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HABITUATION OF SLEEP TO ROAD TRAFFIC NOISE AS DETERMINED BY POLYSOMNOGRAPHY AND AN ACCELEROMETER

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The habituation of human sleep to a noisy environment was investigated by polysomnography (PSG), a wrist activity device (Actiwatch®), subjective evaluation and a performance test on the following morning. Eleven young male students slept for 17 nights in a sleep laboratory. PSG on the first, fourth, fifth, ninth, 14th, and 17th nights was judged visually. Four of the subjects were continuously monitored by the wrist activity device. From the fifth to 14th nights, there was exposure to road traffic noise all-night long, and consecutive experiments were conducted from the fifth to 17th nights. Agreement of sleep/wake assessment for Actiwatch® and PSG was 88·4%, on average, based on the data for 24 nights. Pearson's correlation coefficient of TST for Actiwatch® and sleep PSG was 0·848. Habituation to noise by wrist movement, sleep latency by PSG, and activity of mental muscles was not recognized. The association between wrist activity and mental muscle activity was significant for three subjects out of four ($r = 0{\cdot}56$, 0·81, 0·71, respectively). Percentages of positive wrist movement in each sleep stage, such as the 3 + 4 stages, REM stage and stage MT, were compared with those in other stages. Wrist activity in Stage REM was significantly more frequent than that in other stages for the three subjects. Wrist movement in Stage MT was significantly more frequent than in other stages for the three subjects. REM latency, REM cycle, and five factors of subjective sleep, from the Oguri–Shirakawa–Azumi questionnaire (SQ), showed significant differences by analysis of variance for repeated measurements. When change from the 4th night was checked, sleepiness, worry, integrated sleep feeling and sleep initiation by SQ showed habituation of sleep to noise. Namely, sleep quality recovered to the level on a silent night by the fifth noisy night during the experiment. There is thus a habituation of sleep to noise when a subjective evaluation of sleep, such as the SQ, is used.

1. INTRODUCTION

Recently, methods for continuous measurement of activity by monitors with solid-state memory have been established to assess sleep/wake patterns. Habituation of sleep to road traffic noise was evaluated using sleep polysomnography (PSG) and a wrist-type accelerometer. The activity monitoring device is small and lightweight for collecting time-based activity data over a week or month. Employing algorithms for transforming

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activity data into sleep/wake judgment allows systematic patterns of the natural sleep/wake cycle to be clarified.

If there is an improvement in the quality of sleep with time or differences in sleep for noise-exposure and silent nights disappear, habituation of sleep to noise exists. Griefahn and Gross summarized these definitions as return of sleep to baseline quality [1].

Though it is claimed that habituation does not develop in response to any type of noise [2], Griefahn reported habituation to noise based on the findings that REM latency, subjective sleep latency and reaction time became significantly shorter [3]. Fidel and Jones analyzed PSG-based sleep parameters and reactions of inhabitants living near an airport before and after the cessation of frequent nocturnal air traffic [4]. No differences in these parameters were observed in noisy and quiet environments.

In contrast, Öhrström and Björkman reported the effects of road traffic noise of heavy vehicles on consecutive nights [5]. There was no habituation of subjective sleep quality, mood or performance. The same authors reported from field investigation that double-glazing of windows decreases wrist movement, showing improvement of sleep [6]. There are two other studies reporting that there is no habituation of sleep to noise [7, 8]. Both studied the sleep of subjects who lived along roads with vehicles and found improved sleep quality under quiet conditions as compared with the noisy environment. This shows that the effect of noise persists.

In this study, changes in sleep latency, muscle activity, and wrist movement were checked for 17 experimental nights in four subjects to confirm habituation to a noisy environment. Six sleep PSG out of 17, consisting of three silent and three noisy nights visually judged in 11 subjects were used to assess habituation of sleep to noisy environment.

2. SUBJECTS AND METHODS

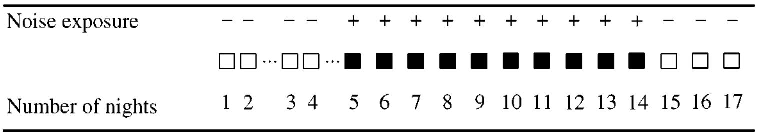
The target subjects were 11 healthy male students aged 19–20 years with no disturbance of hearing acuity by audiometry. Seventeen nights of measurements for each subject, including 10 noise-exposure and seven silent nights, were made. The study was conducted in 1996, 1997, 1998 and 1999. Alcoholic beverages and daytime naps were prohibited before the experiment, but daily activity was not limited. Informed consent was obtained, and the study was performed in accordance with Japanese law and with guidelines for clinical trials drawn up by the World Medical Assembly (Helsinki, Tokyo, Venice, and Hong Kong).

Traffic noise was recorded in a hotel along a busy major road in Tokyo named Kan-nana. Traffic volume was 2300 cars per hour at night. The background sound level in the experimental room was L_{eq} 30 dB (A). Over night L_{eq} and L_{max} of road traffic noise exposure were 49·6 and 71·2 dB (A) respectively. After four non-consecutive control nights, 13 consecutive nights were recorded for each subject. There were thus 10 noise-exposure and three control nights (Figure 1).

The sound level of the ordinary sleeping environment of the subjects could not be monitored. However, all subjects replied that the noise levels of their ordinary sleeping environments were intermediate between the noisy and quiet experimental conditions. Each subject went to bed in an experimental room at 11 PM and was awakened no later than 8 AM by an alarm clock. Each subject was paid 9000 yen for each night.

2.1. SIGNAL RECORDING AND DIGITIZATION

Two EEG derivations (C_3–A_2 or C_4–A_1), one electromyographic (EMG) derivation from the mental muscle, and one electrooculographic (EOG) derivation (left versus right outer



Non-consecutive measurements were expressed as dot sign.
Sleep polysomnographies of no. 1, 4, 5, 9, 14, 17 night were recorded and sleep parameters were visually judged.

Figure 1. Time schedule of noise exposure. Experiment was conducted for 17 nights on each subject.

eye canthus) were recorded during sleep. Analogue amplifiers placed on the subjects were used for signal amplification. High cut-off frequencies were 60 Hz for the EEG, EOG and EMG. Amplified and filtered analogue wireless signals were transmitted to a central analysis machine, digitized at 100 Hz and stored on an MS-DOS-based personal computer assisted by a telemetry system (Nihon Kohden Co. Ltd., Tokyo).

The computerized sleep recording system has been described previously [9]. It is designed for an NEC PC (98 series), a 40 Mbyte hard disk, a 540 Mbyte Magneto-optical disk unit for back-up and incorporates an analog–digital (AD) converter board having a FIFO buffers memory. This allows simultaneous reading and writing of electrophysiological signals. During recording, signals are displayed continuously on the monitor.

2.2. SLEEP SCORING, SLEEP VARIABLE DEFINITION AND PERFORMANCE TEST BY REACTION TIME

Sleep stages were visually scored in 20 s epochs from the recording, according to Rechtschaffen and Kales criteria [10]. Movement time (MT) epochs were scored separately. Inter-rater agreement (two scorers), estimated in the laboratory on an epoch-by-epoch basis, averaged 83·5% [9].

All-night sleep variables were derived from visual scoring using standard criteria: Total sleep time (TST), sleep efficiency in percent (EFFIC) (total sleep time/time in bed × 100), sleep latency (SL) (time from lights-out to the first occurrence of a stage 2 epoch), REM latency (time from sleep onset to first epoch of stage REM), REM cycle (average duration for REM onset to the next REM onset), REM duration (average duration for REM sleep) and number of stage shifts for the entire night (SHIFT). Sleep architecture indices included duration (min) of sleep in different stages of sleep (i.e., stage 1, stage 2, stages 3 + 4, and REM). Time of waking in minutes (TW) and number of frequencies of walking (FW) were used as parameters.

Simple reaction time (RT) was measured by the Standard Reaction Time Tester (Software Science Co. Ltd., Cincinnati), chosen for the WHO neurobehavioral core test battery. The subject's task was to give rapid motor responses to randomized repetitive visual stimuli presented 64 times. Mean time in seconds for the 64 responses were calculated. Simple reaction times within 15 min before going to bed (RT1) and within 15 min after waking in the morning (RT2) were used in the analysis.

The subjects self-rated their sleep the following morning. The authors used the Oguri–Shirakawa–Azumi sleep questionnaire (SQ) for sleepiness (F1), sleep maintenance (F2), worry (F3), integrated sleep feeling (F4), and sleep initiation (F5). As sleep quality improved, scores became higher [11].

2.3. ACTIVITY-MONITORING DEVICE

The activity-monitoring-device-based accelerometer (Actiwatch®), (Mini Mitter Co. Inc., Sunriver) was installed on the wrist of the non-dominant arm. The sampling frequency was 32 Hz, and sensitivity 0·05 G, counting 1 min as a unit (1920 points). Three epochs of visually scored polygraphic data were converted to one epoch to compile the data from the activity monitoring device and polygraphy. The number of wrist movements was calculated by summing the number of active electricities. When the count was 40 or more, we judged it as awakening. Though less than 40, the number of two epochs before the target epoch × 0·04 + number of one epoch before the target epoch × 0·2 + number of the target epoch + number of one epoch after the target epoch × 0·2 + number of two epochs after the target epoch × 0·04 exceeds 40, and thus was judged as awakening.

SPSS 10.0J for Windows was used for statistical analysis. Experiments consisted of two parts, the first part dealing with 17 night's data from four persons in 1998 and 1999, a trend analysis of wrist movement, sleep latency, and the integral value of mental muscle activity (μV), and the second part dealing with visually judged sleep PSG in addition to subjective sleep evaluation and a performance test. There were six PSGs for each of the 11 subjects, and thus multiple comparison by the Dunnet method was used to test the differences between the fourth night and the other five nights.

3. RESULTS

Agreement between sleep/wake assessment for Actiwatch® and sleep PSG was 88·4%, on average, based on 24 nights' data. Means ± standard deviations of TST based on Actiwatch® and PSG were 423·6 ± 42·54 and 449·2 ± 47·46 respectively. Pearson's correlation coefficient of TST between Actiwatch® and sleep PSG was 0·848 ($n = 24$, $p < 0{\cdot}01$) (Figure 2).

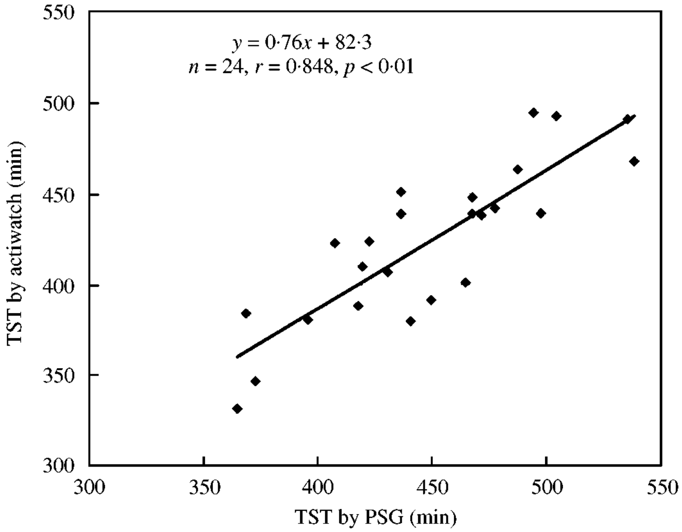


Figure 2. Relationship between total sleep time (TST), by accelerometer and by polysomnography (PSG).

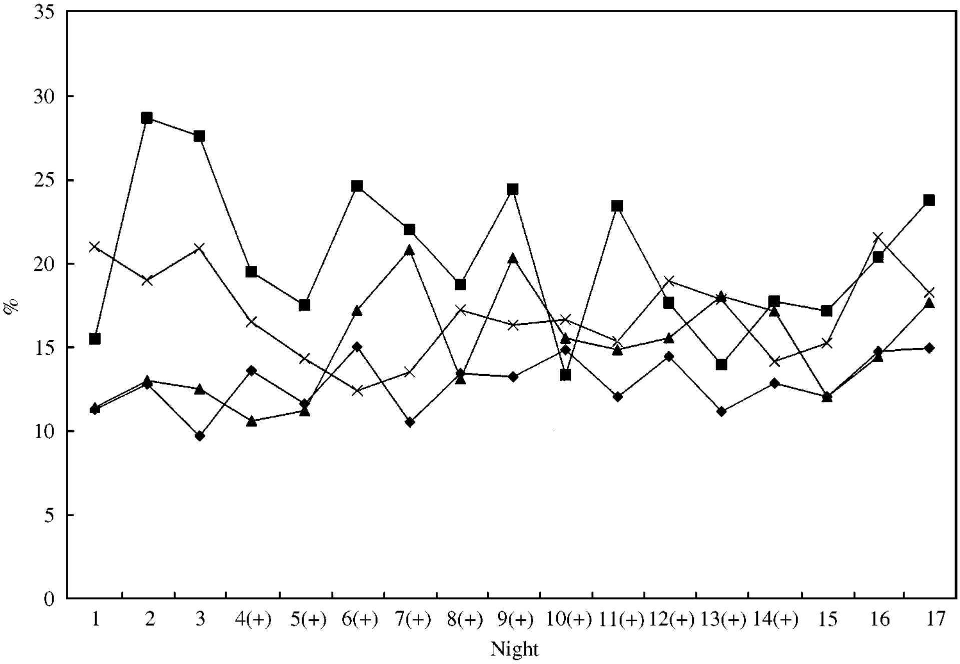


Figure 3. Changes of body movement by accelerometer: -◆- subject-1; -■- subject-2; -▲- subject-3; -×- subject-4.

Part I: The association between wrist movement by accelerometer and mental muscle activity was evaluated. There was a significant relationship between wrist movement % and the electromyogram except in subject-4 (r = 0·56, 0·81, 0·71 respectively).

Wrist movement (%) increased significantly with noise exposure in subject 3 (13·1 ± 2·33 and 16·4 ± 2·99), and decreased with noise exposure in subject 4 (18·9 ± 2·42 and 15·6 ± 2·07) (Figure 3). Sleep latency in subject 1 was significantly greater in the last three silent nights. Variation in sleep latency in subjects 3 and 4 was greater after noise exposure, and that in subject 1 was relatively large (Figure 4, Table 1). Sleep parameters such as sleep latency, wrist movement and muscle activity did not change significantly in response to the noisy environment.

In general, body movement seems more related to movement time (MT). The authors checked wrist movement (%) in each sleep stage, such as the 3 + 4 stages, REM stage and stage MT. Six nights' data on each subject were compiled to test the percentage of the active period classified as stages 3 + 4, stage REM, and stage MT. First, in subjects 1, 2, and 4, wrist movement was significantly more frequent in stage REM than in the other stages. In contrast, subject 3 showed less wrist movement in stage REM. In subjects 2–4, wrist movement was significantly more frequent in stage MT than in the other stages. Wrist movement only decreased significantly in stages 3 + 4 in subject 4 (Table 2).

Part II: Means and standard deviations of various sleep parameters for six nights (see Figure 1) are listed in Table 3. RL, RC, and five SQ factors showed significant differences by analysis of variance for repeated measurements. Duration of each sleep stage in minutes and %, sleep latency, awakening, TST, and performance did not change significantly.

Differences between the fourth and the other nights were checked by Dunnet multiple comparison. In subjective evaluation of sleep by SQ, factors 1, 3, 4, and 5 on the fifth night decreased significantly (p < 0·01, 0·05, 0·05, 0·05 respectively (Table 3, Figure 5)).

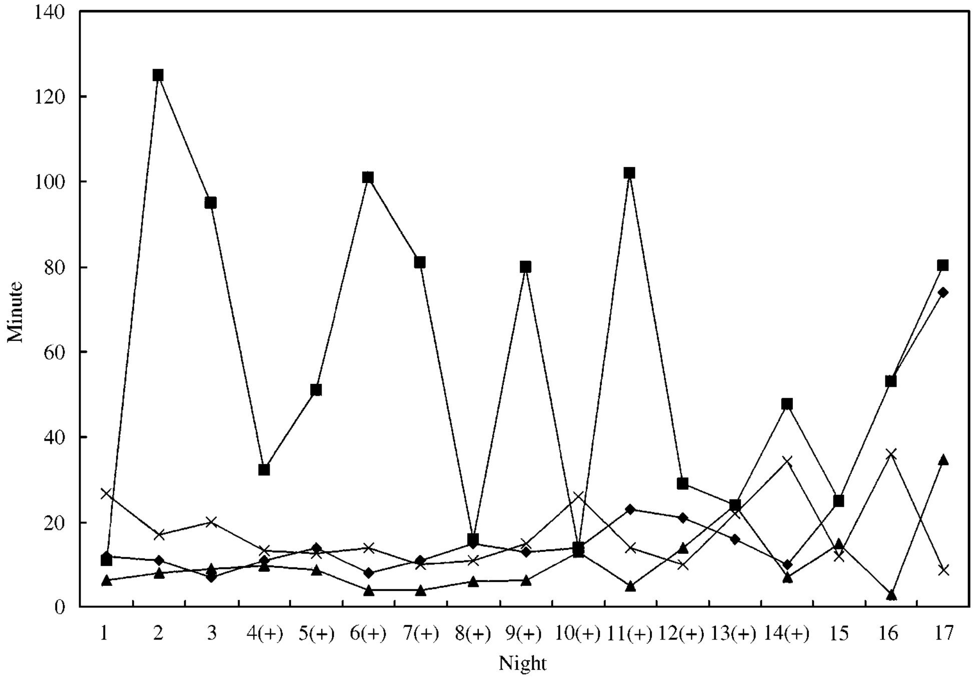


Figure 4. Change of sleep latency by sleep polysomnography: -◆- subject-1; -■- subject-2; -▲- subject-3; -×- subject-4.

Table 1

Sleep latency of each subject divided by three periods

Subject	Pre-exposure $n = 4$	Exposure $n = 10$	Post-exposure $n = 3$
1	10·3 ± 2·22	14·5 ± 4·65	50·7 ± 24·58[†]
2	65·8 ± 53·17	54·6 ± 34·21	52·7 ± 27·65
3	8·3 ± 1·48	9·2 ± 6·25	17·6 ± 16·01
4	19·3 ± 5·67	16·9 ± 8·03	18·9 ± 14·90

[†] $p < 0{\cdot}05$ compared with other two periods by Tukey multiple comparison.

4. DISCUSSION

Thiessen *et al.* reported habituation of awakening to transient noise exposure in a study to detect the percentage of reaction immediately after noise exposure [12–14], and which defined the percentage of stage shift as percentage of a sleep stage that became shallower. Percentages of waking and stage shift decreased linearly and the gradient of waking % was steeper than that of the percentage of stage shift. This study used all-night data and there was no-habituation of waking and stage shift.

Noise did not affect wrist movement by Actiwatch®, mental muscle activity by PSG or sleep latency, which means that there was no habituation to noise. Blood *et al.* reported a decrease in sleep latency under tone-stimulus conditions. This decrease was typically

TABLE 2

Percentage of active period on each sleep stage

Subject	Stage	Target stage	Other stages	Significance
1	SWS	7·6%	12·9%	ns
	REM	16·3	11·9	$p < 0{\cdot}01$
	MT	19·7	12·5	ns
2	SWS	12·3%	19·3%	ns
	REM	24·6	17·9	$p < 0{\cdot}01$
	MT	57·1	18·3	$p < 0{\cdot}01$
3	SWS	0·0%	12·7%	ns
	REM	10·1	13·7	$p < 0{\cdot}05$
	MT	92·3	11·5	$p < 0{\cdot}01$
4	SWS	3·5%	17·4%	$p < 0{\cdot}01$
	REM	23·2	14·9	$p < 0{\cdot}01$
	MT	77·8	14·4	$p < 0{\cdot}01$

Note: SWS; slow wave stage, REM; rapid eye movement, MT; movement time, ns; not significant.

recognized in the second or third multiple sleep latency test on one night. They used PSG, the activity device and behavioral response monitor device for eight subjects (77 nights), and all three methods showed clear habituation of sleep latency to noise [15]. Though this study was an all-night sleep analysis, no habituation of sleep latency by PSG, or activity monitoring by Actiwatch® was found.

When the data of 11 subjects were analyzed, subjective evaluation of sleep showed clear habituation to noise, because sleep quality by the ninth night had already returned to the state of a silent environment (Table 3 and Figure 5). There is thus a clear habituation of sleep to noise when subjective sleep parameters are used, and this is in agreement with our preliminary reports using seven cases analyzed by automatic sleep stage scoring [16]. Saletu *et al.* observed the habituation of subjective sleep and polygraphic sleep to road traffic noise of L_{eq} 75·6 dB (A). Habituation was recognized after 7 days. The sound level was about 25 dB (A) higher than in our study, and habituation may be related to the sound level [17].

There is no clear relationship between slow wave sleep and wrist movement. In contrast, body movement becomes active in REM stage (three subjects out of four), which is not logical. The authors speculate that although anti-gravity muscle power decreases in the REM period, REM continuity correction [10] produces the body movement period as REM. Wrist movement becomes active in the MT period (three subjects out of four), which is logical. The wrist moved before the mental muscle was activated in all the subjects in this study. The physiological mechanism for this is unclear. From the association between body movement recorded by the wrist accelerometer and muscle activity, Actiwatch® appears to be a simple and reliable means of evaluating the effects of noise on sleep.

The reliability of sleep/wake assessment with Actiwatch® has been reported to be satisfactory [18]. Cole reported that wrist activity correctly distinguishes sleep from wakefulness 88·3% of the time [19], which is nearly the same as the 88·4% in this study. In this study, the correlation coefficient (CC) for TST by PSG and Actiwatch® was 0·848. Kripke *et al.* reported that the TST by the activity device and PSG to be almost linear, showing a CC of +0·98 [20]. Mullaney *et al.* reported the CC to be +0·89 [21]. These

TABLE 3

Mean and standard deviation of sleep parameters by the analysis of variance for repeated measure

Noise exposure parameters	– First night	– Fourth night	+ Fifth night	+ Ninth night	+ 14th night	– 17th night
S1	55·2 ± 40·95	54·7 ± 33·92	46·3 ± 21·81	51·0 ± 18·89	49·4 ± 17·92	51·0 ± 18·11
S2	275·7 ± 68·72	269·3 ± 32·60	286·7 ± 47·42	247·3 ± 44·96	271·2 ± 36·26	257·3 ± 28·36
S3+4	22·6 ± 18·17	21·9 ± 14·44	15·9 ± 14·13	25·3 ± 15·40	23·3 ± 13·03	22·0 ± 14·72
SR	91·6 ± 27·91	110·4 ± 36·70	97·1 ± 17·53	102·3 ± 22·24	104·9 ± 24·27	121·5 ± 23·91
MT	13·0 ± 6·91	15·4 ± 7·24	13·1 ± 5·39	13·6 ± 5·38	14·8 ± 4·97	13·1 ± 4·22
S1%	12·4 ± 10·84	11·6 ± 7·19	10·1 ± 4·95	11·4 ± 2·87	10·7 ± 4·16	10·8 ± 3·45
S2%	59·7 ± 11·09	57·3 ± 7·39	62·5 ± 7·13	56·5 ± 4·78	58·5 ± 6·03	55·7 ± 5·67
S3+4%	4·8 ± 3·65	4·6 ± 2·98	3·4 ± 2·83	5·6 ± 2·91	5·0 ± 2·69	4·7 ± 3·00
SR%	20·2 ± 6·14	23·3 ± 7·27	21·3 ± 3·78	23·4 ± 3·23	22·6 ± 4·69	26·0 ± 3·16
MT%	3·0 ± 1·87	3·3 ± 1·56	2·9 ± 1·24	3·1 ± 1·08	3·2 ± 1·30	2·8 ± 0·84
SL	27·2 ± 27·26	29·7 ± 18·07	29·5 ± 20·91	49·2 ± 82·85	37·7 ± 32·87	40·2 ± 25·39
RL*	85·1 ± 41·35	88·8 ± 32·08	110·1 ± 50·54	72·3 ± 18·43	93·8 ± 35·00	63·4 ± 13·17
TST	457·8 ± 70·80	471·3 ± 30·08	458·8 ± 57·03	439·2 ± 80·49	463·2 ± 42·56	464·5 ± 55·56
TW	6·5 ± 10·24	5·4 ± 10·21	6·2 ± 7·18	14·7 ± 26·45	16·2 ± 32·10	5·8 ± 13·86
FW	0·82 ± 1·25	0·55 ± 0·69	1·1 ± 1·04	0·50 ± 0·71	0·60 ± 0·97	0·50 ± 0·71
EFC	92·8 ± 6·16	93·1 ± 2·85	92·8 ± 4·58	87·7 ± 15·39	89·7 ± 7·28	90·7 ± 6·03
SHIFT	168·0 ± 54·00	175·6 ± 58·73	149·1 ± 52·88	175·1 ± 41·02	180·4 ± 32·21	164·8 ± 40·73
RD	20·8 ± 6·23	22·6 ± 9·18	23·0 ± 7·15	18·3 ± 4·47	20·5 ± 5·72	24·4 ± 5·84
RC*	71·7 ± 11·76	59·2 ± 10·07	65·9 ± 15·71	54·2 ± 17·80	55·7 ± 11·57	59·2 ± 10·83
RT1	0·24 ± 0·0278	0·22 ± 0·0270	0·24 ± 0·0489	0·25 ± 0·0553	0·23 ± 0·0246	0·23 ± 0·0257
RT2	0·25 ± 0·0485	0·24 ± 0·0352	0·26 ± 0·0354	0·26 ± 0·0298	0·25 ± 0·0344	0·23 ± 0·0240
SQ–F1*	51·3 ± 3·92	52·1 ± 5·06	43·6 ± 5·94[‡]	47·1 ± 5·63	50·7 ± 3·35	54·4 ± 5·58
SQ–F2*	43·8 ± 5·66	44·0 ± 3·28	39·7 ± 5·94	43·5 ± 3·68	45·7 ± 2·72	47·5 ± 3·83
SQ–F3*	50·1 ± 4·82	50·5 ± 4·55	44·3 ± 4·93[†]	46·6 ± 5·74	50·9 ± 3·41	53·4 ± 4·75
SQ–F4*	50·1 ± 5·82	49·3 ± 6·24	40·7 ± 6·31[†]	44·7 ± 7·70	49·0 ± 4·48	51·4 ± 7·48
SQ–F5*	45·5 ± 4·55	47·0 ± 3·07	40·9 ± 6·17[†]	46·9 ± 5·13	46·6 ± 6·24	48·5 ± 3·58

Note: S1–4. stages 1–4 in minute; SR, stage REM in minute; MT, movement time in minute and %; SL, sleep latency; RL, REM latency; TST, total sleep time; TW, Awakening in minute; FW, Frequency of awakening; EFC, sleep efficiency in percentage; SHIFT, number of stage shifts per night; RD, REM duration in minute; RC, REM cycle in minute, RT1; reaction time measured within 15 min before going to bed. RT2; reaction time within 15 min after waking in the morning, SQ; Oguri–Shirakawa–Azumi sleep questionnaire, F1, sleepiness; F2, sleep maintenance; F3, worry; F4, integrated sleep feeling; F5, sleep initiation.

ANOVA was conducted and marked as * for its significance. Multiple comparison was done by Dunnet method (the fourth night as a control night). [†], $p < 0·05$; [‡], $p < 0·01$

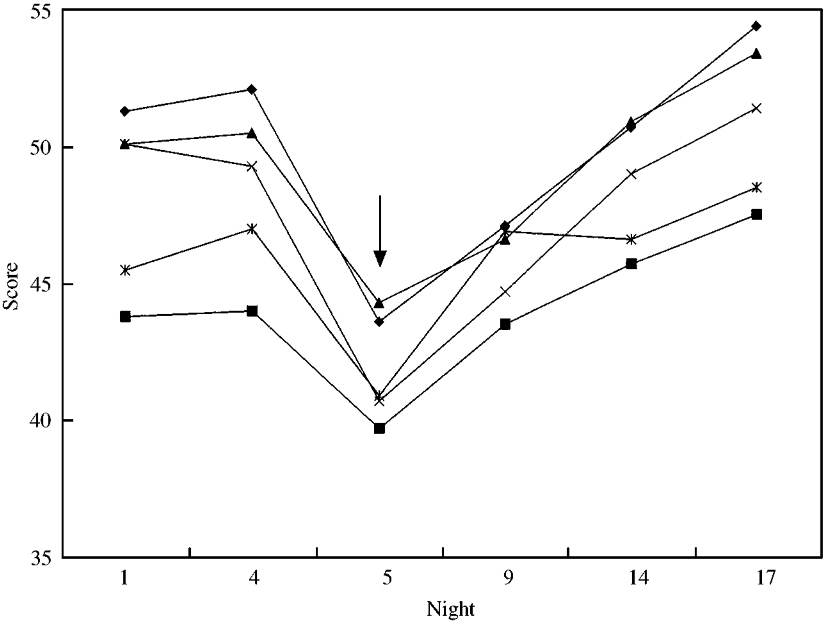


Figure 5. Change of subjective sleep score by Oguri–Shirakawa–Azumi sleep questionnaire (SQ). -◆- F1: sleepiness; -■- F2: sleep maintenance; -▲- F3: worry; -×- F4: integrated sleep feeling; -*- F5: sleep initiation.

reports used normal subjects and a relatively close relationship was reported in a comparison of insomniacs.

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REFERENCES

1. B. Griefahn and E. Gross 1986 *Journal of Sound and Vibration* **105**, 373–383. Noise and sleep at home. A field study on primary and after-effects.
2. C. P. Pollak 1991 in *Noise & Health*, (T. H. Fay, editor) 41–60, New York: The New York Academy of Medicine. The effect of noise on sleep.
3. B. Griefahn 1986 *American Journal of Industrial Medicine* **9**, 261–269. A clitical load for nocturnal high-density road traffic noise.
4. S. Fidel and G. Jones 1975 *Journal of Sound and Vibration* **42**, 422–437. Effects of cessation of late night flights in an airport community.
5. E. Öhrström and M. Björkman 1988 *Journal of Sound and Vibration* **122**, 277–290. Effects of noise-disturbed sleep—a laboratory study on habituation and subjective noise sensitivity.
6. E. Öhrström and M. Björkman 1983 *Journal of the Acoustical Society of America* **73**, 877–879. Sleep disturbance before traffic noise attenuation in an apartment building.
7. M. Vallet, J. M. Gagneux, V. Blanchet, B. Favre and G. Labiale 1983 *Journal of Sound and Vibration* **90**, 173–191. Long term sleep disturbance due to traffic noise.
8. J. L. Eberhardt and K. R. Akselsson 1987 *Journal of Sound and Vibration* **114**, 417–434. The disturbance by road traffic noise of the sleep of young male adults as recorded in the home.

9. S. Aoki, T. Kawada, K. Takeuchi, M. Ogawa and S. Suzuki 1989 *Nippon Eiseigaku Zasshi* **43**, 1092–1101. Effects of noise on sleep. Part 1. Development of an automatic analysing system for all-night sleep polygraphy by microcomputer (in Japanese with English abstract).
10. A. Rechtschaffen and A. Kales 1968 *A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects*. Washington, DC: U.S. Government Printing Office.
11. M. Oguri, S. Shirakawa and K. Azumi 1985 *Seisin Igaku* **27**, 791–799. Construction of standard rating scale to estimate sleep profile. (In Japanese.)
12. G. J. Thiessen 1978 *Journal of the Acoustical Society of America* **64**, 216–222. Disturbance of sleep by noise.
13. G. J. Thiessen and A. C. Lapointe 1978 *Journal of the Acoustical Society of America* **64**, 1078–1080. Effect of intermittent truck noise on percentage of deep sleep.
14. G. J. Thiessen and A. C. Lapointe 1983 *Journal of the Acoustical Society of America* **73**, 225–229. Effect of continuous traffic noise on percentage deep sleep, waking and sleep latency.
15. M. L. Blood, R. L. Sack, D. C. Percy and J. C. Pen 1997 *Sleep* **20**, 388–395. A comparison of sleep detection by wrist actigraphy, behavioral response, and polysomnography.
16. P. Xin, T. Kawada, Y. Sasazawa and S. Suzuki 2000 *Journal of Occupational Health* **42**, 20–26. Habituation of sleep to road traffic noise assessed by polygraphy and rating scale.
17. B. Saletu, R. Frey and J. Grunberger 1989 *Wiener medizinische Wochenschrift* **139**, 257–263. Street noise and sleep: whole night somnopolygraphic, psychometric and psychophysiologic studies in comparison with normal data (in Germany with English abstract).
18. J. J. van Hilten, E. A. Braat, E. A. van der Velde, H. A. Middelkoop, G. A. Kerkhof and H. A. Kamphuisen 1993 *Sleep* **16**, 146–150. Ambulatory activity monitoring during sleep: an evaluation of internight and intrasubject variability in healthy persons aged 50–98 years.
19. R. J. Cole, D. F. Kripke, W. Gruen, D. J. Mullaney and J. C. Gillin 1992 *Sleep* **15**, 461–469. Automatic sleep/wake identification from wrist activity.
20. D. F. Kripke, D. J. Mullaney, S. Messin and V. G. Wyborney 1978 *Electroencephalography and Clinical Neurophysiology* **44**, 674–676. Wrist actigraphic measures of sleep and rhythms.
21. D. J. Mullaney, D. F. Kripke and S. Messin 1980 *Sleep* **3**, 83–92. Wrist-actigraphic estimation of sleep time.