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HABITUATION OF SLEEP TO A SHIP'S NOISE AS DETERMINED BY ACTIGRAPHY AND A SLEEP QUESTIONNAIRE

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Habituation of sleep to a ship's noise was assessed by actigraphy and a sleep questionnaire. Four male students aged 21–24 years were studied for 15 consecutive nights in an experimental bedroom. During the first four nights, the subjects slept in a quiet environment. For the next eight consecutive nights, the subjects were exposed to the noise of a ship' s engine with a sound level of 60 dB(A) (the International Maritime Organization Standard) previously tape-recorded in a room of a diesel engine ship. On the last three experimental nights, the subjects again slept in a quiet environment. The subjects went to bed in the experimental room at about 0:00 and were woken at 8:00 a.m. the next morning by an alarm clock. Sleep was monitored by a wrist-worn actigraphy. On the morning following each experimental night, the subjects were instructed to answer the OSA questionnaire, a structured self-rating sleep scale developed in Japan. Habituation of sleep to the noise of a ship with a sound level of 60 dB(A) was observed to some extent in the subjective sleep parameters but not in the sleep parameters measured by actigraphy.

1. INTRODUCTION

The environment in a ship underway is always full of noise and vibrations caused by the operation of engines, generators and air conditioners, exhaust from funnels and rotation of the propeller, even at midnight. Sailors are exposed to steady loud noise during voyage. As a result of this noise exposure, seamen may have difficulty recovering from fatigue and show poorer daytime performance. Most ships have diesel engines. The noise of a diesel engine ship is predominantly in the lower frequency range of 100–1000 Hz. The sound level in the bedrooms of crewmembers and cabin passengers is over 50 dB(A). In 1980, the International Maritime Organization (IMO) recommended a sound level of 60 dB(A) or less as the standard sound level for the sleeping quarters of crewmembers and cabin passengers on-board ships [1].

There have been many studies on the effects of transportation noise (road traffic, trains, aircraft and ships) on sleep [2–4]. Tamura *et al.* [5] reported the effects of a ship's noise on sleep with a sound level of 65 dB(A), previously recorded in the sleeping quarters of a crewmember on a diesel engine ship at voyage speed. The noise exerted adverse effects on night sleep, to a moderate extent on subjective parameters of sleep and to a slight extent on objective polygraphic parameters. A decrease in the %SREM and increase in %S2 were observed.

Habituation of sleep to road traffic noise has long been studied, but there are still many different views among investigators [6–16]. The objective of this study was to assess the habituation of sleep to the steady noise of a diesel engine ship with a sound level of 60 dB(A) by actigraphy and a sleep questionnaire.

2. SUBJECTS AND METHODS

Four healthy students aged 21–24 years participated in the experiments. They had normal hearing and no physical or mental disorders. They were prohibited from drinking alcohol or taking drugs, daytime naps, or doing exercise during the experimental period. Each subject slept for 15 consecutive nights in a sleep laboratory, the first four nights in a quiet environment. For the next eight consecutive nights, they were exposed throughout the night to the steady noise of a ship with a sound level of 60 dB(A), previously tape-recorded in a bedroom of a diesel engine ship, Ginga-Maru (4888 tons), at voyage speed. Ginga-Maru is a training ship belonging to the Ministry of Transport, Japan. Thereafter, on the last three nights, the subjects again slept in a quiet environment. Data collected during the first night were not used for the analysis. The background noise on the control nights was in the range of 35–40 dB(A). The subjects were exposed to the noise via two loud speakers placed on the right and left sides of the sleep laboratory about 2 m away from the subject's head. The experiments were carried out from January to April 2000. The subjects went to bed in the experimental room at about 0:00 and were woken at 8:00 a.m. the next morning by an alarm clock. Sleep was monitored all night by a wrist-worn actigraph. The actigraph was tied to the wrist of the non-dominant arm. On the morning following each experimental night, the subjects answered a sleep questionnaire, a structured self-rating sleep scale developed by Oguri, Shirakawa and Azumi (OSA) in Japan [17]. The OSA is frequently used in Japan for subjective evaluation of sleep.

The actigraphic parameters were calculated automatically from the original actigraphic data by the scoring analysis program. The sensitivity was $0{\cdot}1g$ (gravity), counting 1 min as a unit. The number of wrist movements was calculated by the summation of counts with active electricity.

The actigraphic sleep parameters derived were time in bed (TIB), sleep latency (SL), sleep period time (SPT), time spent awake after sleep onset (WASO), total sleep time (TST), sleep efficiency (SEI), and the number of wrist movements during the SPT (ACTIVITY). TIB represented the time from lights-off to the final awakening from the main sleep period. SL was the time from lights-off to sleep onset as measured by the actigraphy. SPT was the time from sleep onset to the final awakening from the main sleep period. WASO was the time spent awake during the SPT as measured by the actigraphy. TST was SPT minus WASO. SEI was the % TST relative to the TIB. ACTIVITY was the average count of wrist movements per minute during the SPT. Wake episodes represented the number of awakenings during the SPT.

The five items in the OSA sleep questionnaire are sleepiness, sleep maintenance, worry, integrated sleep feeling, and sleep initiation. The higher the score, the better the sleep quality. To assess the habituation to noise, each sleep parameter was analyzed by simple regression on each exposure night.

3. RESULTS

The mean and standard deviation (S.D.) of all the parameters are shown in Table 1 for each subject and all subjects.

Pearson's moment correlation coefficient (R) for each sleep parameter and the number of experimental nights for each subject and all subjects are listed in Table 2. No significant changes were found in the sleep parameters measured by actigraph in any of the subjects. However, in the case of subjective sleep parameters in the OSA, the score for integrated sleep feeling increased significantly with exposure to the ship's noise ($r = 0{\cdot}367$, $p < 0{\cdot}05$; Figure 1). Furthermore, the score for sleep initiation tended to increase with noise exposure, although not significantly, in all subjects ($r = 0{\cdot}303$, $p < 0{\cdot}10$; Figure 2). In subject B in particular, the scores for sleepiness ($r = 0{\cdot}814$, $p < 0{\cdot}05$), sleep maintenance ($r = 0{\cdot}853$, $p < 0{\cdot}01$), integrated sleep feeling ($r = 0{\cdot}856$, $p < 0{\cdot}01$), and sleep initiation ($r = 0{\cdot}797$, $p < 0{\cdot}05$) all increased significantly with noise exposure.

4. DISCUSSION

While habituation of sleep to road traffic noise has been studied for many years, there are still many different views among investigators. Öhrström and Björkman [6] exposed 24 subjects in a two-week laboratory experiment to intermittent road traffic noise from heavy vehicles with a maximum noise level of 60 dB(A), 57 times per night for eight nights. No evidence of habituation was observed in terms of body movements, heart rate, subjective sleep quality, mood or performance. Vallet *et al.* [7] studied 26 subjects who had lived for more than 4 years near a road with an average traffic volume of 40 000 cars/day. They found that, when the noisy environment (with a sound level of 50–53 dB(A)) of these subjects was replaced with the environment of a quieter house with a sound level of 42–44 dB(A), the number of awakenings from sleep decreased from 1·9 to 1·5 times, the time of sleep latency decreased from 23 to 18 min, and the duration of awakenings decreased from 14·1 to 12·9 min, suggesting the absence of any habituation to noise under these conditions.

On the other hand, Griefahn [8] studied habituation of sleep in 36 students to high density road traffic noise and determined the effect of all-night exposure to noise for 12 consecutive nights. Deep sleep was prolonged and shallow sleep, including intermittent wakefulness, became progressively shorter with noise exposure ranging from 37 to 63·5 dB(A). Saletu *et al.* [9] exposed 10 young subjects to road traffic noise with a sound level of 68–83 dB(A) ($L_{eq} = 75{\cdot}6$ dB(A)) for 1 week in a laboratory. They observed an increase in stage 4 and decrease in stage 3 sleep, together with a significant improvement in subjective sleep quality on the last three exposure nights. Kawada *et al.* [10] investigated the habituation of sleep in 12 students to the recorded noise of passing trucks with peak sound levels of 45, 50, 55 and 60 dB(A) at intervals of 15 min for 12 non-consecutive nights. They found that stage 1 sleep, MT, the frequency of awakenings and the number of sleep stage shifts were significantly decreased towards the end of the experimental period of 12 nights. Xin *et al.* [16] reported sleep habituation in seven male students exposed for 10 nights to recorded road traffic noise with the following sound levels: $L_{max} = 71{\cdot}2$ dB(A), $L_{eq} = 49{\cdot}6$ dB(A) and $LAE = 94{\cdot}1$ dB(A). They found that habituation of sleep to road traffic noise was clearly observed in the subjective sleep parameters but that the polygraphic parameters showed little habituation to the noise.

It is probable that the different views on habituation of sleep to noise among investigators can be attributed to the use of different experimental conditions, tones, noise levels and experimental durations, exposure to steady or intermittent noise, or consecutive or non-consecutive nights.

Table 1

Average sleep parameters with standard deviations (S.D.) of eight nights for four subjects

	Subj.A ($n = 8$)		Subj.B ($n = 8$)		Subj.C ($n = 8$)		Subj.D ($n = 8$)		Total ($n = 32$)	
	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
TIB (min)	509·6	(13·94)	485·5	(14·57)	476·5	(36·10)	506·7	(17·23)	494·5	(26·41)
SL (min)	8·1	(2·20)	27·6	(6·10)	26·7	(29·12)	8·5	(2·29)	17·7	(17·69)
SPT (min)	501·5	(15·19)	457·8	(14·71)	449·7	(49·81)	498·2	(18·89)	476·8	(36·89)
WASO (min)	10·1	(7·80)	7·5	(5·12)	44·3	(16·92)	39·8	(10·39)	25·4	(20·03)
TST (min)	491·3	(13·59)	450·3	(14·12)	404·7	(52·38)	458·3	(23·55)	451·2	(43·32)
SEI (%)	96·4	(1·41)	92·7	(1·62)	84·7	(6·34)	90·4	(2·32)	91·0	(5·52)
Activity (counts/min)	8·7	(2·29)	7·1	(1·34)	18·1	(4·45)	14·8	(1·47)	12·2	(5·22)
Wake episodes (counts/night)	6·1	(4·62)	3·3	(1·40)	11·5	(4·87)	18·6	(4·09)	9·9	(7·05)
Sleepiness (point)	39·8	(3·22)	55·6	(3·81)	49·0	(1·73)	47·7	(3·56)	48·0	(6·43)
Sleep maintenance (point)	35·5	(5·40)	49·6	(5·85)	39·2	(2·02)	40·3	(3·15)	41·2	(6·81)
Worry (point)	45·3	(4·51)	54·1	(2·23)	45·6	(1·36)	53·3	(7·25)	49·6	(5·09)
Integrated sleep feeling (point)	41·7	(9·12)	51·6	(5·69)	42·8	(3·88)	44·1	(5·80)	45·1	(7·50)
Sleep initiation (point)	42·8	(5·71)	53·9	(3·29)	42·1	(1·92)	47·9	(4·17)	46·7	(6·20)

TABLE 2

Pearson's moment correlation coefficient (R) for each sleep parameter and the number of experimental nights

	Subj. A.	Subj. B.	Subj. C.	Subj. D.	Total
TIB (min)	– 0·052	0·048	0·021	0·690†	0·121
SL (min)	0·136	– 0·415	0·756†	– 0·571	0·261
SPT (min)	– 0·068	0·220	– 0·427	0·707‡	– 0·038
WASO (min)	0·339	– 0·457	– 0·185	0·196	– 0·009
TST (min)	– 0·270	0·395	– 0·338	0·480	– 0·025
SEI (%)	– 0·409	0·611	– 0·620	0·051	– 0·154
Activity (counts/min)	0·194	– 0·443	0·036	0·057	0·004
Wake episodes (counts/night)	0·171	0·058	– 0·022	0·590	0·113
Sleepiness (point)	0·435	0·814‡	0·513	0·119	0·226
Sleep maintenance (point)	– 0·179	0·853§	0·527	0·348	0·227
Worry (point)	– 0·722‡	0·291	– 0·087	0·568	0·323
Integrated sleep feeling (point)	0·212	0·856§	0·432	0·434	0·367‡
Sleep initiation (point)	0·402	0·797‡	– 0·055	0·650†	0·303†

†$p < 0{\cdot}10$, ‡$p < 0{\cdot}05$, §$p < 0{\cdot}01$.

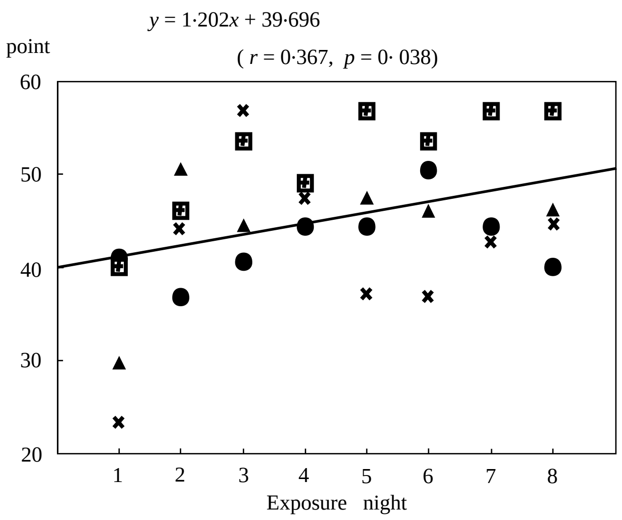

Figure 1. Changes in the score of integrated sleep feeling of the total four subjects: ×, subj. A; ■, subj. B; ●, subj. C; ▲, subj. D.

In this study, the habituation of sleep to the steady noise of a ship with a sound level of 60 dB(A) was found to be significant in two out of the five parameters of the OSA subjective sleep questionnaire, namely, integrated sleep feeling and sleep initiation. Similar results were obtained in the Xin *et al.* study [16], but they reported a significant habituation of sleep to noise in all of the five subjective sleep parameters in the OSA. These differences in results may be ascribed to the smaller number of persons and the 10 dB(A) higher noise level in the present study as compared to their study. Habituation to road traffic noise was observed in terms of subjective sleep parameters by Griefahn [8] and Saletu [9]. The noise

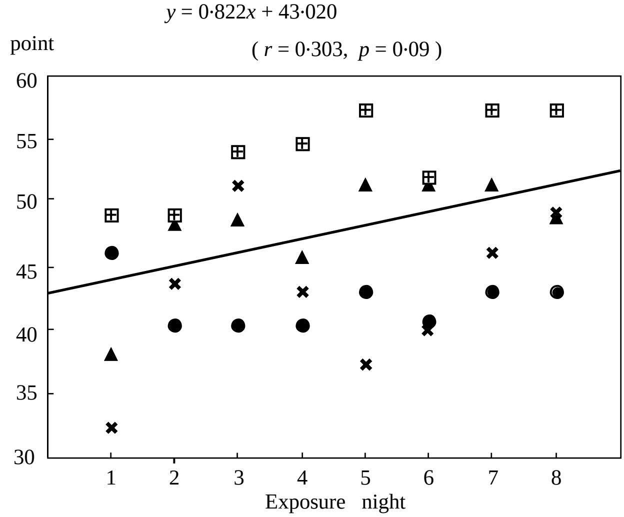

Figure 2. Changes in the score of sleep initiation of the total four subjects: ×, subj. A; ■, subj. B; ●, subj. C; ▲, subj. D.

used in the Xin *et al.* study [16] was road traffic noise recorded at midnight along a busy major road with an average traffic volume of 2300 cars/h at night. Suzuki *et al.* [18] reported that exposure to a steady pink noise could have sleep deepening effects, which suggests adaptation to noise exposure. He mentions in his report, "a continuing inhibitory pulse from a certain center in the cortex may suppress the activation of the reticular formation during exposure to a steady pink noise, which could deepen sleep". This explanation may also be valid for some of the cases showing habituation of sleep to such continuous noise as road traffic noise and a ships' noise. That is, exposure to steady noise could cause habituation of sleep to noise in terms of the subjective sleep parameters.

On the other hand, no significant habituation of sleep to the steady noise of a ship was observed in the sleep parameters measured by actigraphy, including sleep latency, sleep period time, waking after sleep onset, total sleep time, sleep efficiency, levels of wrist movements during the SPT and the number of awakening episodes. The reliability of sleep/wake assessment by actigraphy has been reported to be satisfactory [19]. Cole [20] reported that wrist activity differentiated sleep from wakefulness correctly 88·3% of the times. Generally, it is thought that increased movement time or wrist activity during night sleep is attributable to restlessness, an increased number of awakenings and shallow sleep.

In this study, several nights of exposure to the steady noise of a ship with a sound level of 60 dB(A) did not affect the wrist movements or sleep latency as measured by actigraphy, implying a lack of habituation to noise. However, Blood *et al.* [21] reported a decrease in sleep latency under tone-stimulus conditions. This suggests that habituation to the steady noise of a ship with a sound level of 60 dB(A) may also be noted in the parameters of sleep latency and level of wrist movements during the SPT if there were a sufficiently large number of subjects. Actually, some sailors reported a tendency to fall asleep sitting on a chair when exposed to the steady noise of a ship on a voyage. This could however be due to fatigue.

Based on the inter-individual variation in the sensitivity to noise, habituation should differ accordingly from person to person. Thus, subsequent studies should be done with longer exposure times and larger subject populations.

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REFERENCES

1. IMO London 1982 *Code on Noise Levels on Board Ships*, 1–35.
2. Y. Osada 1993 *The Journal of Sleep and Enviroments* **1**, 6–11. Sound enviroment and sleep (in Japanese with English abstract).
3. B. Griefahn and G. Jansen 1978 *The Science of the Total Enviroment* **10**, 187–199. EEG-responses caused by environmental noise during sleep. Their relationships to exogenic and endogenic influences.
4. B. Griefahn 1991 *Applied Acoustics* **32**, 252–268. Environmental noise and sleep—Review—need for further research.
5. Y. Tamura, T. Kawada and Y. Sasazawa 1997 *Journal of Sound and Vibration* **205**, 417–425. Effect of ship noise on sleep.
6. 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.
7. M. Vallet, J. M. Gagneux, V. Balanchen, B. Faure and G. Labiale 1983 *Journal of Sound and Vibration* **90**, 173–191. Long term sleep disturbance due to traffic noise.
8. B. Griefahn 1986 *American Journal of Industrial Medicine* **9**, 261–269. A critical load for nocturnal high-density road traffic noise.
9. B. Saletu, R. Frey and J. Grunberger 1989 *Wien Med Wochenschr*. **139**, 257–263. Street noise and sleep: whole-night somnopolygraphic, psychometric and psychophysiological studies in comparison with normal data.
10. T. Kawada, Y. Sasazawa, Y. Kiryu and S. Suzuki 1997 *Journal of Sound and Vibration* **205**, 405–409. Daily sleep changes in a noisy enviroment assessed by subjective and polygraphic sleep parameters.
11. 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.
12. B. Griefahn and E. Gros 1986 *Journal of Sound and Vibration* **105**, 373–383. Noise and sleep at home, a field study on primary and after-effects.
13. G. L. Thiessen 1978 *Journal of the Acoustical Society of America* **64**, 216–222. Disturbance of sleep by noise.
14. G. L. 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.
15. G. L. Thiessen and A. C. Lapointe 1983 *Journal of the Acoustical Society of America* **73**, 225–229. Effect of continuous traffic noise on percentage of deep sleep, waking and sleep latency.
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. M. Oguri, S. Shirakawa and K. Azumi 1982 *Japanese Journal of Clinics* **11**, 63–73. Statistical analysis of the subjective estimates of sleep feeling: Item analysis to construct scales (in Japanese).
18. S. Suzuki, T. Kawada, M. Ogawa and S. Aoki 1991 *Journal of Sound and Vibration* **151**, 407–413. Sleep deepening effect of steady pink noise.
19. A. Chang, C. Kushida, L. Palombini, O. Carrillo, J. Hindman, S. Hong, P. Hyde and C. Guilleminault 1999 *Sleep*(*Suppl*) **22**, S43. Comparison study of actigraphic, polysomnographic, and subjective perception of sleep parameters.
20. 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.
21. 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.