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DIFFERENT EFFECTS OF ROAD TRAFFIC NOISE AND FROGS' CROAKING ON NIGHT SLEEP

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This study was designed to assess the effects of road traffic noise and frogs' croaking on the objective and subjective quality of sleep in a laboratory. The subjects were seven male students aged 19–21 years. They were exposed to recorded road traffic noise and frogs' croaking, with 49·6 and 49·5 dB(A) L_{Aeq}, and 71·2 and 56·1 dB(A) L_{Amax}, respectively. The background noise in the experimental room was 31·0 dB(A) L_{Aeq}. The sleep EEG was recorded according to standard methods. The sleep polygraphic parameters examined were the percentage of sleep stage relative to the total sleep time (%S1, %S2, %S(3 + 4), %SREM, %MT), total sleep time, sleep onset latency, and awakening during sleep in minutes and sleep efficiency. A structured sleep rating questionnaire (OSA), was administered to the subjects after they awakened. The %S2 increased and the %SREM decreased during exposure to road traffic noise. However, no significant effect of exposure to frogs' croaking was observed on any of the polygraphic sleep parameters. The subjective quality of sleep was degraded more by exposure to road traffic noise than that to frogs' croaking.

1. INTRODUCTION

Most studies on the effects of noise on sleep have focused on the physiological and psychological effects and annoyance produced by exposure to unpleasant sounds or noise, including that of aircraft, road traffic, railroad traffic, and industrial or other noise. Our research group has been engaged in the study of the effects of road traffic noise and shipping noise on the sleep EEG patterns and subjective sleep ratings since 1985 [1, 2].

Sato *et al.* [3] reported that the percentage of stage REM relative to the total sleep time decreased significantly in five young subjects who slept in an apartment along a noisy road with heavy traffic as compared with that when the same subjects slept in a quiet suburban house. Tamura *et al.* [4] reported that exposure to a steady shipping noise of 65 dB(A) increased the percentage of stage 2 and decreased the percentage of stage REM, both relative to the total sleep time, as compared with those on control nights.

A large number of reports on the effects of noise on human sleep have been published [5]. However, few studies have examined the effects of amenity sounds, such as that of a breeze through a forest, murmuring of a brook or chirping of larks in a meadow. In the present study, we examined the effects of the frogs' croaking on sleep, tape-recorded in a paddy field during the rice-planting season in early summer. The L_{Aeq} of frogs' croaking was 66 dB(A),

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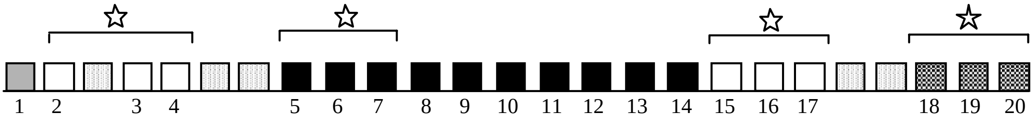

Figure 1. Day-to-day experimental schedule in terms of the conditions of noise exposure: ☆, data for analysis; □, non-exposure; ■, road traffic noise exposure; ▩, frogs' croaking exposure; ▨, preliminary; ░, non-experimental day.

which is a loudness level, almost equivalent to that of road traffic noise. This study was designed to assess the difference in effects of road traffic noise and frogs' croaking on the objective and subjective quality of sleep in the laboratory.

2. METHODS

The subjects were seven healthy men, aged 19–21 years, with normal sleep–wake cycles. They were not in the habit of exercising daily, a point of relevance to the study, since a previous study had suggested that exercise influences sleep EEG patterns and the subjective quality of sleep [6, 7]. Written informed consent was obtained from each of the subjects before the commencement of the study. Alcoholic beverages and daytime naps were prohibited before the experiments.

Each subject slept in a sleep laboratory for an experimental period of 20 nights. The experimental schedule employed is shown in Figure 1. During the first four nights, the subjects slept in a quiet environment. They were then exposed to traffic noise for 10 consecutive nights from the fifth to the 14th nights, and again slept in a quiet environment for three consecutive nights from the 15th to the 17th nights. Thereafter, from the 18th to the 20th nights, for three consecutive nights, they were exposed to frogs' croaking. Data obtained on the first night were not used for the analysis [8].

In Figure 1, we need the nights with star mark as the data of three conditions. The six white boxes denote the non-noise exposure nights; the first, second and third black boxes denote the nights of exposure to road traffic noise, and the last three mesh boxes denote the nights of exposure to frogs' croaking. The three additional nights of exposure to frogs' croaking were added at the end of the original experiment, which had been designed to assess the habituation to traffic noise.

Data from the first three nights of exposure to road traffic noise were selected to avoid the effects of habituation to the noise [9, 10].

Road traffic noise was recorded from 10 p.m. to 7 a.m. from the room of a hotel along Kannana Dori, a busy state road in Tokyo, with an average traffic volume of 2300 cars/h at night. The sound levels of the road traffic noise were: L_{Aeq}, 69·6 dB(A), and L_{Amax}, 88·7 dB(A).

The croaking of Japanese Tree Frogs (*Hyla japonica*) was recorded from 10 to 11 p.m. in a wet rice field in July 1996. The sound levels of the frogs' croaking were: L_{Aeq}, 66 dB(A), and L_{Amax}, 70.7 dB(A).

We assumed the usual sound insulation by windows in Japan of about 20 dB(A). When replaying in the sleep laboratory, the sound levels of the road traffic noise were decreased to 49·6 dB(A) L_{Aeq} and 71·2 dB(A) L_{Amax}, and those of the frogs' croaking noise to 49·5 dB(A) L_{Aeq} and 56·1 dB(A) L_{Amax}. The L_{Aeq} of the background noise in the experimental room was 31 dB(A).

To compare the sounds produced by road traffic noise and the frogs' croaking, a time series of the changes in the sound levels was determined and a frequency analysis was conducted with a sound level meter (NA-23; Rion Co. Ltd., Tokyo) and level recorder (LR-05; Rion Co. Ltd., Tokyo) for the former, and a sound level meter (NA-29; Rion Co. Ltd., Tokyo) for the latter.

The subjects entered the sleep laboratory at 10 p.m. and electrodes were fitted for recording the sleep EEG patterns according to the standard method described by Rechtschaffen and Kales in 1968 [11]. They went to bed at 11 p.m. and were woken up at 8 a.m. by an alarm clock. The EEG at C_3-A_2, EMG on the lower jaw, and EOGs on the right and left sides were recorded using a telemetry system (Nihon Kohden Co., Tokyo). The sleep polygraphic parameters examined were the percentage of sleep stage relative to the total sleep time (%S1, %S2, %S(3 + 4), %SREM, %MT), total sleep time (TST), sleep onset latency (SOL) and awakening during sleep in minutes (TW). All the parameters were assessed using our automatic computerized analyzing system by Aoki *et al.* [12], although the EEG pattern during sleep onset latency was corrected by visual judgment. The criterion for sleep onset was prolongation of S1 or S2 for 5 min. The basic features of this computerized system were as follows. The signals from each channel were sampled at the rate of 100 Hz. The digital data were stored on a hard disk through an A/D converter, and used to calculate the integral of the EMG, sleep spindles, %alpha and %delta waves in an epoch, and rapid eye movements. Each epoch was 20 s, and was identified first for MT, then S4, S3 and S2, waking, SREM, and finally, S1. Using this system, each night's polygraphic record was analyzed in 1 h, and the overall correct identification of the stages was 84% against that by visual judgment.

To investigate subjective sleep, the OSA questionnaire, which is often used in Japan, was administered the morning following the experimental night just after the subject awakened [13]. The scores in the five items of the OSA, namely, sleepiness, sleep maintenance, worry, integrated sleep feeling and sleep initiation, were calculated. The larger the score, the better the quality of sleep.

The effects of exposure to road traffic noise, that to frogs' croaking and non-exposure to noise were compared in terms of the changes in each of the aforementioned sleep parameters and the OSA scores. Two-way analysis of variance was applied using subject and noise exposure factors. The NAP statistical software [14] was used for the analysis.

3. RESULTS

3.1. ANALYSIS OF THE SOUNDS

The time series of changes in the sound levels of road traffic noise and the frogs' croaking noise are shown in Figure 2. Road traffic noise fluctuated mainly between 29 and 65 dB(A), while the frog's croaking fluctuate in the smaller range of 42–50 dB(A).

The results of the frequency analysis of road traffic noise and frogs' croaking are shown in Figure 3. In the 125–1000 Hz band, the sound levels of road traffic noise were higher than those of the frogs' croaking, while in the 4000 Hz band, those of the frogs' croaking were higher as compared to the levels for road traffic noise.

3.2. SLEEP INDICATORS

The average values of the sleep EEG parameters on the nights of non-exposure to noise, and during exposure to road traffic noise and frogs' croaking are shown in Table 1. The results of ANOVA revealed that the subject factors had a significant effect on the %S1, %S2, %S(3 + 4), %SREM, %MT, TST, SOL and TW ($p < 0.01$), noise factors had

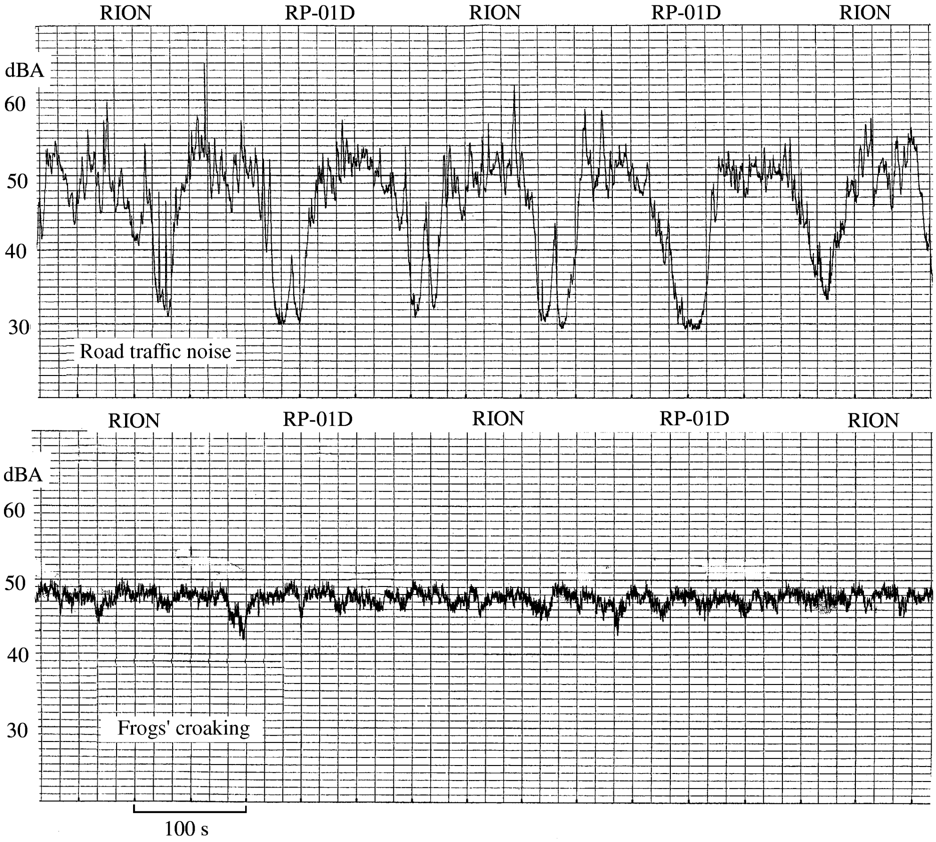

Figure 2. Time series of changes in the sound levels of road traffic noise and frogs' croaking.

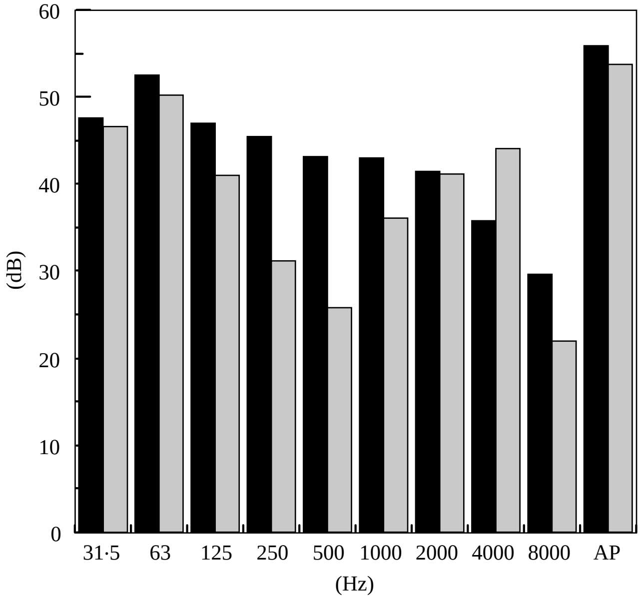

Figure 3. Octave band frequency analysis of: ■, road traffic noise; ▨, frogs' croaking.

Table 1

Average values (± S.D.) of sleep parameters in the seven subjects on the nights of non-exposure to noise (–), nights of exposure to road traffic noise (+) and nights of exposure to frogs' croaking (+ +), as compared by two-way ANOVA

Noise	Sample	%S1 (%)	%S2 (%)	%SWS (%)	%SREM (%)	%MT (%)	TST (min)
–	$N = 42$	6·6 ± 4·56	59·4 ± 9·59	6·1 ± 2·89	24·6 ± 7·57	3·3 ± 2·81	477·5 ±40·29
+	$N = 21$	7·6 ± 5·42	62·5 ± 9·76	5·5 ± 3·16	21·1 ± 6·60	3·3 ± 2·25	478·2 ±36·52
+ +	$N = 21$	7·5 ± 4·80	59·4 ± 8·81	5·2 ± 2·37	24·2 ± 8·34	3·6 ± 2·69	477·1 ±38·95
		S**I*	S**N*	S**	S**N*	S**	S**

Noise	SOL (min)	TW (min)	F1 (points)	F2 (points)	F3 (points)	F4 (points)	F5 (points)
–	35·1 ± 25·01	2·4 ± 4·43	51·1 ± 5·53	45·3 ± 4·00	50·3 ± 5·23	49·1 ± 7·68	45·7 ± 5·77
+	30·2 ± 26·24	2·4 ± 3·70	45·6 ± 5·24	39·8 ± 4·05	46·4 ± 3·74	41·4 ± 5·60	42·3 ± 5·47
++	30·9 ± 24·50	4·0 ± 6·35	47·4 ± 4·82	45·3 ± 4·07	47·5 ± 4·53	43·8 ± 6·67	42·9 ± 6·73
	S**	S**	S*N**	S**N**	N**	S**N*	N*

Note: S1-2, Stages 1–2; SWS: slow-wave sleep (Stages 3 + 4); SREM: stage of rapid eye movement; MT, movement time; SOL, sleep onset latency; TW, awakening during sleep in minutes· F1–F5 are five factors of the OSA, sleepiness, sleep maintenance, worry, integrated sleep feeling, and sleep initiation. S and N are the main effects of subject and noise, respectively, and I is interaction, by two-way analysis of variance. **$p < 0·01$, *$p < 0·05$.

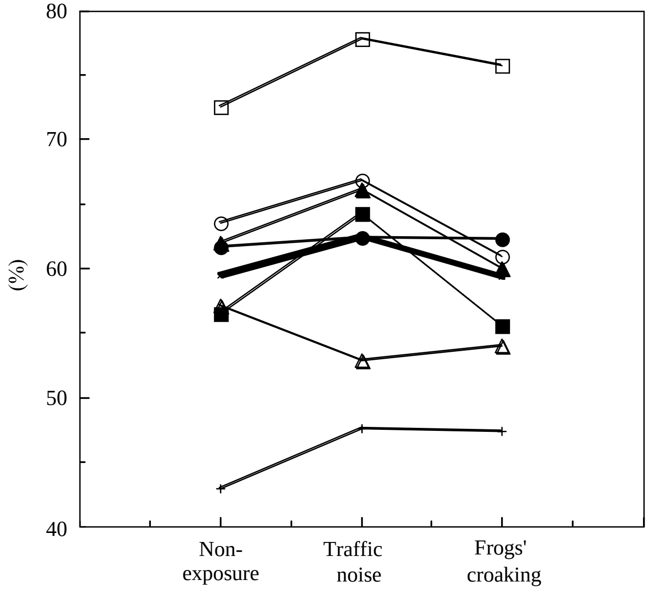

Figure 4. Average %S2 in the seven subjects on the non-exposure nights, nights of exposure to road traffic noise and nights of exposure to frogs' croaking: subjects: —○—, A; —●—, B; —□—, C; —■—, D; —△—, E; —▲—, F; —+—, G; ——×——, total.

a significant effect on the %S2 and %SREM ($p < 0.05$), while the interaction between the two had a significant effect on the %S1.

The average %S2 in the seven subjects is shown in Figure 4 on the nights of non-exposure to noise, exposure to road traffic noise, and exposure to frogs' croaking. A tendency towards

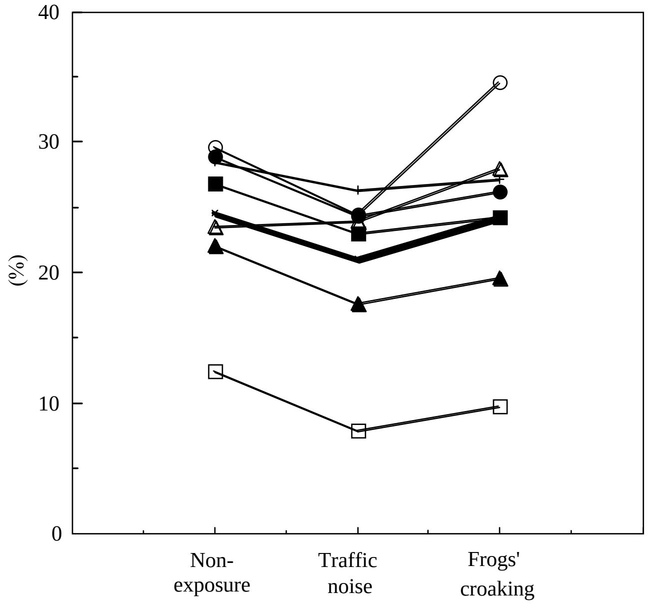

Figure 5. Average %SREM in the seven subjects during nights of non-exposure to noise, exposure to road traffic noise, and exposure to frogs' croaking: subjects: —○—, A; —●—, B; —□—, C; —■—, D; —△—, E; —▲—, F; —+—, G; ——×——, total.

increase in the %S2 on the nights of exposure to road traffic noise was observed in all of the subjects, except subject E. On the other hand, the %S2 on the nights of non-exposure to sound and during exposure to frogs' croaking were almost the same.

Figure 5 shows the %SREM in the seven subjects under the three different conditions. The %SREM was significantly decreased during exposure to road traffic noise, and the values during exposure to frogs' croaking were scarcely different as compared to those on the nights of non-exposure to sound.

The scores in the five items of the OSA questionnaire were determined to examine the subjective sleep quality (Table 1). ANOVA revealed a significant effect of subject factors on the scores for sleepiness, sleep maintenance, and integrated sleep feeling ($p < 0.05$), and a significant effect of noise factors on the scores for sleepiness, sleep maintenance, worry, integrated sleep feeling, and sleep initiation ($p < 0{\cdot}05$).

The average scores for the item of sleep maintenance in the OSA questionnaire, which is related to the depth of sleep and awakening during sleep, are shown in Figure 6. The standardized scores for sleep maintenance tended to be lower following nights of exposure to road traffic noise, than following nights of non-exposure to noise in all the subjects. The effect of the croaking of frogs on the score for sleep maintenance was, as mentioned before, negligible.

4. DISCUSSION

In this study, an increase in %S2 and decrease in %SREM were observed in the subjects during exposure to road traffic noise. Differences in sleep EEG parameters for exposure to frogs' croaking and for non-exposure nights were minimal, even though the sound level of the frogs' croaking was about L_{Aeq} 50 dB(A), which was almost the same as that of the road traffic noise. Many previous studies have reported that road traffic noise, with sound levels

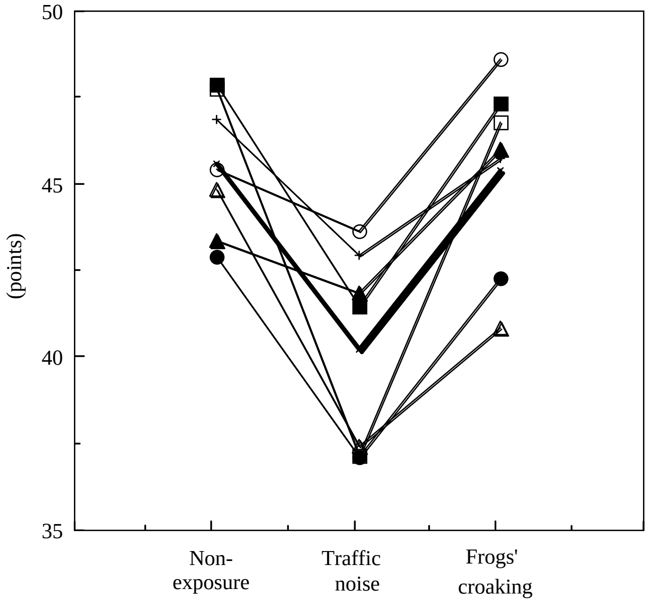

Figure 6. The score in the item of sleep maintenance in the OSA questionnaire in the seven subjects on the nights of non-exposure to noise, exposure to road traffic noise, and exposure to frogs' croaking: subjects: —○—, A; —●—, B; —□—, C; —■—, D; —△—, E; —▲—, F; —+—, G; ——×——, total.

of over L_{Aeq} 44 dB(A), decreased % SREM [15–18]. Furthermore, Saletu *et al.* [18] used a noise level of L_{Aeq} 75·6 dB(A), and observed not only a decrease in the %SREM, but also an increase in %S2. Eberhardt *et al.* [17] and Suzuki *et al.* [1] suggested, respectively, that the % SREM is one of the most sensitive parameters of the sleep EEG during exposure to continuous or irregular noise and that the sound level threshold at which the % SREM decreased was 45 dB(A). The present study revealed that while exposure to road traffic noise depressed the %SREM, exposure to the sound of frogs' croaking had little effect on this parameter. The reason for this difference remains to be clarified.

The L_{Aeq} of both road traffic noise and frogs' croaking was about 50 dB(A), even though the sound level range of road traffic noise was higher than that of frog's croaking. Cycles of about 2 min duration were noted in the sound level of road traffic noise. This was considered to be due to the traffic stopping every 2 min by a red traffic signal. Furthermore, frequency analysis of road traffic noise revealed that the highest peak level was in lower frequency bands, which was different from the case of the frogs' croaking. Broner and Leventhall [19] reported that exposure to low-frequency sounds might be more annoying and disturbing to sleep. To confirm this hypothesis, the time series of changes in the sound levels of the frogs' croaking could be adjusted to the same pattern as that of road traffic noise in a future experiment, and the effects of exposure to the two noises on sleep examined.

Öhrström and Rylander [20, 21] suggested that both the maximum noise level and the number of noise events were more important than the L_{Aeq} level in causing disturbance to sleep. The present study also indicates that it might be insufficient to use only the L_{Aeq} level of the noise for evaluation of the effects of noise on sleep.

Eberhardt *et al.* [17] and Vallet *et al.* [15] reported that exposure to continuous traffic noise of 45 dB(A) degraded subjective sleep. The subjective sleep parameters showed a tendency to be disturbed following exposure to both road traffic noise and the sound of frogs' croaking as compared to those following nights of non-exposure to noise. However, the scores in the sleep maintenance item of the OSA questionnaire were similar following nights of exposure to frogs' croaking and those of non-exposure to noise. Furthermore, the scores in the other items of the OSA questionnaire decreased more following exposure to road traffic noise than that to frogs' croaking.

The two-way analysis of variance revealed considerable individual differences in the sleep EEG patterns. Subject E showed a different pattern during %S2 as compared to all of the other subjects, and Subjects A and E showed the highest %SREM during exposure to the frogs' croaking. And, the scores for sleep maintenance in the OSA questionnaire following nights of exposure to the frogs' croaking were the highest in Subjects A and F. Such individual differences may be related to the sensitivity of the subjects to frogs' croaking. In this study, the sensitivity of the subjects to the croaking sound of a frog was not assessed. Öhrström *et al.* [22] reported that the group with higher sensitivity to a noise showed significantly increased body movements and more degraded subjective sleep quality during exposure to the sound than the subjects in the low-sensitivity group. Contrary to the expectation at the start of the experiment that exposure to frogs' croaking may improve sleep, no such evidence was obtained. It would be of great interest to examine the effects of much lower sound levels of frogs' croaking than the level (L_{Aeq}, 50 dB(A)) examined in this study.

Osada [23] suggested that more research on the effects of amenity sounds that induce sleep is necessary. Zimmerman and colleagues [24] reported that the playing of music reduced the severity of pain and had a beneficial effect on sleep in coronary artery bypass graft (CABG) patients. In addition, Levin [25] reported that music therapy might be effective in patients of insomnia. Williamson [26] also reported that the sounds of the ocean had a positive effect on sleep in CABG patients. Unfortunately, these reports provided no information on the sound levels. We believe that the sound levels and frequency may be important factors to be considered while examining the effects of amenity sounds on sleep.

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