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APPROACHES TO THE STUDY OF NOISE INDUCED SLEEP DISTURBANCE

N L Carter

National Acoustic Laboratories, Sydney, Australia

1. INTRODUCTION

Increasing population, urbanisation, use of mechanised transportation, and the development of the "24-Hour Society" [1] have made the study of the effects of noise on sleep of considerable relevance to planners and those concerned with public health. Dose/response curves relating noise exposure to noise-induced sleep disturbance could be a useful tool for land-use planning with applications to airports, roadways, railways, and industrial and military establishments. Presumably, the first decisions to be made in the development of such curves is how to measure noise and how to measure sleep disturbance. The question arises however, as to what such dose/response curves are for. Are they designed to be used to predict sleep disturbance per se, or the harmful consequences, if any, of such sleep disturbance, or merely to 'head off' complaints? Should we try to assess the effect of noise on sleep relative to that of other disturbances, and if so, how? This paper is a brief comment on these and some related questions in the light of recent research.

2. NOISE METRICS RELATED TO SLEEP DISTURBANCE

Laboratory and field research during the past 15 years has established that intermittent noise is more disturbing than continuous noise of similar average energy [2,3,4,5,6,7]. As well as its intermittency, the main characteristics of noise related to the likelihood of sleep disturbance have been shown to be the maximum levels of single noise events (such as that due to truck passbys and aircraft flyovers) measured in L_{Amax} or SEL, and the 'emergence' of noise events (roughly, the difference between L_{Amax} and SEL of noise events and background noise level)

[2,4,5,7,8,9,10]. Overnight sleep disturbance is related to the number of single noise events during the night, although the form of this relationship is not clear and may depend on which measure of sleep quality is used as the outcome variable [8,10,11,12].

3. MEASURES OF SLEEP DISTURBANCE

Measures of the effect of noise on sleep can be divided into those made during, and those made after the sleep period. (Community questionnaire surveys are not considered here).

Measures Made During The Sleep Period

The Sleep Polygraph. The sleep polygraph records EEG activity, eye movement and muscle tone to derive measures of time in the various stages of sleep. With the possible exception of effects on SWS in young persons (see [13] for review) results of research on noise effects on the various stages of sleep appear to be somewhat inconsistent. Moreover, it has never been clear what implications, if any, measures such as time in the various stages of sleep had for short or long term effects of noise on people, largely because the functions of sleep were not known [cf. 14]. On the other hand, polygraphic indicators of changes in sleep stage, body movement, arousal and awakening in response to particular noise events are relatively robust (repeatable) measures which can be enumerated to provide a measure of the degree of disturbance overnight [15].

Actimetry. Actimetry, which records arousals and awakenings by means of accelerometers worn on the sleeper's wrist, has recently been used to monitor sleep disturbance in large numbers of people exposed to aircraft noise while sleeping in their homes [16,17]. One version of the method was previously validated against polygraphic measures of noise-induced arousal and awakening [16]. The large differences in sensitivity between actimeters using algorithms based on threshold crossings and time above threshold, and the low correlation of both with measures of behavioural awakening (see below), reported by Fidell et al [17], are grounds for concern and suggest that these methods require further work.

Voluntary Responses. Reliable results have been found using button-pressing to indicate behavioural awakening [17,18]. It is possible that button-pressing may underestimate awakenings from the 'deeper' stages of sleep (SWS), because of the degree of sleep inertia present at these times. Nevertheless this measure appears to be relatively easy to standardise, and because it represents a conscious act and, unlike brief EEG arousals, is easily recalled the next day, it should be useful in predicting and hence avoiding complaints about aircraft and traffic noise.

Measures Made The Next Day

It may be argued that persistent effects on performance, behaviour and health, if they occur, are the final justification for the control of environmental noise during sleep, even though people may not be aware of these effects. Various measures of sleepiness, task performance and mood are available, including the following.

Measures of Sleepiness Based on the Sleep Polygraph. In the Multiple Sleep Latency Test (MSLT) sleep polygraphs are recorded for 20 minutes, or until the subject falls asleep, at intervals throughout the day, and the times required to go to sleep are averaged [19]. The MSLT is usually impractical for noise studies because subjects are reluctant to devote entire days to the study. However, analysis of alpha frequency in the EEG using an ambulatory EEG recorder [20] may offer a means for studying the after-effects of noise at times of day when normal circadian peaks in daytime sleepiness interact with the effects of impairment of sleep the previous night.

Task Performance. Reliable results have been obtained using tests of Reaction Time [7,21,22], with less reliable findings on short term Memory [22] and Vigilance Tasks [23]. The scope of these tests is limited and, except for arousal theory, they appear to lack a rationale [14].

Self-Ratings Of Sleepiness And Mood. Self-rating scales have yielded somewhat inconsistent results in studies of effects of continuous and intermittent noise on subjective sleep quality and alertness [cf.2, 4]. Mood scales have also shown rather inconsistent results, perhaps because different scales were used, and because mood is a function of other life events and physiological variables.

Research on most of the outcome variables listed above cannot be used at present as a basis for estimating the responses of large numbers of people to noise during sleep. Also, some of the results are based on laboratory studies, which, in the view of many researchers, means that they may not be quantitatively generalisable to situations where people are sleeping in their own homes [24]. For reasons given below, however, it is important that this research should continue, because of the information it may provide on sleep itself and on the effects of noise on individuals.

4. DOSE/RESPONSE CURVES

Sleep Stage Change Or Arousals/Awakenings?

Reviewers have generally concluded that (a) arousals and awakenings, and (b) sleep stage change, are the outcome variables which provide the best chance of developing dose/response curves relating noise level to sleep disturbance [25,26]. The question arises as to which of these two measures should be used to develop dose/response curves for noise regulation.

When plotted against L_{Amax} or SEL, change to a lighter stage of sleep has a lower threshold value and steeper slope than EEG arousals/awakenings or behavioural awakenings. It would therefore be expected to result in more conservative dose/response curves. In the author's view a conservative approach is preferable because of collateral research suggesting that (a) task performance and sleepiness may be affected in ways that are not proportional to effects on arousals/awakenings; and (b) certain health effects of noise may occur without arousals/awakenings, or may be related to time in certain stages of sleep.

It has been found that subjective reports of health and sleep disturbance were unrelated to objective measures of exposure to traffic noise at home, but were related to measures of noise sensitivity and annoyance, that is, to psychological responses to the noise [27]. Also, attitude to the noise source and individual noise sensitivity account for at least as much of the variance in annoyance and dissatisfaction with environmental noise [28]. Rylander et al. [29] found large differences between civilian and military populations in reported sleep disturbance and difficulty in returning to sleep due to sonic booms from military aircraft, probably reflecting differences in attitude to the noise source. In critical situations social factors may also be important in noise-induced sleep disturbance. So far, these factors do not appear to have been investigated closely within civilian populations or using objective measures of sleep disturbance, and could at least be expected to correlate with measures of behavioural awakening mentioned above.

5. RELATED NOISE AND SLEEP RESEARCH

The results of some research on task performance, sleepiness, blood pressure response and the immune system challenge our current assumptions on the effects of noise on sleep, and again advise a conservative approach to the development of dose/response curves.

Task Performance LeVere et al. [21] exposed subjects to 0, 6, or 24 bursts of 80 dBA narrow band noise (125 Hz centre frequency) 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 3-choice reaction time task the next day was proportional to the number of noise events. This could mean that merely counting arousal responses overnight, without other measures, such as performance the next day, may underestimate the effects of chronic exposure to noise during sleep.

Sleepiness. Research on sleep fragmentation by noise bursts has recently been reviewed by Gillberg [30]. The studies described were laboratory studies, but the presentation rates of noise bursts and sleep interference were comparable with many situations in which people are exposed to transportation noise. Gillberg concluded that sleep fragmentation can reduce alertness the next day without increased awakenings or reduced overnight SWS.

Blood Pressure Response. Guilleminault and Stoohs [31] exposed sleeping subjects to repeated 5-second 1000 Hz tones at levels ranging from 50 to 130 dB. They found that an increase in diastolic and systolic blood pressures always followed administration of the tone, even when there was no change in the EEG nor any increase in heart rate. Chronic repetition of such blood pressure changes could in theory lead to morphological changes in arterial blood vessels and permanent increases in blood pressure [32]. Such changes need only to exceed 5 mm Hg to have implications for individuals' long-term cardiovascular health [33].

Studies measuring blood pressure response in subjects exposed to traffic and aircraft noise during sleep are presently being carried out in Sydney by the author and colleagues. Pending the results of these studies the results by Guilleminault and Stoohs [31] support a conservative approach to limits placed on noise exposure during sleep.

Immune Response. Elsewhere it has been speculated that if noise leads to a chronic reduction in slow wave sleep (SWS) this may impact on immune response [13]. There are 12 papers [e.g. 22] suggesting SWS is reduced by noise [cf. 13]. It may be that time in certain sleep stages could be chronically reduced without major arousals and/or behavioural awakening. This possibility constitutes a further reason for adopting a conservative approach to the development of dose/response curves.

6. CONCLUSION

Arousals/awakenings are more easily measured than other aspects of sleep, constituting a powerful argument for using this measure in field studies aimed at evaluating noise effects on sleep in large populations. However, other effects may occur in individuals at lower noise levels than the starting point for arousals/awakenings. It may be prudent to use the more sensitive measure of change to a lighter stage of sleep as the outcome variable in dose-response curves, or, if actimetry is used, those actimeters which employ the more sensitive algorithms. At the same time, research should continue into the role of psychological factors in noise-induced sleep disturbance, the functions of sleep, and the possible effects of sleep disruption on complex task performance, physiology and health.

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