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EFFECT OF SHIP NOISE ON SLEEP

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The effects of a steady sound level of 65 dB(A) from a diesel ship engine on nocturnal sleep were studied using polygraphic and subjective sleep parameters. Three healthy men, aged 29 to 33 years, participated in the experiment. Sleep polygrams and the sound level in a sleep laboratory were recorded for each subject for five exposure nights and five control nights. The following morning, the subjects answered a self-rating sleep questionnaire (called the OSA) and underwent simple reaction time tests. The percentage of S2, SREM latency and the REM interval increased, while %SREM decreased during the noise-exposed nights as compared with corresponding values on the control nights. Other parameters of sleep EEG were unchanged. Five scale scores for OSA, sleepiness, sleep maintenance, worry, integrated sleep feeling and sleep initiation deteriorated significantly on the noise-exposed nights as compared with the control nights. Canonical discriminant analysis was conducted using 19 sleep parameters. The standard partial regression coefficients of %SREM, %S2 and %S1 were somewhat higher than other parameters. It was suggested that exposure to the 65 dB(A) ship noise exerted adverse effects on nocturnal sleep, subjectively and in part polygraphically (REM sleep and shallow sleep).

1. INTRODUCTION

The work environment and off-duty area of sailors are not completely separated on a voyage. The environment of a ship during a voyage is always full of noise and vibration caused by operation of engines, generators and air conditioners, exhaust from funnels and rotation of the propeller. Sailors are exposed to a loud, steady noise on a voyage. Under these constant noise conditions, sailors may have difficulty recovering from fatigue, which may lead to poorer daytime performance and, possibly, disasters at sea.

Recent progress in shipbuilding techniques has reduced noise and vibrations in ships. In 1981, the International Maritime Organization (IMO) recommended 60 dB(A) as the standard noise level for the sleeping quarters of crew members on ships.

Ships can be divided into two broad groups, those with diesel and those with turbine engines. Most recently built ships have diesel engines, as diesel engine ships are cheaper to operate. However, the sound level is higher on a diesel than on a turbine engine ship, the sound frequency of noise on a diesel engine ship being predominantly from 100 to 1000 Hz. Reducing noise and vibration is important for improving the quality of life of those living on ships.

There have been many studies on the effects of road, train and aircraft noise on sleep [1–3]. However, there are few studies on the effects of ship noise on sleep, an important factor in the labor management of sailors. The main purpose of this study was to clarify

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the effect of continuous diesel engine ship noise on nocturnal sleep using polygraphic and subjective sleep parameters.

2. METHODS

2.1. SUBJECTS AND EXPERIMENTAL DESIGN

Three healthy men, aged 29 to 33 years, participated in these experiments. All had normal hearing levels and none had any physical or mental disorder. Each subject slept for 11 non-consecutive nights in a sleep laboratory. Adaptation to the sleep environment was characterized predominantly on the first night using sleep parameters such as delta sleep, REM sleep, and certain latencies [4, 5]. Data from the first night were thus not used for the analysis. The sleep polygrams and the sound level in the sleep laboratory were recorded for each subject for the five exposure nights and five control nights during the night. The experiment was conducted two nights per week on each subject, one exposure night and one control night. The order of the experiments was random. The experiments were carried out in July and August, 1995. The room temperature was maintained at 28°C with an air conditioner. The subjects were prohibited from drinking alcoholic beverages and taking medication, naps or exercise before the experiment. The subjects entered the sleep laboratory at 22:00, and the electrodes were applied. They went to bed at about 23:00 and were awakened at 07:00 by an alarm clock, such that the total recording time was eight hours on average.

Electrodes for electroencephalograms (EEG) were positioned according to the international 10–20 method. An EEG at C3-A2, an electromyogram (EMG) at the submental muscle and left and right electrooculograms (EOG) at the external epicanthus based on A2 were recorded using the telemetry system (WEE-6112, NIHON KOHDEN Company Ltd., Tokyo).

The following morning, the subjects answered a self-rated sleep questionnaire, the OSA [6]. The OSA is often used in Japan for subjective evaluations of sleep. Five OSA scales were applied: sleepiness, sleep maintenance, worry, integrated sleep feeling and sleep initiation. Improved sleep quality increases each scale score.

The subjects also underwent a simple reaction time test to assess arousal conditions in the morning. This was done using a DATICO "Terry 84" reaction time device, chosen for the WHO neurobehavioral core test battery [7].

2.2. NOISE EXPOSURE AND NOISE RECORDING

The noise to which subjects were exposed in the sleep laboratory during the night was at a steady level of 65 dB(A), recorded in the sleeping quarters of a crew member on the diesel engine ship Ginga-Maru (4888 tons) at voyage speed. Ginga-Maru is a training ship belonging to the Institute for Sea Training of the Ministry of Transport. The noise exposure was achieved with two loudspeakers on the right and left sides of the sleep laboratory, located 2 m from the head of the subject and at the same distance from the floor. The microphone of an NA-23 sound level meter (RION Company Ltd., Tokyo) was positioned 0·3 m from the head of the subject in the sleep laboratory, and the noise level was measured. The background noise on the control nights ranged from 35–40 dB(A), and was briefly 50 dB(A) once every 50 min due to the air conditioner. The noise level changes for the entire night and the noise frequencies are shown in Figures 1 and 2.

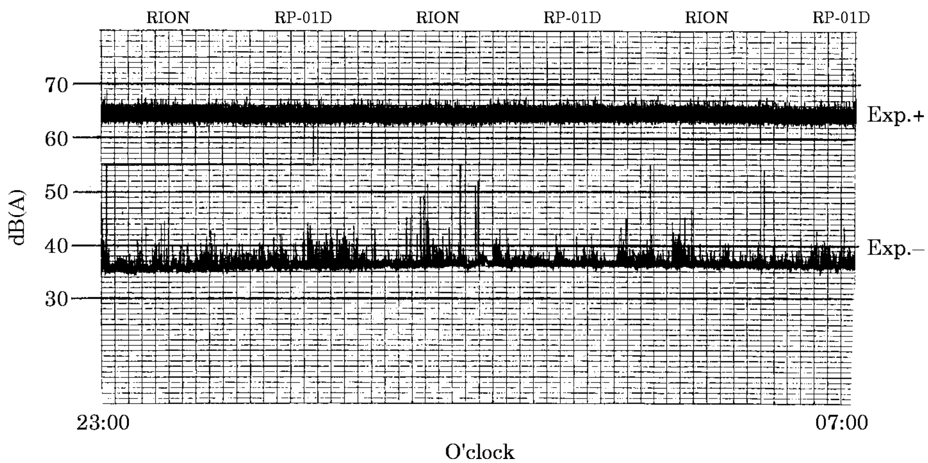

Figure 1. Time records of sound levels in the sleep laboratory of a noise-exposed night (Exp. +) and the control night (Exp. –).

2.3. SLEEP PARAMETERS

The sleep stage was judged visually by one of the authors according to the standard atlas of Rechschaffen and Kales [8] with the assistance of an automatic computer analyzing system developed by Aoki *et al*. [9]. One epoch has a 20 s duration. Sleep latency was defined as the time elapsed from going to bed until the first appearance of a visually judged sleep spindle. If the interval between the end of one SREM period and the beginning of the next SREM period was within 15 min, the two SREM periods were considered to be continuous.

The sleep parameters used in this study consisted of 19 polygraphic and 5 subjective parameters. The polygraphic parameters were % of waking and % of each sleep stage of the sleep period time (%SW, %S1, %S2, %S(3 + 4), %SREM, %MT), time in bed (TIB), sleep period time (SPT), total sleep time (TST), waking after sleep onset (WASO), sleep

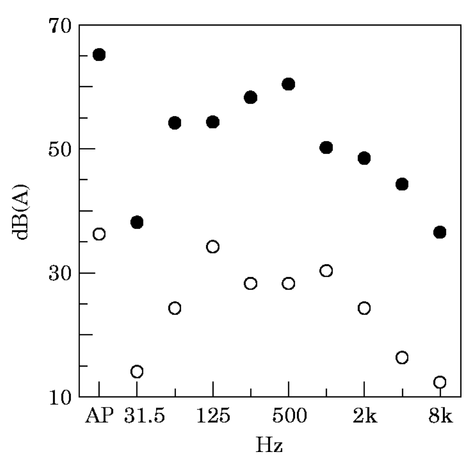

Figure 2. The analysis of frequency of noise in the sleep laboratory of a noise-exposed night (●, Exp. +) and the control night (○, Exp. –).

latency (SL), S3 latency (S3L), SREM latency (SREML), REM interval (RI), REM duration (RD), sleep efficiency index (SEI), frequency of awakenings per night (FW), number of stage shifts per hour (SHIFT) and simple reaction time after sleep (RT). SPT was the time from sleep onset to final awakening from the main sleep period. WASO was the time spent awake during SPT. TST was SPT minus WASO. SL was the time from lights-off to sleep onset. S3L and SREML were the time from sleep onset to the beginning of the first S3 period and the SREM period, respectively. RI was the average duration from the end of one SREM period to the beginning of the next. RD was the average duration of SREM periods. SEI was the % of TST of TIB. FW was the number of awakenings per night. SHIFT was the number of stage shifts per hour. RT was the time from lights-on to pushing the button.

The subjective parameters were five scales of the OSA: sleepiness, sleep maintenance, worry, integrated sleep feeling and sleep initiation.

2.4. STATISTICAL ANALYSIS

First, the paired *t*-test was applied to each sleep parameter on the exposed and the corresponding control nights.

Second, canonical discriminant analysis was applied to predict the exposed and the control nights based on polygraphic and subjective sleep parameters. Some parameters (sleepiness *vs*. sleep initiation, %SW *vs*. WASO, TST *vs*. SL, SPT and SEI) had high intercorrelation coefficients, exceeding 0·8, leading to multicollinearity problems. To resolve this difficulty, sleepiness, %SW and TST were chosen. A total of 19 sleep parameters was used for the analysis.

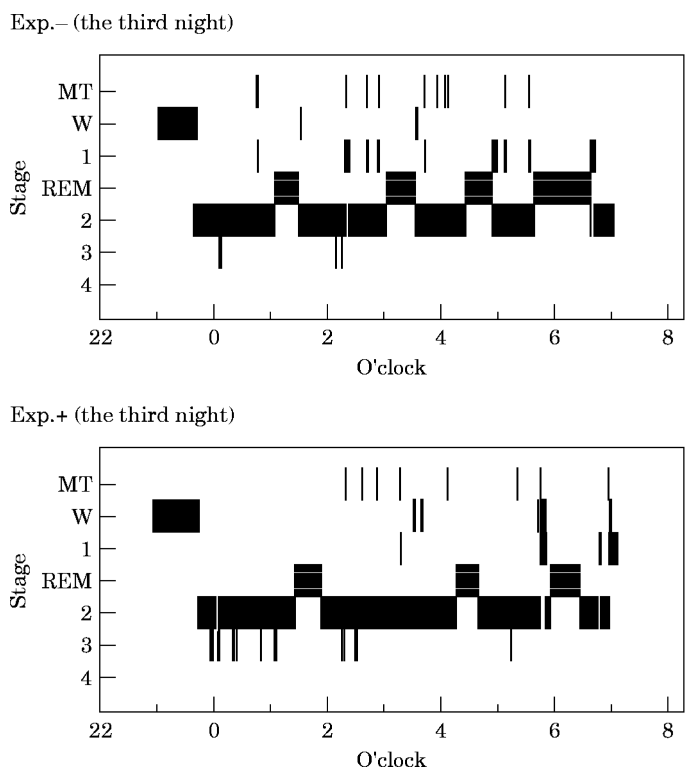

Figure 3. Hypnograms from Subject C on a noise-exposed night (Exp.+) and the control night (Exp.−).

3. RESULTS

Hypnograms from Subject C on the noise-exposed and control nights are shown in Figure 3. Polygraphic sleep parameters averaged for all three subjects are shown in Table 1. SREM latency ($p < 0{\cdot}05$), REM interval ($p < 0{\cdot}001$) and %S2 ($p < 0{\cdot}05$) of all subjects increased significantly, while %SREM ($p < 0{\cdot}05$) decreased with noise exposure. None of the other polygraphic sleep parameters were significantly changed. Figure 4 shows SREM latency, REM interval, %SREM and %S2 for each subject individually.

Subjective sleep parameters averaged for all three subjects on the noise-exposed and control nights are shown in Table 2. All five OSA scale scores for the three subjects on the noise-exposed nights were significantly reduced as compared with those on the control nights. Figure 5 shows five OSA scale scores for each subject individually on the noise-exposed and control nights.

Canonical discriminant analysis using 19 sleep parameters is shown in Table 3. The standard partial regression coefficients of %SREM, %S2 and %S1 were somewhat higher than other parameters. The overall correct rate was 100%.

4. DISCUSSION

According to a study of ship noise in the sleeping quarters of crew member on ships of more than 3000 tons [10], the noise level ranged from 50 to 75 dB(A) on a voyage, and the average was 60 to 65 dB(A). According to a study of annoyance related to ship noise

TABLE 1

Comparison of polygraphic sleep parameters between the noise-exposed (Exp. +) *and control nights* (Exp. −); SREM: *stage of rapid eye movement*; MT: *movement time*; TIB: *time in bed*; SPT: *sleep period time*; WASO: *waking after sleep onset*; SL: *sleep latency*; S3L: S3 *latency*; SREML: SREM *latency*; RI: REM *interval*; RD: REM *duration*; SEI: *sleep efficiency index*; FW: *frequency of awakening per night*; SHIFT: *number of stage shifts per hour*; RT: *simple reaction time after sleep*; *significant level*: *, $p < 0{\cdot}05$; **, $p < 0{\cdot}01$, ***, $p < 0{\cdot}001$

		Exp. − ($n = 15$) Mean (S.D.)	Exp. + ($n = 15$) Mean (S.D.)
%SW	(%)	1·4 (2·3)	1·2 (2·3)
%S1	(%)	7·5 (3·9)	8·8 (6·5)
%S2	(%)	60·3 (6·3)	64·7 (6·6)*
%S(3 + 4)	(%)	5·4 (3·3)	4·7 (3·5)
%SREM	(%)	22·9 (5·1)	18·0 (5·9)*
%MT	(%)	2·0 (1·3)	2·2 (1·3)
TIB	(min)	489·5 (18·1)	487·7 (17·5)
SPT	(min)	436·5 (50·4)	437·9 (36·7)
TST	(min)	430·4 (53·3)	432·5 (40·3)
WASO	(min)	6·0 (9·8)	5·4 (9·9)
SL	(min)	52·9 (46·6)	49·7 (35·3)
S3L	(min)	30·2 (37·6)	16·8 (8·7)
SREML	(min)	84·5 (32·7)	130·4 (69·8)*
RI	(min)	82·2 (23·2)	102·4 (26·7)***
RD	(min)	27·7 (4·8)	27·0 (6·0)
SEI	(%)	87·8 (9·7)	88·7 (7·7)
FW	(/night)	1·2 (0·6)	1·3 (1·0)
SHIFT	(/hour)	17·2 (5·9)	17·8 (6·2)
RT	(s)	0·437 (0·263)	0·436 (0·271)

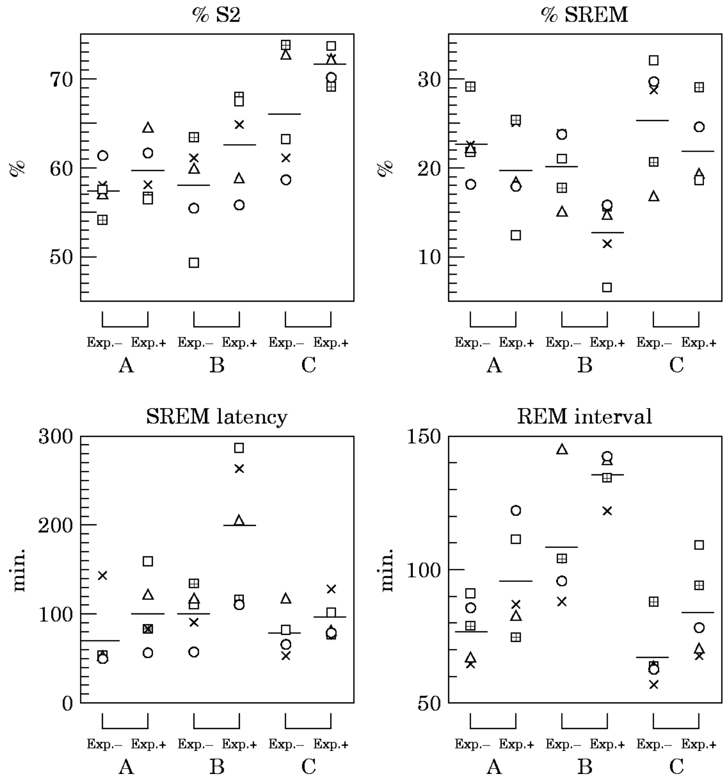

Figure 4. %S2, %SREM, SREM latency and REM interval of subjects A, B and C on the noise-exposed nights (Exp.+) and the control nights (Exp.−). Legend: ○, the first night; △, the second night; □, the third night; ×, the fourth night; and ⊞, the fifth night.

[11], a 50 dB(A) noise level was regarded as very quiet, 55 dB(A) slightly quiet, 62 dB(A) neutral, 65 dB(A) slightly noisy and 70 dB(A) very noisy. The steady ship noise of 65 dB(A) to which subjects were exposed in this study was thus considered to be a slightly noisy environment.

In this study, an increased %S2 and decreased %SREM were observed during the noise-exposed night. Poorer sleep can be defined as reduced %SREM and %S$(3+4)$ [8]. Many investigators have reported that continuous noise leads to decreased REM sleep.

TABLE 2

Comparison of subjective quality of sleep judged by the OSA *sleep inventory between the noise-exposed* (Exp.+) *and control nights* (Exp.−); *figures are standardized scores, with the mean value set equal to* 50; *improved sleep quality increases each scale score*; *significant level*: *, $p < 0{\cdot}05$; **, $p < 0{\cdot}01$; *** $p < 0{\cdot}001$

	Exp.−(n = 15) Mean (S.D.)	Exp.+(n = 15) Mean (S.D.)
Sleepiness	52·4 (4·8)	45·3 (3·9)**
Sleep-maintenance	44·9 (3·9)	39·2 (2·4)***
Worry	51·2 (3·3)	45·4 (2·1)***
Integrated sleep	48·2 (4·0)	38·3 (5·7)***
Sleep initiation	45·7 (5·0)	39·3 (2·8)**

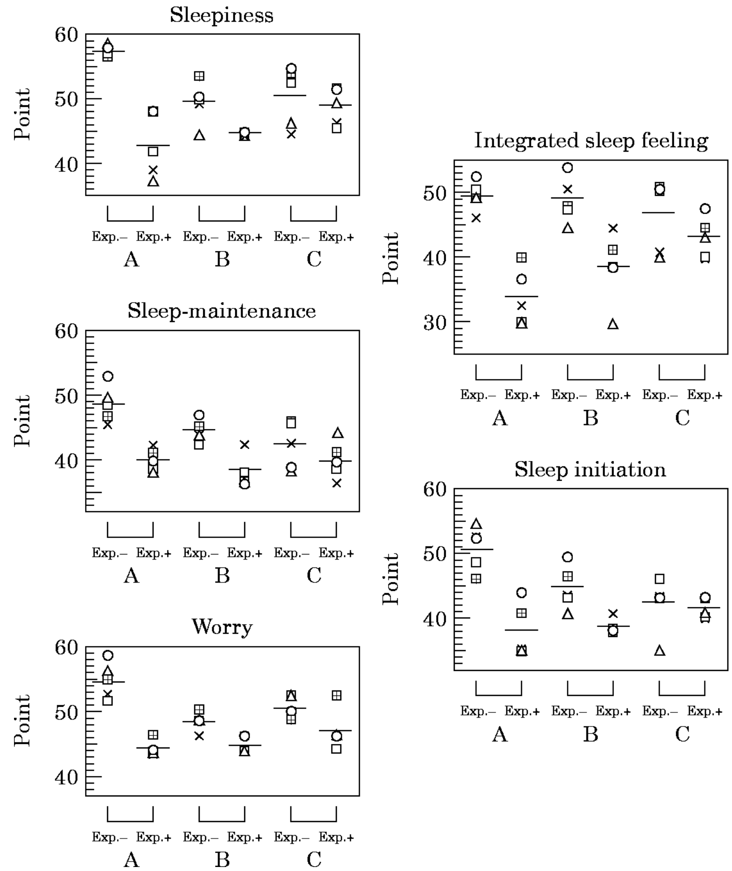

Figure 5. Five scale scores of a self-rating sleep questionnaire, OSA of subjects A, B and C on the noise-exposed nights (Exp. +) and the control nights (Exp. −). Legend: ○, the first night; △, the second night; □, the third night; ×, the fourth night; and ⊞, the fifth night.

Kawada and Suzuki [12, 13] reported that a steady pink noise of 60 dB(A) produced a %S2 increase and %SREM decrease, as compared with a 40 dB(A) noise. Eberhardt *et al*. [14] reported that continuous 45 dB(A) traffic noise caused REM sleep deficits. Scott [15] found that sleepers exposed to 93 ± 2 dB(A) of white noise all night showed decreased REM sleep and increased S1 and S2 (shallow sleep), but no effects were seen on slow wave sleep, sleep

TABLE 3

Standard partial regression coefficient by canonical discriminant analysis of 19 *sleep parameters between the noise-exposed and control nights*; *abbreviations*: *as in Table* 1

%SW	64·514	SREML	−2·970
%S1	133·586	RI	−3·453
%S2	172·537	RD	−4·589
%S(3 + 4)	98·063	FW	3·489
%SREM	144·072	SHIFT	1·453
%MT	39·443	RT	−11·768
TIB	−5.458	Sleepiness	−4.105
TST	−0·960	Sleep-maintenance	2·018
S3L	4·938	Worry	11·374
		Integrated sleep	6·267

latency, sleep time or total time of arousal associated with noise exposure, even with high, steady noise exposure. Sato *et al*. [16] reported that the %SREM of young subjects in a noisy apartment along a road with heavy traffic (L_{eq} 46·7 dB(A)) was decreased as compared with that of individual in a quiet suburban house (L_{eq} 27·7 dB(A)). Öhrström and Rylander [17] reported that continuous noise had a significantly smaller effect on sleep quality than intermittent noise. Ehrenstein and Muller-Limroth [18] found that the sleep pattern adapted to a continuous noise with the exception of a persistent decrease in Stage REM. Eberhardt *et al*. [14] and Suzuki *et al*. [19] reported, respectively, that REM sleep was one of the most sensitive parameters of sleep EEG with continuous noise and that the sound level threshold at which REM sleep decreased was 45 dB(A). A decrease in %SREM was also recognized in the present study.

In this study, %S(3 + 4) was unchanged, but there have been reports indicating that continuous noise depresses %S(3 + 4). Osada *et al*. [20] reported that the %S3 of young subjects in a noisy district along a road with heavy traffic (L_{eq}: 40 dB(A)) decreased as compared with a quiet district (20–25 dB(A)). They concluded that the threshold of sleep disturbance caused by continuous noise was 40 dB(A). Eberhardt *et al*. [14] reported that continuous noise influenced REM sleep, while intermittent noise influenced deep sleep. Ship noise is continuous, suggesting that the decrease in %SREM on the noise-exposed nights was natural.

In this study, REM latency and the REM interval were prolonged on noise-exposed nights. Topf *et al*. [21, 22] reported a similar prolongation with continuous CCU noise (L_{eq}: 56·8 dB(A)) as compared with the control nights. They reported that the REM duration decreased on the noise-exposed night. We recognized no such change in this study. Continuous noise might create the appearance of REM sleep prolongation, and the %SREM decrease in this study would thus be the result of a delay in the appearance of REM sleep.

Among the subjective sleep parameters, all five OSA scale scores on the noise-exposed nights were reduced as compared with those recorded on the control nights. Eberhardt *et al*. [14] and Vallet *et al*. [23] reported, independently, that a continuous traffic noise of 45 dB(A) degraded subjective sleep. Sleep maintenance, among the subjective sleep parameters, correlates with waking after sleep onset per night and the number of stage shifts per hour, detected polygraphically. Sleep initiation correlates with sleep latency. In this study, however, sleep maintenance and sleep initiation were worse on the noise-exposed nights, and waking after sleep onset per night, number of stage shifts per hour and sleep latency were unchanged. The relation between subjective sleep and polygraphic sleep parameters showed no parallel.

Canonical discriminant analysis using 19 sleep parameters showed that %SREM, %S2 and %S1 were somewhat higher than other parameters. It was thus thought that REM sleep and shallow sleep responded sensitively to continuous noise.

The results of this study suggest that exposure to the ship noise of 65 dB(A) may exert adverse effects on night sleep, subjectively and in part polygraphically (REM sleep and shallow sleep).

Hereafter, the development of shipbuilding technology is expected to reduce the noise level. It is also necessary to conduct experiments on daytime exposures of sailors after long voyages to clarify mechanisms of noise adaptation.

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