Experimental investigation on sleep disturbance for transportation noise – follow-up test of the noise effect on sleep using recorded traffic noise.

Masaaki Hiroe[1], Kotoka Nagai[2], Fumioki Koyama[2], Kazuma Enomoto[2] and Mari Ueda[2]

[1] Kobayasi Institute of Physical Research, Tokyo, Japan (corresponding author)
[2] Kanagawa Institute of Technology, Kanagawa, Japan

Corresponding author's e-mail address: hiroe@kobayasi-riken.or.jp

ABSTRACT

In this study, we investigate how noise affect sleep using recorded traffic noise in participants' own home. A road traffic noise, a conventional railway noise and an aircraft noise were used in this experimental study. Participants were mainly collected from the students of Kanagawa Institute of Technology. Participants were exposed to the artificially controlled traffic noise all night long using portable CD player which was set on repeat. The sleep disturbance for traffic noise was evaluated in the following two manners: self-reported sleep quality based on questionnaire and the measurement of body movement using wrist actimetry method. The relationships among subjective sleep disturbance, kinds of traffic noise, noise sensitivity and noise level were analyzed through several statistical test. On the other hands, objective sleep disturbance was evaluated according to how frequently bodily reactions happen to traffic noise events. In this paper, we report the relationship between subjective and objective sleep disturbance, and that between noise level and incidence of waking after sleep onset (WASO).

INTRODUCTION

The publication of the Environmental Noise Guidelines for the Europe Region [1] by World Health Organization (WHO) Regional Office Europe in October 2018 triggered many Japanese researchers to treat more investigations about health effects on traffic noise. Although there are many large-sized social surveys on long-term annoyance and/or self-reported sleep disturbance which caused by traffic noise, the investigations on sleep disturbance based on objective data are not sufficient. Therefore, we carried out experimental study on sleep disturbance by traffic noise based on objective manner.

MATERIALS AND PROCEDURES

We conformed with the experimental procedure in previous study [2]. This experimental investigation was not conducted in the laboratory but in the house of each subject. The bodily reactions to indoor noise events were recorded continuously in the subjects' bedrooms. Night-related as well as event-related outcome variables were analyzed, such as self-reported sleep quality and body movements. The study itself and all the procedures further described were approved by the ethics committee of Kanagawa Institute of Technology.

Subjects

One female and nine male subjects aged between 20 and 47 (24±7 years old) with self-reported normal hearing ability participated in the experiment. All subjects read the recruitment information on the experiment and agree to participate. The compact disc (CD) player (BOSE Wave System Series) was set in the subjects' bedroom after obtaining informed consent. Each subject answered the questionnaire on usual sleep pattern and noise sensitivity before starting the first night experiment. Subjects were instructed on how to use an actigraph (GT3X series, AMI) and to fill in a sleep diary every morning. After the 10-night experimental period was over, subjects were debriefed and given a remuneration of 15,000 Japanese Yens.

Design

In this study, we used three types of traffic noise as stimuli. The first noise was from a major surface road with large level-fluctuations, the second was from a conventional railway line which included six trains per hour, and the third was from a landing aircraft which included four airplanes per hour. Each noise was recorded on a CD 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 [2]. The sound pressure levels of the stimuli were set at three levels; 27.5, 35, and 42.5 dB, $L_{\text{Aeq,1h}}$, considering that the Japanese environment quality standard at night is 60 dB for residential areas 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 **Table 1**, were used in total.

Table 1: Stimulus type and sound pressure level.

CD No.	Type of traffic noise	SPL, dB ($L_{\text{Aeq,1h}}$)
1	Road traffic noise with large level-fluctuation [**RTN**]	42.5
2		35.0
3		27.5
4	Conventional railway noise (6 trains/h) [**CRN**]	42.5
5		35.0
6		27.5
7	Aircraft noise (4 airplanes) [**ACN**]	42.5
8		35.0
9		27.5

Procedure

The stimuli were reproduced all night long using a compact disc player, unless subjects switched off the player. We allowed subjects 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 sleep disturbance was judged by two indices, namely whether a self-rating questions asking sleep impact and the amount of arm movement during sleep measured by an actigraph.

The self-reported questionnaire was answered as soon as possible after waking up the next morning. The questionnaire consisted of the bedtime hour, the awakening hour, the alcohol drinking at last night, the sleep-producing drug (or drug for common cold) taking behavior at last night and various questions asking subject's sleep at last night. One of the key items in the questionnaire was "Q6. How much was your sleep disturbed by the sound last night?" The answer was obtained using five categories of response, from category one being "not annoyed at all" to category five, where "Sleep was extremely disturbed". Other important items were "Q10-2. How was overall quality of your sleep last night?", and "Q10-7. How many times did you have dreams?". The answers were obtained using seven categories of response, from category one being "very good (or a little)" to category seven being "very bad (or many)".

The actigraph is a small device worn the wrist, and was attached to each subjects' non-dominant arm. The actigraphic data were collected in one-minute epochs. The sleep/wake identifications were assessed based on the Cole-Kripke sleep scoring algorithm [4] using wrist activity data of one-minute length. The final judgement whether the subject was in the stage of wake after sleep onset (WASO) or not was determined under the algorithm proposed by Kageyama et al. [2] as shown in **Fig. 1**. As can be seen from the figure, one of two wakening epochs were not regarded as WASO, and it requires three or more wakening epochs under certain noise exposure. When a series of waking epochs was judged to be a WASO, the sound pressure level of the first epoch was regarded as the relevant exposure level.

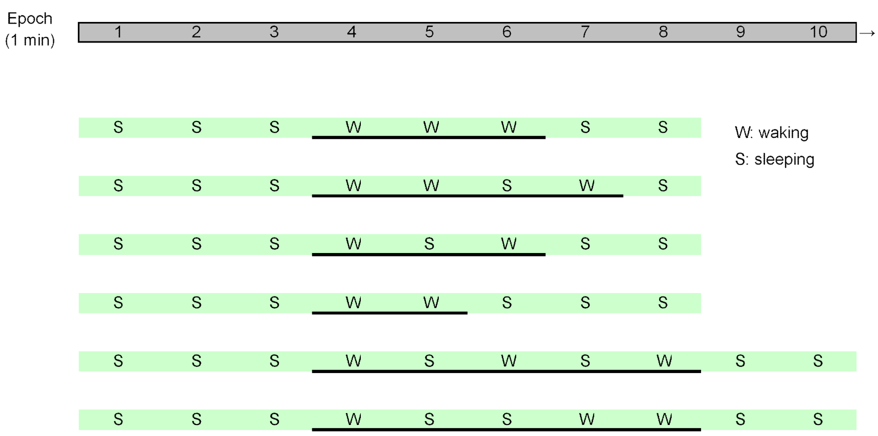

Figure 1: The method of judging wake after sleep onset (WASO).
#1, #2 and #5 are judged as WASO, but the others are not.

RESULTS

Analysis results of night-related outcome variables

Fig. 2 shows the answers to the five categories of the key question Q6 on the effect of each stimulus. The 28-night data for RTN were analyzed and each 26-night data for CRN and CAN were analyzed, because of failure to playback and lack of actigraphic data. The results showed that self-reported sleep disturbance by intermittent noise (CRN stimuli 4-6, ACN stimuli 7-9) was associated with sound pressure level $L_{\text{Aeq,1h}}$, although that by road traffic noise (RTN stimuli 1-3) was not associated with $L_{\text{Aeq,1h}}$. In the previous study [2], the sleep disturbance by road traffic noise with large level-fluctuations has a tendency to increase with sound pressure level $L_{Aeq,1h}$. The response of subjects to road traffic noise between two studies is clearly different.

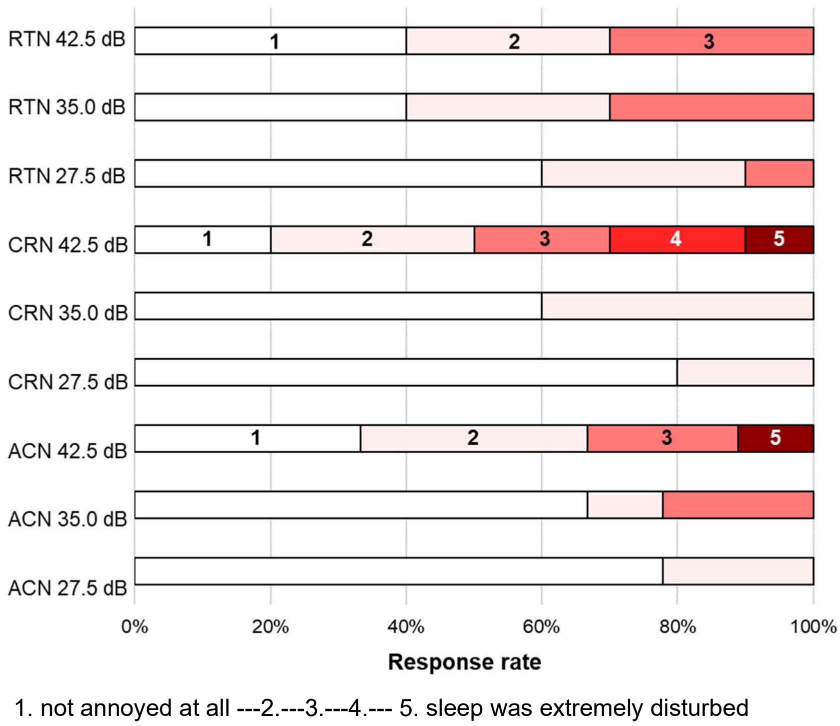

Figure 2: Subjects' reaction to each stimulus for Q6.

The correlation analysis between subjective data (answers in Q6, Q10-2 and Q10-7) and sound pressure level $L_{Aeq,1h}$, objective data (latency, total counts, efficiency, total sleep time [TST] and wake after sleep onset [WASO]) is shown in **Table 2**. Firstly, we notice that Q6 (sleep disturbance) and Q10-2 (quality of sleep) were significantly associated with SPL $L_{Aeq,1h}$ for intermittent noise. Secondary, it was clear that there were significant correlations between TST (total sleep time) and Q10-7 (amount of dream), regardless with source type. With the exception of some correlations depending on source type, there were no significant correlations between subjective and objective data. Moreover, objective (actigraphic) data shown in **Table 2** were not associated with SPL $L_{Aeq,1h}$.

Analysis results of event-related outcome variables

Fig. 3 shows the dose-response relationship between SPL in $L_{Aeq,1m}$ and the incidence of WASO for three source types. In any source type, there was no tendency to increase the incidence of WASO with a raise in $L_{Aeq,1m}$. With consideration for time lag between appearance of SPL and awakening, we regarded SPL for two minutes including the first epoch of WASO and epoch before one-minute as the relevant exposure level. Although we used the averaged SPL ($L_{Aeq,2m}$) or the maximum SPL ($L_{Aeq,1m,\,max}$) instead of SPL $L_{Aeq,1m}$, there were no proportional relationships between SPL and the incidence of WASO. These results do not agree with the results of the self-reported questionnaire.

Table 2: Correlation analysis between subjective data (answers in Q6, Q10-2 and Q10-7) and $L_{Aeq,1h}$, objective data (latency, total counts, efficiency, TST and WASO) for each source type.

	Q6	Q10-2	Q10-7
Sound pressure level ($L_{Aeq,1h}$)	+0.224 (*p*=0.252) **+0.625** (*p*=0.001)*** **+0.466** (*p*=0.016)*	-0.059 (*p*=0.766) **+0.421** (*p*=0.032)* **+0.380** (*p*=0.055)†	-0.141 (*p*=0.475) +0.070 (*p*=0.735) -0.048 (*p*=0.814)
Latency	**+0.540** (*p*=0.003)** -0.018 (*p*=0.929) +0.259 (*p*=0.201)	**+0.331** (*p*=0.086)† -0.039 (*p*=0.851) **+0.448** (*p*=0.022)*	-0.097 (*p*=0.624) -0.265 (*p*=0.191) -0.005 (*p*=0.979)
Total counts	+0.197 (*p*=0.314) +0.089 (*p*=0.665) -0.177 (*p*=0.388)	-0.066 (*p*=0.739) -0.040 (*p*=0.847) -0.159 (*p*=0.437)	**+0.409** (*p*=0.031)* +0.195 (*p*=0.339) **+0.508** (*p*=0.008)**
Efficiency	-0.301 (*p*=0.120) +0.049 (*p*=0.812) -0.202 (*p*=0.322)	-0.072 (*p*=0.715) +0.256 (*p*=0.206) -0.082 (*p*=0.690)	-0.173 (*p*=0.378) -0.002 (*p*=0.990) **-0.389** (*p*=0.049)*
Total sleep time [TST]	-0.128 (*p*=0.516) +0.026 (*p*=0.899) **-0.514** (*p*=0.007)**	-0.277 (*p*=0.154) +0.226 (*p*=0.266) -0.307 (*p*=0.127)	**+0.335** (*p*=0.082)† **+0.453** (*p*=0.020)* **+0.331** (*p*=0.099)†
Wake after sleep onset [WASO]	+0.190 (*p*=0.333) -0.005 (*p*=0.981) -0.166 (*p*=0.416)	-0.078 (*p*=0.692) -0.145 (*p*=0.478) -0.199 (*p*=0.330)	**+0.340** (*p*=0.076)† +0.173 (*p*=0.397) **+0.492** (*p*=0.011)*

Note: †$p<0.10$, *$p<0.05$, **$p<0.01$, ***$p<0.001$, where p-value indicates the significance probability of correlation analysis. The upper / middle / lower values mean correlation coefficient for road traffic noise / conventional railway noise / aircraft noise.

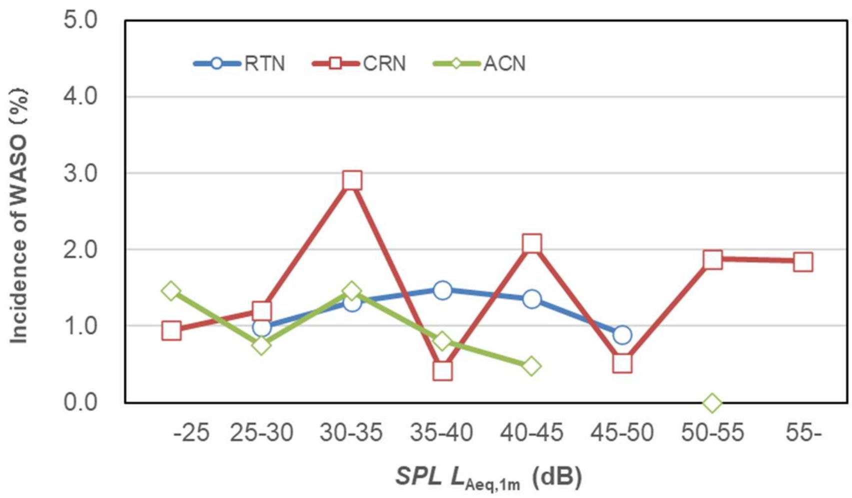

Figure 3: Dose-response relationship between SPL $L_{Aeq,1m}$ and incidence of WASO.
RTN: road traffic noise, CRN: conventional railway noise, ACN: aircraft noise

DISCUSSIONS

In this study, self-reported sleep disturbance by intermittent noise obtained a result similar to that of previous study. However, self-reported sleep disturbance by road traffic noise could not increase with a raise of sound pressure level $L_{Aeq,1h}$, and there were no dose-response relationships between the incidence of WASO and relevant noise exposure level $L_{Aeq,1m}$. Some results of this study differed from those of previous study clearly.

Some comparisons on usual sleep pattern of subjects between two studies show as follow: percentage of whom feel lack of sleep was 70% (in this study) vs 75% (in previous study), those of whom go to bed until 0 am was 50% vs 33%, those of whom get out of bed until 10 am was 60% vs 92%, those of whom feel light sleep was 20% vs 0%, those of whom have day-by-day difference of sleep time within an hour was 20% vs 67%.

On the other hand, the amount of data collected by wrist actigraph differs between two studies: the total number of one-minute epochs was about 28,000 vs about 35,000, and the total number of awakening epochs was about 330 vs about 150. The incidence of WASO (1.2%) which was assessed in this study was about three times as great as that (0.4%) in previous study.

From the fact just described, the remarkable characteristics of subjects participated in this study are irregularity of usual sleep patterns and high incidence of awakening epochs. Moreover, the significant correlations between TST (total sleep time) and Q10-7 (amount of dream) in this study could be associated with a percentage of REM sleep that subjects got during the experiments. It is said that the sleeper reaction to a given noise event during night not only depend on the acoustical property of the noise event, but also situational moderators (e.g., current sleep stage) and personal moderators (e.g., sex, age). The difference of subjects' characteristics in between two studies could be one of reasons caused some different objective results between them. In order to compare with the results of previous study, the confounding factors of subjects which have influence on sleep disturbance had to be controlled carefully.

CONCLUSIONS

Based on objective manner in previous study, we investigated how noise affect sleep using recorded traffic noise in participants' own home. The self-reported sleep disturbance by intermittent noise obtained in this study a result similar to that of previous study. However, some results of this study differed from those of previous study clearly: self-reported sleep disturbance by road traffic noise could not increase with a raise of sound pressure level, and there were no dose-response relationships between the incidence of WASO and relevant noise exposure level. The difference of subjects' characteristics in between two studies could be one of reasons caused some different objective results between them.

REFERENCES

[1] World Health Organization Regional Office for Europe, Environmental Noise Guidelines for the European Regions (2018).

[2] Kaku J., Hiroe M., Kuwano S. and Namba S. (2004). Sleep disturbance by traffic noise: an experimental study in subjects' own houses using a portable CD player. *Journal of Sound and vibration*, 277, 459-464.

[3] Kageyama T., Kurokawa T. and Kabuto M. (1997). An epidemiologic study on insomnia in metropolitan areas IV: a relationship between incidence of waking estimated by actimetry and nighttime road traffic noise, *Proceedings of 1997 Meeting of INCE/J, 1997 (in Japanese)*.

[4] Cole RJ., Kripke DF., Gruten W., Mullaney DJ. and Gillin JC. (1992). Automatic sleep/wake identification from wrist actigraphy. *Sleep* 1992(15), 461-469.