Journal of Sound and Vibration (2002) **250**(1), 83–90
doi:10.1006/jsvi.2001.3903, available online at http://www.idealibrary.com on IDEAL®

THE EFFECT OF DIFFERENT KINDS OF NOISE ON THE QUALITY OF SLEEP UNDER THE CONTROLLED CONDITIONS

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(*Received* 5 *September* 2001)

Many laboratory and field studies of the effect of noise on sleep have been performed where subjects sleep whole nights. It was suggested from our former studies that the most serious effect of noise on sleep is disturbance in falling asleep and that people have to make efforts to try to sleep in noisy situations. In this study, the effort to fall asleep was used as an index of sleep and the effect of various physical properties of sounds was examined. Subjects were asked to try to sleep listening to sounds presented with a mini-disk and they were allowed to switch off the sound after 1 h if they could not sleep. The results suggest that (1) whether subjects can sleep within 1 h after they start to try to sleep is a good index of the effect of noise on sleep and that L_{Aeq} is a good index of the effect of noise on sleep except for the sounds which have meanings such as songs and people's talk.

1. INTRODUCTION

Among many adverse effects of noise, sleep disturbance by noise is one of the most serious effects and may deteriorate health conditions. Many laboratory and field studies of the effect of noise on sleep have been investigated with subjects asleep whole nights [see e.g., references 1–6]. There are many difficulties in the study of the effect of noise on sleep. One of them may be due to the place where subjects sleep. It is difficult to control physical conditions at home and therefore many subjects are needed in order to detect clear effects of noise. On the other hand, it is an unnatural situation for subjects to sleep in a laboratory. It needs much time for subjects to be adapted to sleeping in a laboratory. It is also very hard for experimenters to watch whole night experiments. It was suggested from the former study [7] that the most serious effect of noise on sleep is disturbance in falling asleep and that people have to make an effort to try to sleep in noisy situations. In our previous study, the effect of noise on sleep was examined paying attention to the effect during 1-h period after

0022-460X/02/060083 + 08 $35.00/0

subjects started to fall asleep and it was suggested that the effect of noise on whole night sleep may possibly be estimated from 1-h exposure of sounds when subjects fall asleep [8]. The present experiment was designed to confirm the reliability of the results of our previous study while controlling the experimental situations in detail.

2. EXPERIMENT

2.1. STIMULI

Five kinds of sound source were used. They were simulated air-conditioner noise, two kinds of road traffic noise, KARAOKE songs and conversation between two people. The simulated air-conditioner noise was a steady state noise of 25 dB(A) whose frequency components were simulated to actual air-conditioner noise. Road traffic noise (1) was recorded at the four-lane road side where various types of road vehicle were passing. The sound level was fluctuating widely and the dynamic range was about 41 dB. The L_{Aeq} values were 25 and 45 dB(A). Road traffic noise (2) was recorded at a remote place of a 10-lane highway with a large traffic volume. The dynamic range of level fluctuation was about 18 dB and the L_{Aeq} values were 25, 35 and 45 dB(A). KARAOKE songs were recorded in a KARAOKE bar and L_{Aeq} was 25 dB(A). The conversation between two people was recorded from broad casting and L_{Aeq} was 25 dB(A). The duration of these sounds was 60 min. Except for the simulated air-conditioner noise, all the sounds were recorded through a filter of 5 dB/oct band in order to simulate the sounds transmitted through walls. Simulated air-conditioner noise was used as a training and the eight stimuli including simulated air-conditioner noise were used in random order among subjects.

In order to calibrate the sound level from the earphones of a mini-disk, loudness matching was conducted between the sound presented from a loudspeaker and the sound presented through earphones of a mini-disk using pink noise. Seven subjects, three females and four males aged between 22 and 29, conducted the loudness matching. They were asked to adjust the level of the sound presented from the loudspeaker using a remote control attenuator so that the loudness of the sound presented from the loudspeaker and that from the earphones should be perceived as being equal. A linear correlation was found between sound pressure levels of the sound presented from the loudspeaker and those measured from the line output of the mini-disk ($r = 0{\cdot}9998$). The sound presented from the earphones was calibrated using this relation.

It is not usual for most of the subjects to sleep with earphones. To sleep while wearing earphones itself may affect the sleep. Therefore, before starting the experiment, subjects tried to sleep with earphones for three nights. The earphones were fixed with an adhesive tape. Sounds were not presented during these nights. It was found that subjects were gradually accustomed to sleep wearing earphones and on the third night, about 90% of the subjects reported that they could sleep within 1 h.

2.2. PROCEDURE

The experiment was conducted in the bedroom of the house of each subject. The sounds were reproduced with a mini-disk player which had an automatic reverse function. Therefore, if subjects did not switch it off, the sound was presented continuously the whole night. Subjects were asked to try to sleep while listening to the sound via earphones. If the sound was disturbing and subjects could not sleep, they were allowed to switch off the sound 1 h after they started to try to sleep. If subjects fell asleep within 1 h, the sounds were

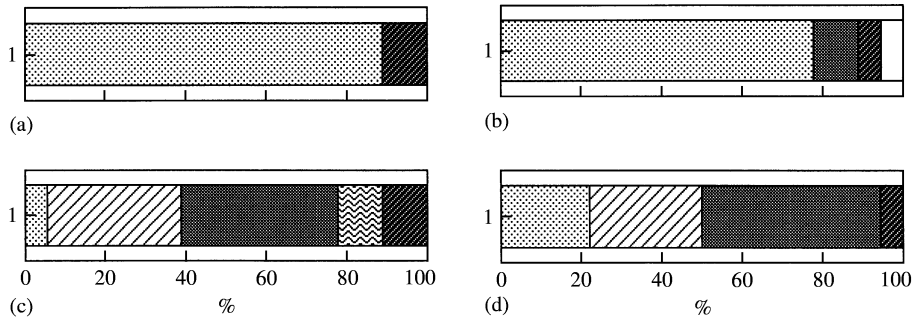

Figure 1. Results of the questionnaire where daily life situations were asked. (a) Quietness in the surroundings: ⊡, quiet; ▨, a little noisy. (b) Effect of noise on sleep: ⊡, sound has no effect; ■, sometimes sound creates disturbance in falling asleep; ▨, awakened by sound in early morning; □, no response. (c) Duration of sleep: ⊡, 5 h; ▨, 6 h; ■, 7 h; ▨, 8 h; ▨, 9 h. (d) Habituation to noise: ⊡,easily habituated; ▨, fairly; ■, it depends; ▨, difficult.

presented continuously. Next morning they filled in a questionnaire in which quality of sleep, disturbance of sounds, the time when they switched off the sound, etc. were asked. Subjects had a training with simulated air-conditioner noise. One of the eight stimuli was presented in random order after training. The experiment was conducted when the subjects went about with their usual daily lives and irregular days for them were avoided. Another questionnaire asking about their daily life situations was conducted before the experiment.

2.3. SUBJECTS

Four female and 14 male subjects aged between 19 and 38 (average 23·9) participated in the experiment.

2.4. DAILY LIFE EXPERIENCE OF SUBJECTS

The results of a questionnaire survey conducted before the experiment are shown in Figure 1. Most of the subjects answered that their surroundings were quiet as shown in Figure 1(a). Sound levels were measured in bed rooms of some subjects and the values of $L_{Aeq,6-8\,h}$ were from 27·5 to 30·7 dB(A).

The effect of noise on sleep in their daily lives is shown in Figure 1(b). About 80% of the subjects answered that noise had no effect on sleep. About 15% of subjects answered that they were disturbed by noise when they fell asleep or they were awakened by noise early in the morning. The average sleeping duration is shown in Figure 1(c). Generally, they slept for an appropriate duration. It is shown in Figure 1(d) as to how easily they were habituated to noise. About half of the subjects answered that they could be habituated to noise and only one subject answered that it was difficult to be habituated to noise.

3. RESULTS OF EXPERIMENT

3.1. EFFECT OF NOISE ON SLEEPING BEHAVIOR

Whether subjects could sleep in an hour after they started to try to sleep is shown in Figure 2. It was found that about 70% of the subjects could not sleep under the exposure of 45 dB(A) road traffic noise. Road traffic noise (1) had large level fluctuation, while road

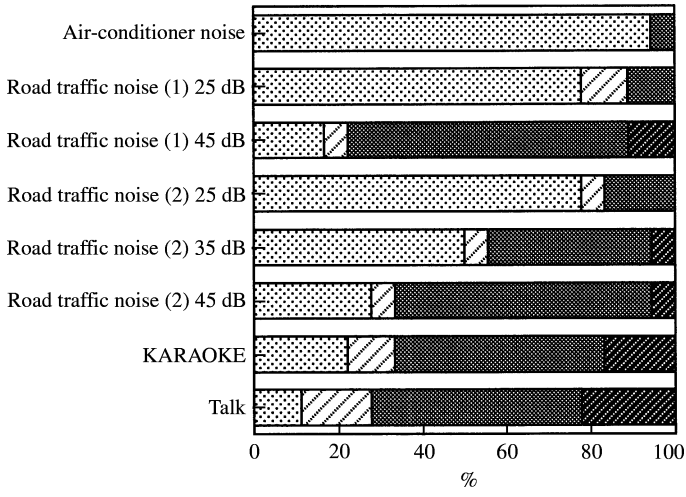

Figure 2. Effect of noise on falling asleep: ⊡, the percentages of subjects who could sleep within 1 h; ⊘, the percentages of subjects who could sleep, but awakened; ■, the percentages of subjects who could not sleep within 1 h; ▨, the percentages of subjects who could not sleep even after switching off the sound.

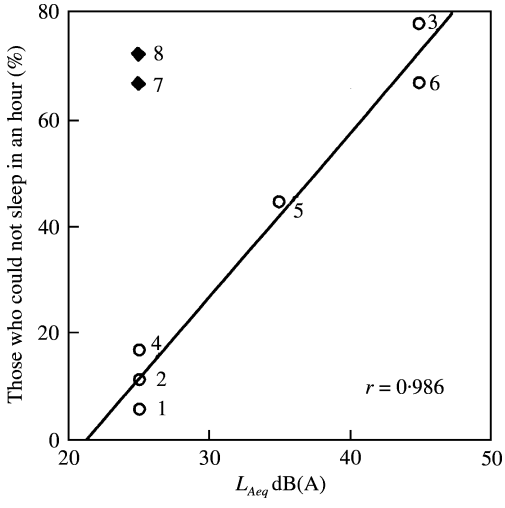

Figure 3. Relation between L_{Aeq} and the percentages of subjects who could not sleep within 1 h. The stimuli nos. 7 and 8 indicated by (◆) are Karaoke songs and people's talk. These meaningful sounds had a great effect on sleep regardless of the sound level. Therefore, the coefficient of correlation was calculated excluding these stimuli.

traffic noise (2) had small level fluctuation. No effect of level-fluctuation was found. When the level of road traffic noise was 25 dB(A) and when the simulated air-conditioner noise was exposed, most of the subjects fell asleep listening to the sound. The level of KARAOKE songs and people's talk on the radio was low (25 dB(A)), but since they had meanings, about 70% of the subjects reported that the sound was disturbing and they could not sleep. About 20% of the subjects reported that they could not sleep even after they switched off the sound.

The relation between L_{Aeq} and the percentages of the subjects who could not sleep in an hour is shown in Figure 3. High correlation can be found between them except for KARAOKE songs and people's talk. This result suggests that L_{Aeq} is a good measure of the

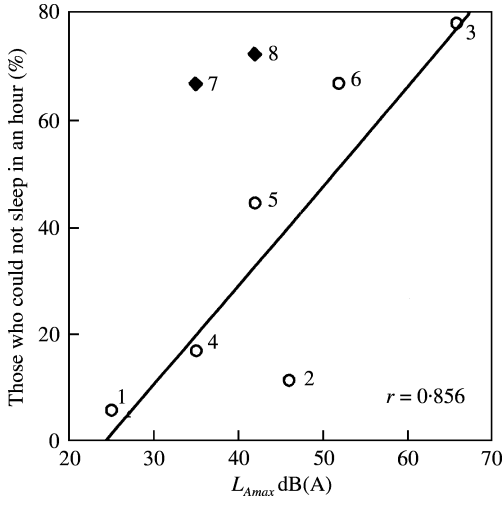

Figure 4. Relation between L_{Amax} and the percentages of subjects who could not sleep within 1 h. Coefficient of correlation was calculated excluding stimuli 7 and 8 as in Figure 3.

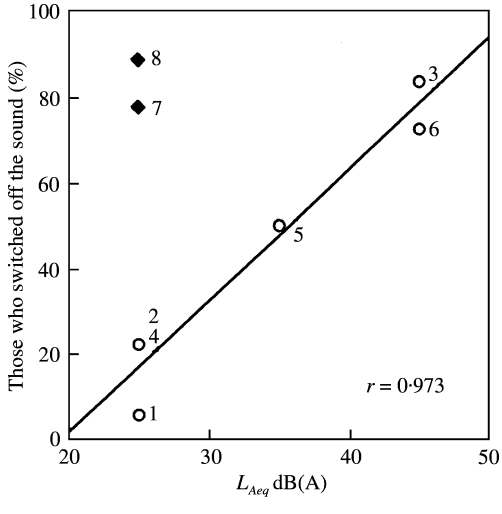

Figure 5. Relation between L_{Aeq} and the percentages of subjects who switched off the sound. Coefficient of correlation was calculated excluding stimuli 7 and 8 as in Figure 3.

effect of road traffic noise on sleep as far as the sounds used in this experiment are concerned.

The relation between L_{Amax} and the percentages of the subjects who could not sleep in an hour is shown in Figure 4. The coefficient of correlation is lower with L_{Amax} than with L_{Aeq} though there is no statistically significant difference.

Subjects were allowed to switch off the sounds at any time after 1 h had passed. The percentages of the subjects who switched off the sounds are plotted against L_{Aeq} in Figure 5. There were subjects who could not sleep within 1 h and switched off the sound and those who fell asleep within 1 h, but were awakened later and switched off the sounds. This figure shows that the higher the sound levels were, the more the subjects switched off the sounds. It

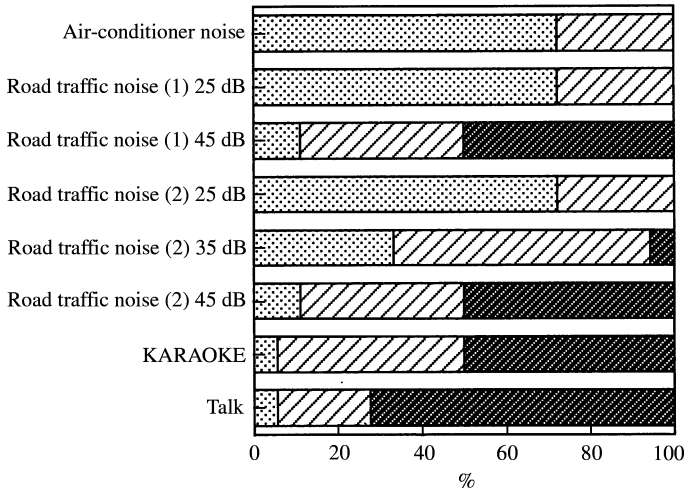

Figure 6. Results of the question whether the sound was disturbing: ⊡, sound was not disturbing at all; ▨, sound was disturbing only at the beginning; ▩, sound was disturbing.

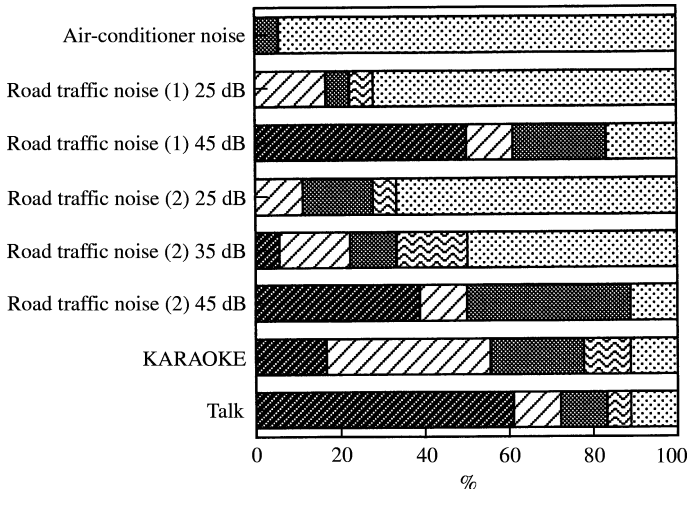

Figure 7. Health conditions after awakening next morning: ▩, those who could not sleep and have headache; ▨, those who slept well, but feel bad; ■ ,those who could not sleep well, but do not feel bad; ▧, those who could not sleep well, but feel well; ⊡, those who could sleep and feel well.

can be noted that most of the subjects switched off the meaningful sounds, KARAOKE songs and people's talk.

3.2. EFFECT OF NOISE IN QUESTIONNAIRE

The response to the question on disturbance is shown in Figure 6. Air-conditioner noise and road traffic noise of 25 dB(A) had no effect on sleep or an effect of only a short period when the subjects tried to sleep. On the other hand, road traffic noise of 45 dB(A), KARAOKE songs and people's talk showed a tendency to be disturbing.

The health conditions reported are shown in Figure 7. Many of the subjects reported that they had headaches or they felt bad when they were exposed to road traffic noise at

45 dB(A), KARAOKE, or people's talk. On the other hand, many subjects reported that they could sleep and felt well at 25 dB(A) air-conditioner noise or road traffic noise. Similar results were found concerning the quality of sleep.

3.3. RELATION BETWEEN BEHAVIOR AND SUBJECTIVE RESPONSE

The results suggest that similar results were found between two indices, i.e., behavioral index and the feeling reported in the questionnaire. There was a high correlation between the percentages of subjects who could sleep within 1 h and the percentages of subjects who reported in the questionnaire that they could sleep well and felt well next morning as shown in Figure 8. Similar results were found between whether they could sleep within 1 h and the percentages of subjects who reported in the questionnaire that the sound had no effect on sleep. These results suggest that whether subjects can sleep within 1 h can be used as an index of the quality of whole night sleep.

3.4. CROSS ANALYSIS

Cross analysis was conducted using whether subjects slept in an hour as a key item. Since the number of subjects was not sufficient, the results of all the sound sources were combined together. It was found that the percentages of the subjects who felt that the sound was disturbing, could not sleep so well as usual and had headaches in the next morning are higher in the group of subjects who could not sleep within 1 h than in the other group.

4. DISCUSSION

The method used in this experiment has a merit that subjects are not forced to listen to the sounds the whole night. They are allowed to switch off the sound any time after listening to the sound for 1 h. Even though they slept after switching off the sound, an effect of the

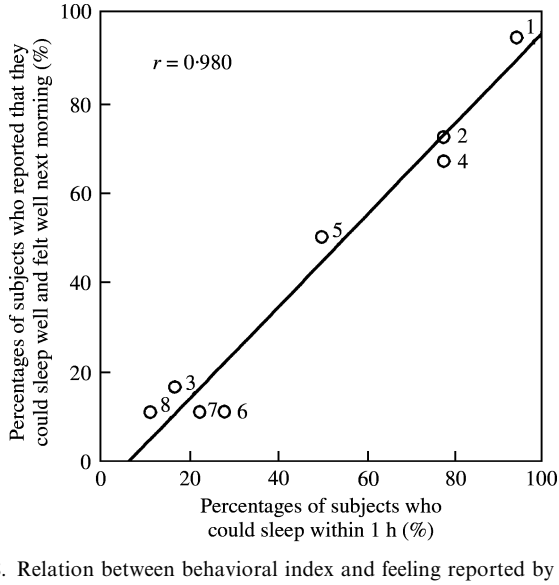

Figure 8. Relation between behavioral index and feeling reported by subjects.

sound was found in the questionnaire conducted the next morning. Another merit is that subjects can sleep on their own beds. This does not make subjects feel uneasy.

It was found that L_{Aeq} shows good correlation with the effect of noise on sleep as far as the stimuli used in this experiment are concerned except for KARAOKE songs and people's talk. There are a lot of discussions on how to decide the criteria concerning the sleep disturbance of noise. If the value of L_{Aeq} is tentatively calculated from the regression line indicated in Figure 3 which corresponds to the 30% of the subjects who could not sleep within 1 h, it was found to be 31·0 dB(A). This is quite similar to 30 dB(A) in $L_{Aeq,\,8\,h}$, which is the guideline value recommended by WHO [9]. The result of this experiment agrees with the guideline of WHO, though it is necessary to discuss about the criteria carefully on the basis of the data with many other sounds and many subjects with various generations.

The sounds which convey verbal information such as songs and people's talk were found to be disturbing even if their sound levels were low. It is suggested that these sounds should be lower than the threshold in order not to disturb sleep.

5. CONCLUSION

The results of the experiment show that sounds whose levels are high and which are meaningful may have a greater effect on sleep than sounds whose levels are low and which are meaningless. There was little effect of the level fluctuation of the sounds in this experiment. These results were found in the sleeping behavior in an hour after subjects started to try to sleep as well as in the impression reported after they slept the whole night. This suggests that the effect of noise on whole night sleep may possibly be estimated from 1-h exposure of sounds when subjects fall asleep. L_{Aeq} seems to be a good index of the effect of road traffic noise on sleep.

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