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Sleep disturbance caused by meaningful sounds and the effect of background noise

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Abstract

To study noise-induced sleep disturbance, a new procedure called ''noise interrupted method''has been developed. The experiment is conducted in the bedroom of the house of each subject. The sounds are reproduced with a mini-disk player which has an automatic reverse function. If the sound is disturbing and subjects cannot sleep, they are allowed to switch off the sound 1 h after they start to try to sleep. This switch off (noise interrupted behavior) is an important index of sleep disturbance. Next morning they fill in a questionnaire in which quality of sleep, disturbance of sounds, the time when they switched off the sound, etc. are asked. The results showed a good relationship between L_{Aeq} and the percentages of the subjects who could not sleep in an hour and between L_{Aeq} and the disturbance reported in the questionnaire. This suggests that this method is a useful tool to measure the sleep disturbance caused by noise under well-controlled conditions.

1. Introduction

Sleep disturbance is one of the most serious effects of noise. To prevent the adverse effects and to make appropriate noise criteria, it is important to determine the dose–response relationship between physical parameters of noise and the degree of sleep disturbance.

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Many laboratory and field studies on the effect of noise on sleep have investigated subject's sleep during the whole night (e.g. [1–7]). There are many difficulties in studies of the effect of noise on sleep. One may be due to the place where subjects sleep. It is difficult to control physical conditions at home and therefore many subjects are needed to detect clear-cut effects of the noise. On the other hand, it is an unnatural situation for subjects to sleep in a laboratory. Subjects need time to adapt to sleep in a laboratory. It is also very hard for experimenters to watch whole night experiments.

In a previous study [8] it was suggested that the effect of noise on whole night sleep might possibly be estimated from 1 h exposure to sounds during the period when subjects fall asleep.

A new procedure called "noise interrupted method" have been developed paying attention to the effect during 1 h period after subjects start to fall asleep. In this method, noise is presented to subject through headphones or earplugs of a mini-disk (MD) player. A MD player is portable, and then this method can be applied in each subject's house. The physical conditions of noise can be controlled by calibrating the output of headphones.

In our previous study using this method [8] the clear dose–response relationship was found between L_{Aeq} and switch-off behavior in the case of road traffic noise as shown by the open circles in Fig. 1. But in the case of meaningful sounds such as Karaoke song and people's talk, the effect on sleep was serious even when the level of these sounds was low as shown by the filled diamonds in Fig. 1. The relation between the disturbance answered in the questionnaire and L_{Aeq} is shown in Fig. 2. The same tendency was found between the responses to questionnaire and noise-interrupted behavior.

Recently, sound insulation of houses has been much improved and the level of noise in residential place has become very low. Low-level noises, which were formerly masked by ambient noises in residual area have become audible and disturb sleep especially in the case of meaningful sounds. To examine the effect of meaningful sounds and to design efficient sound insulation of walls are important. Regretfully, in our previous study, the number of meaningful stimuli was

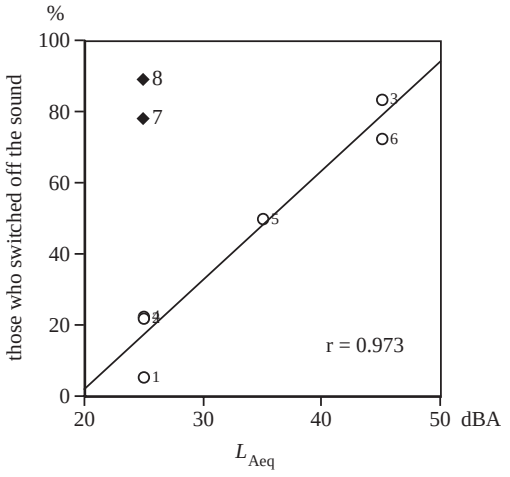

Fig. 1. Relation between L_{Aeq} and the percentages of the respondents who switched off the sounds in our previous study [8].

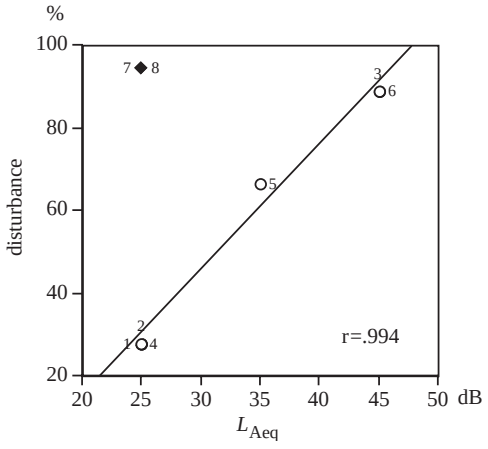

Fig. 2. Relation between L_{Aeq} and the the percentages of the respondents who answered that the sounds were disturbing or the sound were disturbing at the beginning in our previous study [8].

only two. The purpose of this study is to examine the effect of meaningful sounds with different levels and the masking effect of neutral sounds such as air-conditioner noise.

2. Material and methods

The experiment is conducted in the bedroom of the house of each subject. The sounds are reproduced with a MD player which has an automatic reverse function. Therefore, if subjects do not switch it off, the sound is presented continuously the whole night. Subjects are asked to try to sleep listening to the sounds through earphones connected with a MD player. If the sound is disturbing and subjects cannot sleep, they are allowed to switch off the sound 1 h after they start to try to sleep. This ''switch off'', or ''noise interrupted behavior'' is used as an index of sleep disturbance.

Next morning they fill in a questionnaire in which quality of sleep, disturbance of sounds, the time when they switched off the sound, etc. are asked. Before starting the experiment, subjects sleep with earphones for three nights. The earphones are fixed with an adhesive tape and sounds are not presented during these nights. According to our previous studies [8], it was found that subjects were gradually accustomed to sleep wearing earphones and on the third night, the subjects reported that they could sleep within 1 h. The experiment was conducted when the subjects went about with their usual daily lives and irregular days for them were avoided.

3. Experiment

3.1. Stimuli

Sixteen kinds of sound source were used. Karaoke songs were used as meaningful sounds and simulated air-conditioner noise was used as neutral sound. Taking actual situation into

Table 1
Stimulus conditions

No	Air-conditioner noise (dB)	Karaoke songs (dB)	L_{Aeq} (dB)
1	30		30
2	35		35
3	40		40
4	45		45
5	50		50
6		30	30
7		35	35
8		40	40
9	30	25	31.5
10	35	30	36.5
11	40	35	41.5
12	45	40	46.5
13	35	25	35.4
14	40	30	40.4
15	45	35	45.4
16	50	40	50.4

consideration, the levels of the stimuli were selected. The simulated air-conditioner noise was a steady-state noise of 30, 35, 40, 45 and 50 dB (A) whose frequency components were simulated to actual air-conditioner noise. Karaoke songs were recorded in a Karaoke bar and the values of L_{Aeq} were 25, 30, 35, 40 and 45 dB (A). Karaoke sounds were recorded through a filter of 5 dB/oct band in order to simulate the sounds transmitted through walls.

Karaoke sounds and simulated air-conditioner noise were mixed as shown in Table 1. The duration of these stimuli was 60 min. At the beginning of the experiment, a simulated air-conditioner noise of 30 dB(A) was used as training and the 16 stimuli including combined simulated air-conditioner noise and Karaoke songs were used in random order among subjects.

3.2. Procedure

Stimuli were presented to subjects individually according to the procedure of "the method of noise interrupted behavior" described above. Another questionnaire asking about their daily life situations was conducted before the experiment.

3.3. Subjects

The total number of subjects was 20 (12 male and eight female) aged between 20 and 42.

4. Results and discussion

Whether subjects "could sleep without stopping MD", or "could sleep after stopping the MD" or "could not sleep even after stopping the MD" is shown in Fig. 3. When the level of the

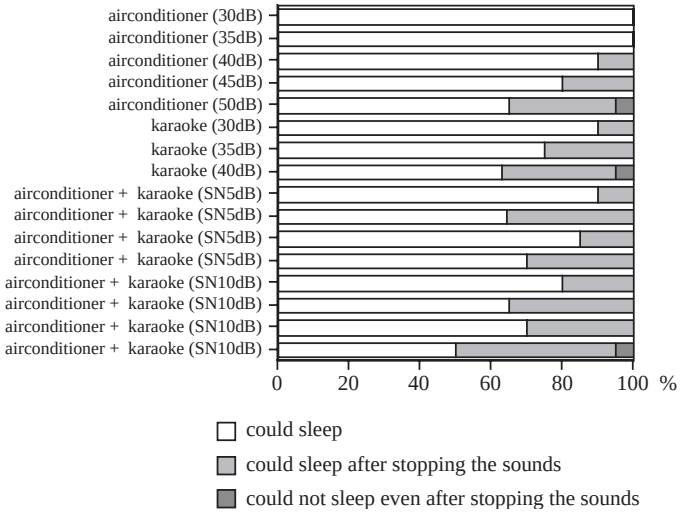

Fig. 3. The results of the experiment indicating whether the subjects "could sleep listening to the sounds", "could sleep after stopping the sounds", or "could not sleep even after stopping the sounds".

simulated air-conditioner noise was 35 dB (A), no effect of noise was found. When the level of the simulated air-conditioner noise increased from 40 to 50 dB(A), the percentages of the subjects who could not fall asleep in an hour also increased. In daily life situations, if someone suffers from noise, it is probable for him/her to make protest against noise source. The "noise interrupted behavior" is a kind of simulation or a representative of protest behavior against noise source. If subjects fall asleep within 1 h, the sounds are presented automatically and continuously. This whole night exposure of noise suggests that subject can be adapted to noise source and he/she can sleep well under that noise condition. Regarding air-conditioner noise of 30 dB, three subjects stopped the sound. According to the subjects' report, this was because they suffered from some reasons other than noise.

In the case of Karaoke songs, there was also a good relation between L_{Aeq} and the percentages of the subjects who could not fall asleep in an hour. But in the same L_{Aeq} conditions, the percentage caused by Karaoke was significantly higher than that of air-conditioner noise ($p < 0.05$).

Although the effect of masking was one of the main topics to examine in this study, no clear result was found. There is no significant difference between Karaoke alone conditions (stimuli 6–8), S/N-5 dB conditions (stimuli 9–12) and S/N-10 dB conditions (stimuli 13–16).

The responses to the question on disturbance are shown in Fig. 4. In the case of air-conditioner noise alone and Karaoke songs alone conditions, the same tendencies are found as in the results based on noise-interrupted behavior. Concerning the effects of background noise, there was no significant results between signal-to-noise ratio conditions, that is, "no noise: Karaoke songs only" conditions, "SN-5 dB" conditions and "SN-10 dB" conditions.

Within the same SN condition, some dose–response relation between disturbance response and L_{Aeq} values was found. The relation between L_{Aeq} values and the verbal response is shown in Fig. 5. There was a fairly good dose–response relation between the total percentages of

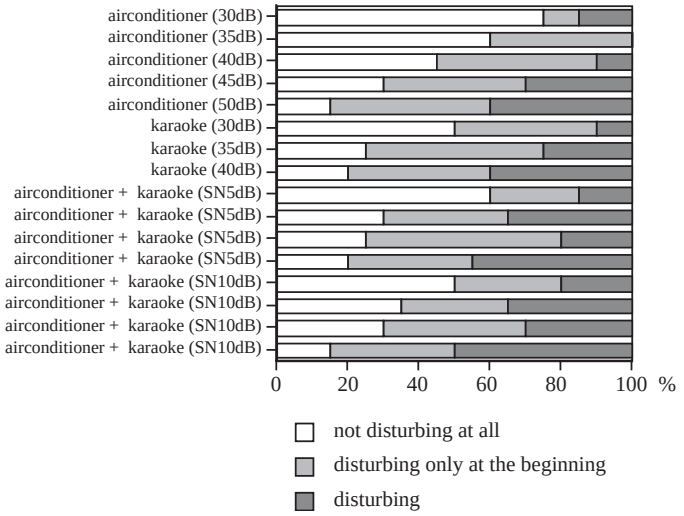

Fig. 4. The results of the questionnaire indicating whether the sound was ''not disturbing'', ''disturbing only at the beginning'', or ''disturbing''.

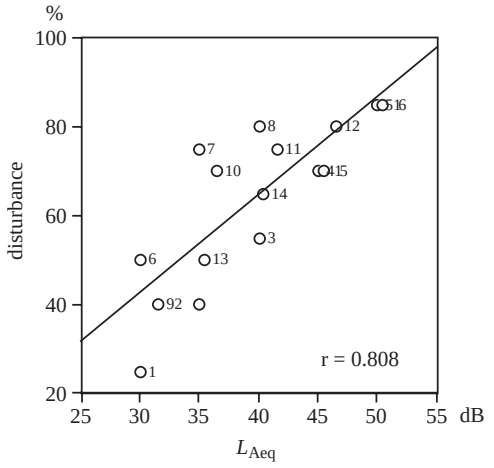

Fig. 5. Relation between L_{Aeq} and the percentages of the respondents who answered that the sounds were disturbing or disturbing only at the beginning.

''disturbing only at the beginning'' and ''disturbing'' responses and L_{Aeq} values, although data are scattered around regression lines.

Fig. 6 shows the regression lines of each stimulus group. There were good relations between the percentages of total disturbance and L_{Aeq}. The coefficient correlations of each group are close to 1. This means that the overlapping of air-conditioner sounds to Karaoke sounds increases the sleep disturbance corresponding to the increase in L_{Aeq} values. According to subjects' reports, even when the value of signal-to-noise ratio was -10 dB (the level of Karaoke was 10 dB below the level of air-conditioner sound) subjects can detect the Karaoke sounds. This suggests that when a meaningful sound is audible, there is not clear effect of background noise.

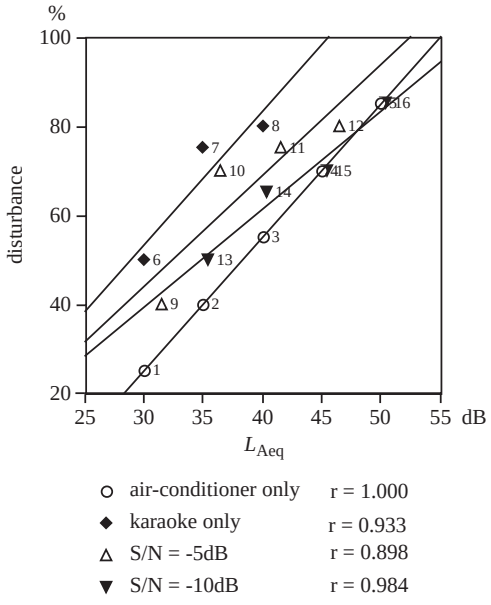

Fig. 6. The same results are shown as in Fig. 5 with the regression line of each condition.

As suggested by the results shown in Fig. 6, there was about 10 dB difference between simulated air-conditioner noise and meaningful sounds, Karaoke in the effect on sleep. This must be taken into consideration when the permissible level of noise is determined.

5. Summary

There was a good relationship between L_{Aeq} and the percentages of the subjects who could not fall asleep in an hour. This suggests that this method is a useful tool to measure the sleep disturbance caused by noise under well-controlled conditions. The method used has an advantage to lighten the load imposed to subjects as well as experimenters. The noise-interrupted method decreases the stress caused by experimental situations and the switch off response itself is a useful behavioral clue of sleep disturbance.

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