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Sleep disturbance by traffic noise: an experimental study in subjects' own houses using a portable CD player

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Abstract

The current study investigated the effect of noise on sleep in subjects' own houses using recorded traffic noises. A railway noise and two kinds of road traffic noise differing in level-fluctuations were used as stimuli. Subjects were exposed all night to the artificially controlled stimuli for 10 days through a portable compact disc (CD) player. The effect of noise on sleep was judged in three ways, namely whether the subject had switched off the CD player, a self-declaration of the subject based on a questionnaire, and the amount of arm movement of the subject during the night as measured by an actigraph. The results of the analysis of the self-declaration data showed that the thresholds where sleep disturbance began were 40–45 dB in $L_{\mathrm{Aeq,1\,h}}$ for road traffic noise and about 35 dB for railway noise, which corresponded to 50–55 dB in $L_{\mathrm{A,F_{max}}}$ of each train noise event. The results of the analysis of the actigraphy data showed a rapid increase in the incidence of mid-sleep awakening at sound pressure levels higher than 50 dB, $L_{\mathrm{Aeq,1\,m}}$ for railway noise. However, neither of the road traffic noises showed such a tendency, as long as the sound pressure level was less than 55 dB, $L_{\mathrm{Aeq,1\,m}}$.

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1. Introduction

There are two methods commonly used to investigate the effect of noise on sleep, namely social surveys (field research) and laboratory experiments. Social surveys and other types of field research have the benefit of showing how sleep is affected in an everyday-life setting. Drawbacks are that disturbance is evaluated primarily according to the subjective judgement of residents, and it is difficult to measure the sound pressure level of the noise to which the residents were actually exposed. In laboratory experiments it is possible to control the sound pressure level of a stimulus and evaluate the effect of noise on sleep by using objective methods such as electroencephalography (EEG), polysomnography (PSG), and others. Drawbacks are that the laboratory environment is an unusual situation for test subjects. It is generally recognized that subjects are more likely to be awakened from a sleeping stage in the laboratory than at home at the same sound pressure level.

To eliminate such influences, several researchers have conducted investigations on the effect of noise on sleep in everyday situations by bringing an objective measuring device of sleep disturbance into the subject's own house [1,2]. In addition, some experiments have been conducted on the effects of noise on sleep with recorded sounds in the subject's own house using the behavior to switch off the sounds as an index of sleep disturbance (noise interrupted method) [3,4].

In the present research continuous road traffic noise and intermittent railway noise were used as stimuli to investigate their effect on sleep (sleep disturbance). The degree of the effect of each stimulus on sleep was assessed by a subjective method, i.e. a self-declaration based on a questionnaire, and by objective methods, i.e. whether the subject switched off the CD and the amount of body movement as measured by a wrist-worn actigraph.

2. Experiment

2.1. Stimuli

Three types of traffic noise were used as stimuli in the experiment: The first noise was from a main road with large level-fluctuations, the second was from an expressway with small level-fluctuations, and the third was from a conventional railway, which included six trains per hour. The road traffic noise with large level-fluctuations had a dynamic range of 27 dB and was recorded at a distance of 20–25 m from a main road. The railway noise was recorded at the same distance. The other road traffic noise with small level-fluctuations, with a dynamic range of 10 dB, was recorded at a distance of about 100 m from an expressway. For the railway noise, the maximum sound pressure levels of each passing train noise were higher by 14–21 dB (18 dB on average) than the value of $L_{\mathrm{Aeq,1\,h}}$.

The noises were recorded on a compact disc with a duration of 60 min. To simulate realistic indoor listening conditions, the stimuli were reproduced after adjusting the spectrum level according to the average insulation characteristics of Japanese houses as shown in Fig. 1. The sound pressure levels of the stimuli were set at three levels; 27.5, 35, and 42.5 dB, $L_{\mathrm{Aeq,1\,h}}$, considering that the Japanese environment quality standard at night is 60 dB for residential areas

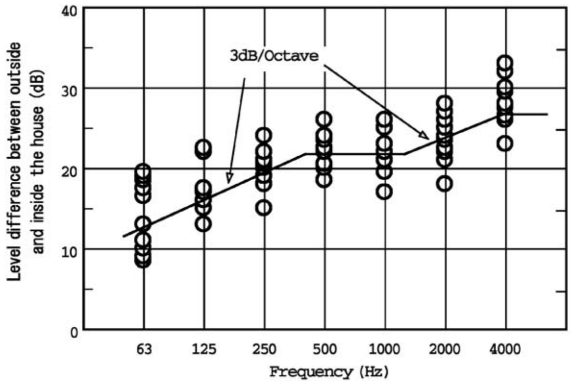

Fig. 1. Insulation characteristics of Japanese houses.

Table 1
Stimulus type and sound pressure level

CD no.	Sound source	SPL dB ($L_{Aeq,1\,h}$)
1	Road traffic noise with large level-fluctuations [RT(LF)]	42
2		35
3		27
4	Road traffic noise with small level-fluctuations [RT(SF)]	42
5		35
6		27
7	Railway noise (6 trains/h) [RW]	42
8		35
9		27

facing a road with two or more traffic lanes and the average insulation ability of Japanese houses is about 25 dB. Consequently, nine stimuli, as shown in Table 1, were used in total.

2.2. Subjects and effects

Four female and eight male subjects aged between 19 and 53 with normal hearing ability participated in the experiment. Most of them live in relatively quiet areas.

The experiment was conducted in the house of each subject. The stimuli were reproduced all night long using a compact disc player (BOSE Wave Radio/CD), unless subjects switched off the player. Subjects were allowed to mute the noise an hour after they went to bed if they judged that it was too disturbing for them to sleep at all. The degree of the effect of noise on sleep was judged by three indices, namely whether the subject had switched off the player, a self-declaration of the subject based on a questionnaire and the amount of arm movement during sleep measured by an actigraph.

The self-declaration was made as soon as possible after waking up the next morning. The key item in the questionnaire was "*How much was your sleep disturbed by the sound last night?*"

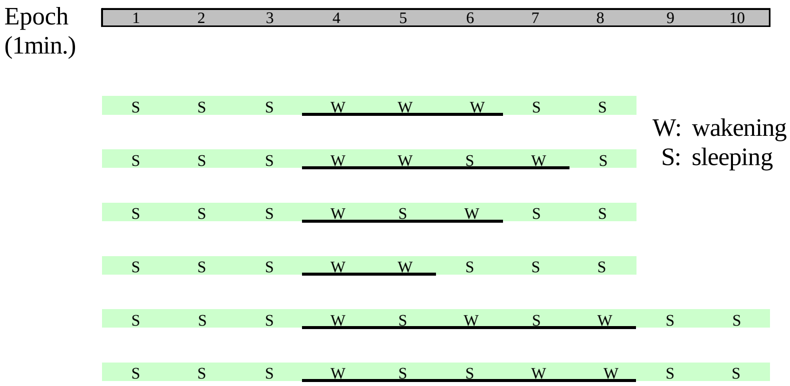

Fig. 2. Method of judging mid-sleep awakening (MSA). #1, #2 and #5 are judged as MSA, but the others are not.

The answers were obtained using five categories of response, from category one being "not annoyed at all" to category five, where "Sleep was extremely disturbed".

The actigraph (AW-64: Mini-Mitter Co.) is a small device worn on the wrist. It provides a continuous record of arm movement for every time sequence (e.g. 1 min) and gives the first indication of whether the subject is asleep or awake according to the occurrence of events that exceed a certain threshold. The final judgement whether the subject was in the stage of mid-sleep awakening (MSA) or not was determined under the algorithm proposed by Kageyama et al. [2] as shown in Fig. 2. As can be seen from the figure, one or two wakening epochs were not regarded as MSA, and it requires three or more wakening epochs under a certain noise exposure. When a series of waking epochs was judged to be a MSA, the sound pressure level of the first epoch was regarded as the relevant exposure level. The exposure level of the subjects was measured by an integrated sound level meter placed near the subject's pillow and completely time-synchronized to the actigraph.

3. Results

3.1. Self-declaration

In our previous study where meaningful sounds were used as stimuli, many subjects muted the stimuli, such as Karaoke songs and conversations, even at the sound exposure level of 25 dB in $L_{\mathrm{Aeq,1\,h}}$. However, in this experiment all 12 subjects fell asleep without muting noise stimuli consisting of road traffic and railway noises.

Fig. 3 shows the answers to the five categories of the key question on the effect of each stimulus. The results showed that the sleep disturbance by railway noise (stimuli 7–9) was greater than that of road traffic noise (stimuli 1–6) under equal values of $L_{\mathrm{Aeq,1\,h}}$. The effect of road traffic noise with large level-fluctuations (stimuli 1–3) was slightly larger than that of road traffic noise with small level-fluctuations (stimuli 4–6).

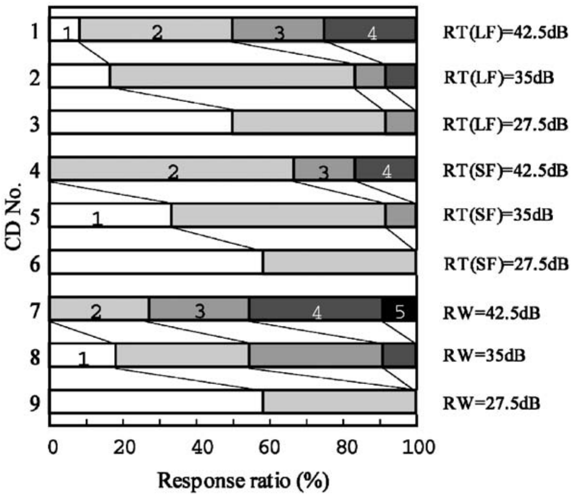

Fig. 3. Subjects' reaction to each stimulus. Category 1: not annoyed at all, 2: a little annoyed but no effect on sleep, 3: sleep was a little annoyed, 4: sleep was disturbed, 5: sleep was extremely disturbed.

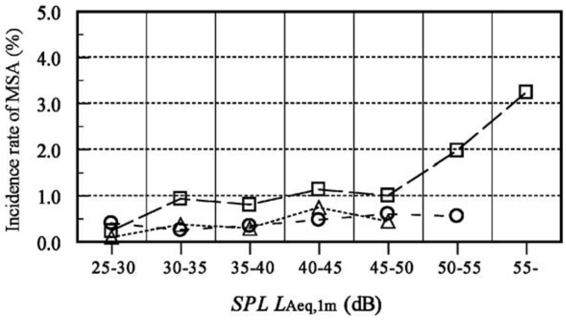

Fig. 4. Dose–response relationship between SPL ($L_{\mathrm{Aeq,1\,m}}$) and incidence rate of MSA. ○: road traffic noise with large level-fluctuation, △: road traffic noise with small level-fluctuation, □: railway noise.

It is obvious that the maximum sound pressure level of stimuli has great influence on sleep as well as L_{Aeq}, and this result supports the combination of L_{Amax} and L_{Aeq} in the nighttime noise regulations introduced in Nordic countries.

Considering that category 3 and more is the zone in which sleep disturbance occurs, the threshold where half of the subjects were disturbed was 40–45 dB in $L_{\mathrm{Aeq,1\,h}}$ for road traffic noise and 35 dB for railway noise, which corresponds to 50–55 dB in $L_{\mathrm{A,Fmax}}$ of each train noise.

3.2. Actigraphy

Fig. 4 shows the dose–response relationship between SPL in $L_{\mathrm{Aeq,1\,m}}$ and the incidence rate of MSA. When $L_{\mathrm{Aeq,1\,m}}$ was 50 dB and more, the incidence rate of MSA of railway noise rapidly increases. No such tendency could be after exposure to road traffic noises, even though there are no data points for the road traffic noise with small level-fluctuations above 50 dB in $L_{\mathrm{Aeq,1\,m}}$ and for large level-fluctuations above 55 dB in $L_{Aeq,1\,m}$. These results, however, do not agree with the results of the self-declaration questionnaire.

4. Conclusions

The followings are the major conclusions of the study.

The validity of the experimental technique was conformed which was implemented in the subjects' own houses with artificially produced traffic noises.

The effect of railway noise on sleep was larger than that of road traffic noise under equal values of L_{Aeq}. There was little effect of the level of fluctuations in road traffic noise.

The results of the self-declaration questionnaire showed that the threshold where half of the subjects were disturbed was about 35 dB, $L_{Aeq,1\,h}$ for railway noise and 40–45 dB, $L_{Aeq,1\,h}$ for road traffic noise.

The actigraph data showed that a rapid increase in the incidence of mid-sleep awakening occurred at more than 50 dB in $L_{Aeq,1\,m}$ for railway noise. In contrast, neither of the road traffic noises showed such a tendency at less than 55 dB in $L_{Aeq,1\,m}$.

The discrepancy between the self-declaration data and the actigraphy data for the road traffic noise exposures requires further investigation.

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