of the likelihood of an arousal/awakening in the absence of a noise event [18]. In a field study using behavioural awakening they found that the number of awakenings in the absence of any noise event was only slightly less than the number of non-noise induced awakenings [9]. Horne et al., [8] found that idiosyncratic, non-noise factors accounted for more arousals than aircraft noise events, though in their study the levels of aircraft noise were lower than in many areas near airports, and the prevalence of double-glazing was greater. In a laboratory study of traffic noise Carter and Ingham [5] found that the total number of body movements was similar in subjects exposed to noise and quiet overnight, even though there were clear (polygraphic) arousal responses to particular noise events. They suggested that this may be because body movements are necessary during sleep to relieve pressure points, and that noise events sometimes triggered body movements which may soon have occurred anyway.

'Net' increase in arousals/ awakenings or sleep stage changes should be considered in assessing noise-induced sleep disturbance in the community. Nevertheless public policy must be accountable for sleep disturbance for which avoidable sound sources such as aircraft and traffic noise are responsible.

4. NOISE-INDUCED SLEEP DISTURBANCE, HEALTH, TASK PERFORMANCE

4.1. Task Performance

LeVere et al. [20] exposed subjects to bursts of narrow band noise during sleep. They found that even though the EEG response to each noise event decreased as the number of noise events increased, impairment of performance of a reaction time task the next day was proportional to the number of noise events. This could mean that counting arousal responses overnight may underestimate the effects of chronic exposure to noise during sleep. However, data by Carter and Ingham [5] did not support this earlier finding.

4.2. Blood Pressure Response

Guilleminault and Stoohs [21] exposed sleeping subjects to 5-sec. 1000 Hz tones. They found that an increase in diastolic and systolic blood pressures followed the tone, even when there was no EEG response. Chronic repetition of such blood pressure changes could in theory lead to morphological changes in arterial blood vessels and permanent increases in blood pressure [22]. A study measuring blood pressure response in subjects exposed to traffic and aircraft noise during sleep is presently being completed in Sydney.

4.3. Immune Response

Twelve reports have suggested that slow wave sleep (SWS) is reduced by noise [cf. 6]. It has been speculated that reduction in SWS may impact on immune response [23], and an exploratory laboratory study has been carried out [4]. Until this question is clarified it constitutes a further reason for adopting a conservative approach to setting criteria for permissible noise exposure for the protection of sleep.

5. CONCLUSIONS AND RECOMMENDATIONS

Past research has provided valuable insights into noise and sleep. Nevertheless the aims of research on noise and sleep should be re-examined. There is a critical difference between research which is limited to determining the extent of sleep disturbance (as a form of activity disturbance and a forerunner of complaints) and that aimed at determining whether or not there are effects on daily functioning and physical and/or psychological health. While it may appear that measures of sleep disturbance are related to the likelihood of health effects this is not necessarily so, and until this is established health variables should be studied in their own right.

Most sleep/noise research to date has concentrated on relating measures of noise to measures of sleep disturbance. However, the role of psychological factors (for example attitude to the noise source and noise sensitivity) lifestyle variables (such as shiftwork) and demographic modifiers (age) may prove to be as influential as noise level in determining effects of noise on sleep and health.

Noise-induced sleep disturbance has mainly been related to indoor noise levels, but regulations and standards must be stated in terms of outdoor noise levels. Variation in outdoor/indoor attenuation is of the same order of magnitude as potential noise reduction due to quieting noise sources, buffer zones and noise barriers. The available information on outdoor/indoor attenuation is inadequate for estimating the effects of most noise environments on sleep.

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