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# HABITUATION OF SLEEP TO ROAD TRAFFIC NOISE OBSERVED NOT BY POLYGRAPHY BUT BY PERCEPTION

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The habituation of sleep to road traffic noise was investigated. Habituation of sleep is improvement of sleep quality. Nine male students aged 19–21 were exposed to tape-recorded road traffic noise of $L_{eq}$ 49·6 dB(A) in an experimental bedroom. Among 17 nights, the first four and the last three nights were non-exposure nights and the other consecutive 10 were exposure nights. The polygraphic sleep parameters were: sleep stages S1, S2, S(3 + 4), rapid eye movements (REM), and so on. Subjective sleep quality was assessed by five scales of a self-rating sleep questionnaire named the OSA, sleepiness (F1), sleep maintenance (F2), worry (F3), integrated sleep feeling (F4), and sleep initiation (F5). In this experiment, the habituation of sleep to road traffic noise was observed clearly in all of the subjective sleep parameters of the OSA, though all of the polygraphic sleep parameters showed little or no evidence of habituation. This suggests that habituation to noise has two aspects, sensation and perception mechanisms, corresponding to sleep polygraphy and to questionnaire respectively.



## 1. INTRODUCTION

There are many studies of the habituation of sleep to road traffic noise, but there are also many different views among investigators [1–10]. For example, Öhrström said that no evidence of habituation was observed in body movements, heart rate, subjective sleep quality in experimental exposure of intermittent road traffic noise [1]. Eberhardt found that the proportion of slow wave sleep of subjects in their homes along noisy roads had been depressed, even if they had lived for at least a year at their residences [2]. Vallet studied subjects living for more than 4 yr near noisy roads, suggesting that no habituation to noise was observed in the latency of REM and %REM [3]. On the other hand, Saletu exposed young subjects to road traffic noise for a week in a laboratory. He observed an increase in stage 4 with a significant improvement in subjective sleep quality in the last three exposure nights [6].

In order to assess the effect of road traffic noise on sleep, we investigated the habituation of sleep to road traffic noise. We recorded typical road traffic noise along a busy state road in Tokyo and exposed each of nine subjects to this noise for 17 nights. The effect of road traffic noise on sleep and the habituation of sleep to road traffic noise were assessed by sleep polygraphy and subjective self-rating sleep scores.

 

## 2. METHODS

The subjects were nine male students aged 19–21 years who had normal hearing ability as assessed by audiometry with a frequency range from 125 Hz to 8 KHz. They were selected not to have a habit of exercise in the daytime because a previous study suggested that exercise had some effect on sleep EEG and subjective sleep [11]. Alcoholic drinks, drugs and daytime naps were prohibited before the experimental night. Informed written consent was obtained before the experiment. Each subject was tested from October 1996 to November 1999 in an experimental bedroom for 17 nights, the first four and the last three of which were non-exposure nights and the other consecutive 10 of which were noise exposure nights. The subjects went to bed at 23:00, and were awakened not later than 8:00 the next morning by an alarm clock.

The effect of road traffic noise on sleep and the habituation of sleep to road traffic noise were assessed by sleep polygraphy and subjective self-rating sleep scores.

Polygraphic sleep parameters were determined by electroencephalogram (EEG), electrooculogram (EOG) and electromyogram (EMG). EEG electrodes were positioned according to the international 10-20 methods (C3-A2 and C4-A2). C3-A2 recordings were mainly used in the analysis. EEG, EOG and EMG were recorded by a telemetry system (Model WEE-6112, Nihon Kohden Co. Ltd. Tokyo). The sleep polygraphic parameters evaluated in this study were: sleep stages S1, S2, S(3 + 4), rapid eye movements (REM) and movement time (MT), as percentages based on total sleep time (%S1, %S2, %S(3 + 4), %REM, %MT). Moreover, total sleep time in minutes (TST), sleep latency in minutes (SL) and awakening time after sleep onset in minutes (TW), sleep efficiency in percentages (EFFIC), number of stage shifts per hour (SHIFT), number of sleep spindles per hour (SP), alpha and delta wave in percentages (%$\alpha$, %$\delta$) and the reaction time in seconds (RT). The onset of sleep was defined as the continuation of stage 1 or 2 for 5 mins. Polygraphic sleep parameters were detected with the help of an automatic computer system that could give reliable results to us within 84% of the recorded data by expert human scorer's analysis [12].

The reaction time in seconds (RT) was measured with the reaction time device, chosen for the WHO neurobehavioral core test battery. The subject's test was to give rapid motor responses to repetitive visual stimuli that were presented at random intervals of 1·0–10·0 s. The subjects were presented with 64 stimuli, to which they must respond, and the mean reaction time for these 64 responses was calculated. The reaction time in seconds (RT) within 15 min after awakening the following morning was used in the analysis.

Subjective parameters were measured by a self-rating sleep questionnaire. Each of the experimental sleeps was self-rated the following morning. The OSA questionnaire, which consists of 31 items, is often used in Japan [13]. The five scales of the OSA are sleepiness (F1), sleep maintenance (F2), worry (F3), integrated sleep feeling (F4), and sleep initiation (F5). The better the sleep quality is, the higher the score is.

In this study, we recorded typical road traffic noise on a tape recorder total 9 hr at night, in a hotel room along a busy state road, *Kan-nana*, in Tokyo with an average traffic volume of 2300 cars per hour at night [14]. The subjects were exposed to the same tape-recorded road traffic noise by using an integrated amplifier, and the speakers were positioned 1·5 m from the subject. In the experimental bedroom the exposed noise level was $L_{max}$ 71·2 dB(A), and $L_{eq}$ 49·6 dB(A). The frequency range of the road traffic noise was from 31·5 Hz to 8 kHz. The change in $L_{eq}$ per hour across the recording was from 49·4 to 51·4 dB(A). Background sound level in the experimental bedroom was $L_{eq}$ 30·0 dB(A). Previous experience suggested that effects during the first experimental night were non-typical because of the changed sleep environment [15], and the effect of environmental change on sleep became less from the second experimental night. The first experimental night data were not used for the analysis. Two nights' polygraphic data were failed. Therefore, 142 nights of non-exposure or exposure were used in the final analysis.

To analyze the effect of road traffic noise on sleep in comparison with quiet nights, the *t*-test was applied to each sleep parameter for the six non-exposure and ten exposure nights. To assess the habituation of sleep to road traffic noise, each sleep parameter of the consecutive ten exposure nights was analyzed by Pearson's moment correlation coefficients. The statistical analyses were performed with the statistics software program NAP [16].

## 3. RESULTS

The *t*-test results for parameter groups of non-exposure and exposure nights are shown in Table 1. Of the 13 polygraphic sleep parameters, mean %REM ($p < 0{\cdot}05$) was significantly decreased by the noise exposure. Among the subjective sleep parameters, mean sleep scores of F1 ($p < 0{\cdot}01$), F2 ($p < 0{\cdot}05$), F3 ($p < 0{\cdot}01$) and F4 ($p < 0{\cdot}01$) of the OSA significantly became worse on the noise exposure nights. RT ($p < 0{\cdot}01$) after awakening the following morning was significantly elongated.

Table 2 shows Pearson's moment correlation coefficients ($R_s$) between each sleep parameter and the consecutive ten exposure nights. No significant changes were found in polygraphic sleep parameters. But among the subjective sleep parameters, mean sleep scores of F1 ($p < 0{\cdot}01$), F2 ($p < 0{\cdot}001$), F3 ($p < 0{\cdot}01$), F4 ($p < 0{\cdot}001$) (Figure 1) and F5 ($p < 0{\cdot}01$) of the OSA all significantly correlated with exposure nights. Figure 1 shows the OSA scale scores of integrated sleep feeling (F4) of nine subjects plotted against ten exposure nights, individually. Figure 2 shows regression lines of the OSA scale scores of integrated sleep feeling (F4) plotted against 10 exposure nights of nine subjects. The scale scores increased slightly during the ten exposure nights. The other four scale scores also

TABLE 1

*Average of polygraphic sleep parameters and self-rating scale scores of the OSA of nine subjects*

| | Control ($n = 54$) Mean (S.D.) | | Exposure ($n = 88$) Mean (S.D.) | | | Control ($n = 54$) Mean (S.D.) | | Exposure (n = 88) Mean (S.D.) | |
|---|---|---|---|---|---|---|---|---|---|
| %S1 | 6·1 | (4·23) | 7·4 | (4·43) | SP | 166·0 | (117·31) | 174·1 | (126·53) |
| %S2 | 59·5 | (9·13) | 61·0 | (8·93) | %α | 24·6 | (6·39) | 24·6 | (6·67) |
| %S(3 + 4) | 5·5 | (2·84) | 5·2 | (2·96) | %δ | 3·7 | (1·10) | 3·7 | (1·19) |
| %REM | 26·0 | (7·70) | 23·2 | (6·65)† | | | | | |
| %MT | 2·9 | (2·64) | 3·2 | (2·44) | F1 | 51·7 | (5·72) | 48·0 | (5·40)‡ |
| TST | 479·1 | (36·96) | 473·1 | (43·02) | F2 | 45·3 | (4·18) | 43·5 | (4·42)‡ |
| SL | 35·1 | (23·00) | 35·2 | (37·14) | F3 | 51·1 | (5·04) | 48·6 | (5·00)‡ |
| TW | 4·8 | (8·62) | 5·1 | (9·94) | F4 | 50·5 | (7·95) | 46·3 | (6·37)‡ |
| EFFIC | 92·2 | (4·91) | 92·3 | (7·01) | F5 | 46·6 | (5·78) | 45·4 | (5·24) |
| SHIFT | 26·9 | (8·24) | 27·5 | (7·97) | RT | 0·237 | (0·029) | 0·254 | (0·041)‡ |

† $p < 0{\cdot}05$. ‡ $p < 0{\cdot}01$.

*Note*. S.D.: standard deviation; %S1-%S(3 + 4), sleep stages1-(3 + 4) in percentages; %REM, sleep stage REM in percentages; %MT, movement time in percentages; TST, total sleep time; SL, sleep latency; TW, awaking time after sleep onset in minutes; EFFIC, sleep efficiency in percentages; SHIFT, number of stage shifts per hour; SP, number of sleep spindles per hour; %α and %δ, α and δ wave in percentages; F1–F5, self-rating scale scores of the OSA (O: M. OGURI: S: S. SHIRAKAWA and A: K. AZUMI [13]), F1, sleepiness; F2, sleep maintenance; F3: worry; F4, integrated sleep feeling and F5, sleep initiation; RT: reaction time in seconds after awakening the next morning

TABLE 2

*Pearson's moment correlation coefficients ($R_s$) between each sleep parameter and exposure nights from* 1 *to* 10

| | | | | | | |
|---|---|---|---|---|---|---|
| %S1 | %S2 | %S(3 + 4) | %REM | %MT | TST | SL |
| – 0·031 | – 0·107 | 0·055 | 0·143 | – 0·009 | – 0·059 | 0·05 |
| TW | EFFIC | SHIFT | SP | %α | %δ | |
| – 0·027 | – 0·05 | 0·015 | 0·012 | – 0·027 | 0·031 | |
| F1 | F2 | F3 | F4 | F5 | RT | |
| 0·297† | 0·495‡ | 0·299† | 0·377‡ | 0·285† | – 0·038 | |

† $p < 0{\cdot}01$. ‡ $p < 0{\cdot}001$. See Table 1 note.

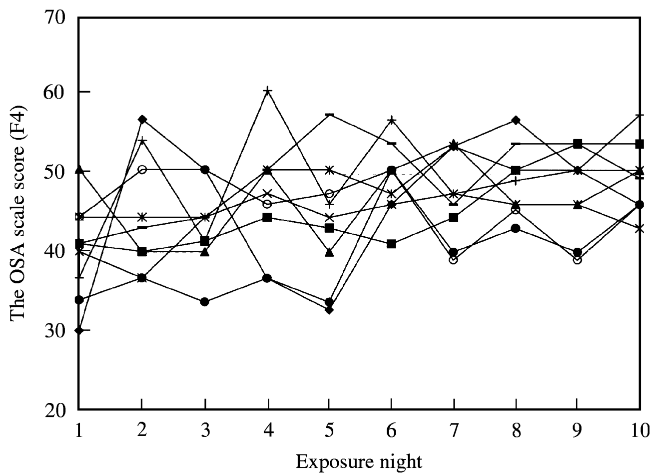


Figure 1. Daily changes of integrated sleep feeling (F4) of the OSA in nine subjects.

showed almost the same results, which meant that the habituation of sleep to road traffic noise was clearly observed in all of the subjective sleep parameters. The polygraphic sleep parameters, however, showed little or no evidence of habituation.

## 4. DISCUSSION

The first major finding in our study was decreased %REM, elongated RT, and decreased subjective scale scores of F1, F2, F3 and F4 due to exposure to road traffic noise at night. A more important result was that the habituation of sleep to road traffic noise was observed clearly in all of the subjective sleep parameters of the OSA, but the polygraphic sleep parameters showed little or no evidence of habituation.

There are four previous reports [1–4] in which no habituation of sleep to road traffic noise was observed, but three [2–4] of them studied sleep of subjects living along noisy roads and found improved sleep in a quiet environment. Another study [1] evaluated the effects of noise on sleep in a laboratory with intermittent noise instead of actual road traffic noise, and the sleep parameters were body movements, heart rate, subjective sleep quality, mood and performance. So these results cannot be directly compared to our study.

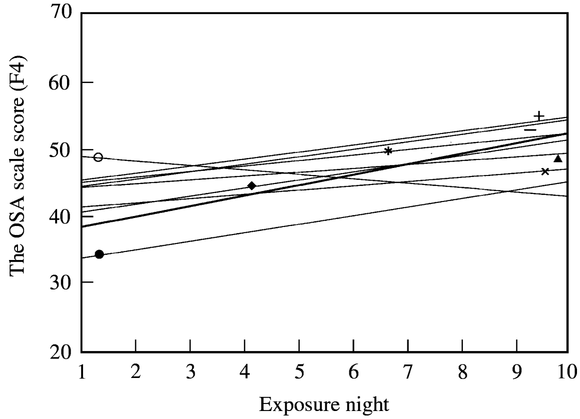


Figure 2. Regression lines of integrated sleep feeling (F4) of the OSA in nine subjects.

Among six reports [5–10] indicating habituation of sleep to noise, three [7,8,10] used intermittent noise. One report [9] observed habituation of sleep to noise in the reduced number of awakenings by road traffic noise, but no subjective assessment of noise effects was made and the experiments were planned for non-consecutive exposure nights. Griefahn [5] observed habituation of sleep to noise from some polygraphic parameters, subjective sleep quality and performance, but she studied only one noise level. In Saletu"s [6] study, only subjective sleep quality was found to be significantly improved from the last three nights in 1 week exposure.

Judging from the Pearson's moment correlation coefficients ($R_s$), the five increased scales of the OSA indicate the habituation. Polygraphic sleep parameters reflect primary effects caused by auditory stimuli whose information is monitored during sleep, whereas subjective parameters reflect secondary perceptual effects reported after awakening [17]. Both parameters are closely related [18], but primary effects are usually more sensitive to noise than secondary effects [19,20], although exceptions exist [21]. Because self-rating sleep parameters are closely related to sleep efficiency, but not to sleep stages, different conclusions may be drawn from the polygraphic and subjective parameters. In our study, the habituation of sleep to road traffic noise was observed only in subjective parameters of sleep and little or no evidence of habituation was detected in polygraphic parameters during the ten exposure nights. This suggests that habituation to noise has two aspects, sensation and perception mechanisms, corresponding to sleep polygraphy and to questionnaire respectively. Sensation and perception levels are to be considered separately in studies exploring the habituation of sleep to noise. There are few reports that clearly explained the physiological mechanism of the habituation of sleep to noise in terms of polygraphic sleep parameters. In order to explore the relation between polygraphic and subjective parameters, subsequent studies with more exposure nights and a larger number of subjects should be conducted.

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