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Original Article

Instantaneous Change in Transient Shift of Sleep Stage in Response to Passing Truck Noise

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Abstract

The transient effects of passing truck noise on sleep stage shift were examined in fifteen male students aged 19-21 years old for 7 to 11 non-consecutive nights. Shift percentage for proceeding from Stage 2 to shallower stages (Stage 1, waking or movement time) as well as that from Stages 3 to 2, Stage 1, waking or movement time were determined. Change in Stage REM by noise was examined for shift to other stages. The percentage for shallower stages from Stage 2 significantly increased by exposure to 45, 50, 55 and 60 dBA noise compared to the non-exposed control, though this was not observed in Stage REM. The percentage of shift to shallower stages from Stage 3 significantly increased at 50, 55 and 60 dBA noise compared to the control. The minimum effective sound level for the percentage of shift to shallower stages from Stage 2 by the passing truck noise was less than 45 dBA, while that for the percentage of change in Stage REM was greater than 60 dBA and that for the percentage of shift to shallower stages from Stage 3 by the noise was between 45 and 50 dBA. Responses to noise exposure in Stage REM was less sensitive than in Stage 3.

Key words: Transportation noise, Sleep electroencephalogram, Sleep stages, Instantaneous change, Adaptation

Introduction

Passing truck noise affects sleep by making it shallower or causing awakening, although the type and /or magnitude of noise effects may vary depending on peak or equivalent sound level (Leq), duration and frequency. Loudness and intermittence of noise may cause poorer sleep than low level and continuous noise exposure.[1] If traffic volume at night is reduced, the all-night effect of noise on sleep may become negligible, though a level-response relationship between peak sound level and transient effects on sleep may continue to be observed.

Peak level of noise is positively related to a transient increase in the amount of delta-wave sleep, but inversely related to the decrease in the amount of delta-wave sleep throughout the night.2) Rapid eye movement decreases transiently due to exposures to noise, although all-night REM may increase.[2] Another discrepancy between the effect of short period and all-night noise on sleep has also been observed in the number of sleep spindles.[3]

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The increased threshold of awakening by noise means "not being awakened by noise easily" or "not being influenced by stage in spite of sound stimulation and the term "deep sleep" derives from this finding.[4] Deep sleep corresponds to Stages 3 and 4. However, change in slow wave sleep is limited only to shallower stages, though Stage 2 may take on either shallow or deep directions. This study was conducted to compare percentages of shallow (changed) sleeps in Stages 2, 3, and REM during traffic noise exposure.

The relationship between peak level of passing truck noise and change in proceeding to shallower stages was previously studied.[5,6] Only Stages 2 and REM could be investigated, since the sample size was too small to detect change in Stage 3. In the present study, the transient effect of noise on sleep stages were studied in greater detail.

Subjects and Methods

Fifteen healthy male students, 19 or 21 years of age, slept in an experimental room for 12 non-consecutive nights with no consumption of alcoholic beverages or drugs. Bedtime was about 11:00 p.m. and the students were awakened by alarm clock at 7:00 a.m.

EEG electrodes were placed as stipulated by the international 10-20 method. An electroencephalogram (EEG) at C3-A2, an electromyogram (EMG) over the submental muscle, and left and

right electrooculograms (EOG) were recorded using the telemetry system of Nihon Kohden Company, Ltd. Sleep stages were judged according to the standard atlas of Rechtschaffen and Kales7) by which an epoch was defined as 20 seconds. An epoch was considered Stage 4 when delta waves constituted 50% or more of the epoch. An epoch was Stage 3 when delta waves comprised from 20% to less than 50% of the epoch. Stage 2 epochs were less than 20% delta waves or contained sleep spindles. When alpha waves comprised 50% or more of an epoch, it was considered as "awake". An epoch was Stage REM when rapid eye movements (REMs) was present during low level EMG activity. Other stages were Stage 1. If more than half of an epoch was disturbed and unable to be read, it was considered movement time (MT).

Data from the first night were not used for analysis.[8,9] The experiment was conducted from May to July and October to December, 1992, 1993, 1994, and 1995. Road traffic noise was recorded at night in the winter of 1990 and passing truck noise of 20 seconds duration with peak level of 70 dBA served as the master tape. Four peak levels of noise were prepared from the master tape by turning down the volume to 45, 50, 55, and 60 dBA with an integrated amplifier (Model AU-D707X, Sansui Co, Ltd., Tokyo).[6] Passing truck noise showed 54 dB as maximum at 2 KHz by octave band analysis. Noise exposure order was 60, 50, 45, 55, 55, 60, 45 and 50 dBA, with intervals of 15 minutes between exposure levels, so that a single cycle lasted for two hours.[6] The same cycle was repeated all-night long. Complete random exposure thus was not achieved. When subjects could predict the time of peak sound levels during sleep, habituation or adverse effect of noise on sleep may be accelerated and affect the data. It was considered that eight event randomization would not produce the above phenomena. When the subjects slept for exactly eight hours, they had been exposed to thirty-two (8×4) noises. The first noise started 15 minutes after going to bed. Loud speakers were placed about 1.5 m away from the feet of a subject. The peak sound level of truck noise was measured at the subject's head. Exposure was continued throughout the night. Background sound in the experimental room was *L*eq 30 dBA.

The epochs became shallow in Stages 2, 3 and REM and were counted and expressed as percentage. The first epoch after noise exposure was used to clarify the level-response relationship.[5,6]

Data recording in some cases was terminated due to mechanical problems but all-night data were obtained for each subject for seven to eleven nights. The percentage of shift to shallower stages from Stage 2, and from Stage 3 to Stage 2, Stage 1, waking and movement time were calculated. Epoch percentage changes in Stage REM were also determined. Shallow (changed) epoch percentage with no-exposure for the control were obtained starting from the epoch eight minutes after 45 and 50 dBA exposure of noise for 18 epochs. As shown in Table 1, the total number of noise events in Stage 2 just before noise exposures ranged from 590 to 643, in Stage 3 from 52 to 78, and in Stage REM from 151 to 222. The control number of events in Stages 2, 3, and REM were 1158, 134, and 344, respectively. These numbers become denominators and numbers of changes to shallower stages for each noise event served as numerators to calculate shallow (changed) epoch percentages.

"Threshold" in the present study was defined as the minimum peak noise level causing increase in the percentage of change to shallower stages compared with the control with background noise of 30 dBA. The difference between the percentages of shift to shallower stages in noise events and the control were statistically examined by the chi-square test. The Cochran-Armitage test was used to assess the linearity of the dose (night)-response relationship in epochs immediately after noise exposure. SPSS for Windows software (Ver.6.1.3) was mainly used in the analysis.

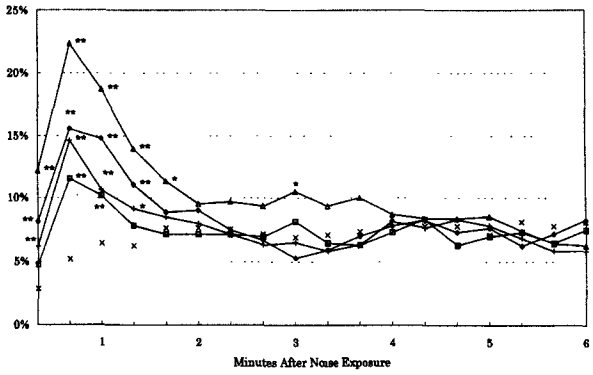

Fig.1 Time series of percentage of shift from Stage 2 to shallower stages, Stage 1, waking or movement time by exposure to passing truck noise with four peak levels of 45 (□), 50(+), 55(◇), and 60(△) dBA (Control group: ×). Statistical significance of differences within epochs was tested against the control group (*p=.05; **p=.01).

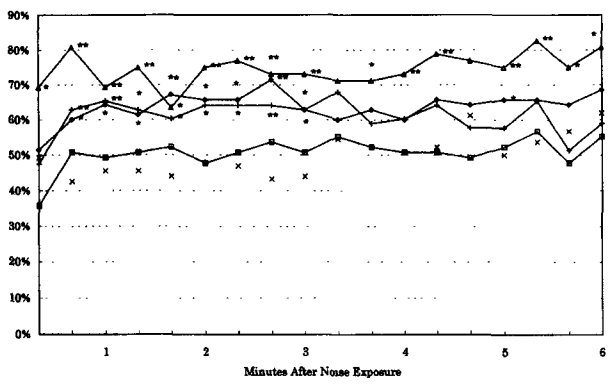

Fig.2 Time series of percentage of shift from Stage 3 to shallower stages, Stage 2, Stage 1, waking or movement time by exposure to passing truck noise with peak levels of 45 (□), 50(+), 55(◇), and 60(△) dBA (Control group: ×). Statistical significance of differences within epochs was tested against the control group (*p=.05; **p=.01).

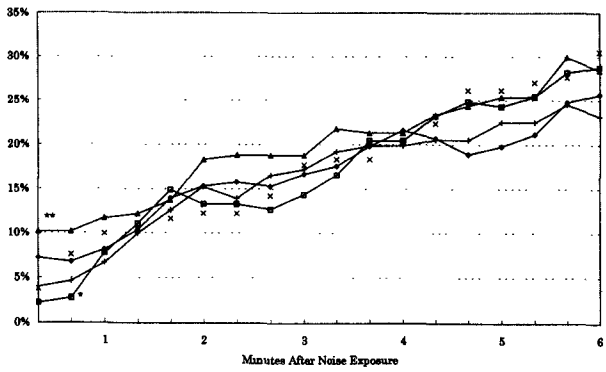

Fig.3 Time series of percentage of shift from Stage REM to other stages, waking or movement time by exposure to passing truck noise with peak levels of 45 (□), 50(+), 55(◇), and 60(△) dBA (Control group: ×). Statistical significance of differences within epochs was tested against the control group (*p=.05; **p=.01).

Results

Stages immediately after noise exposure were converted to binary data according to the criteria for shift to shallower stages. The peak sound level was used as the main factor for analysis of variance and the subject served as a covariate. Noise effect was significant in Stages 2 ($p < 0.001$), 3 ($p < 0.001$), and REM ($p < 0.05$). Subject effect was not significant in any stage.

The change in Stage 2 was greatest immediately after noise exposure at all peak levels (Fig. 1). Change was peak-level dependent and lasted for 1 minute following the noise exposure. The percentage of shift to shallower stages from Stage 2 was significant up to 2 minutes after exposure when compared to the non-exposed control except 60 dBA at 3 minutes. The percentage of shift to shallower stages from Stage 3 lasted for 3 minutes after exposure to 50 and 55 dBA and for 6 minutes to 60 dBA while no significant change was observed with exposure to 45 dBA (Fig. 2). Changed epoch percentage from Stage REM, compared with control, was not observed at 50, 55, or 60 dBA exposure (Fig. 3). Decrease in percentage of change was observed for noise exposure at 45 dBA.

Percentages of shift to shallower stages from Stage 2 were 11.5, 14.6, 15.6 and 22.3 immediately after noise exposure at 45, 50, 55 and 60 dBA, respectively. Significant linearity with little dissociation from the line was indicated by the equation, Y(%) = 0.666X-18.9 in the Cochran-Armitage test ($p < .01$). The percentages of shift to shallower stages from Stage 3 were 50.8, 62.8, 60.0 and 80.8 at 45, 50, 55 and 60 dBA, respectively. Significant linearity was shown by Y(%) = 1.660X-23.8 ($p<0.01$). Percentages of change from Stage REM were 2.8, 4.6, 6.8 and 10.2 at 45, 50, 55 and 60 dBA, respectively and linearity was shown by the equation: Y(%) = 0.485X-19.4. (Table 1).

Constituent elements in Stages 2 and 3 such as slow waves and the number of spindle changes within these stages and Stage REM were predominant in the second half of the all-night sleep. Thus, the same analysis was conducted by dividing all-night data into halves with 3 AM as the point of division. The gradient of the percentage of shift to shallower stages from Stage 2 was steeper and higher for the noise peak level in the second half of the all-night sleep compared to the first half, with Y(%) = 0.431X - 10.6 and 0.961X-30.3 for the first and second halves, respectively. The gradient of changed epoch percentage of Stage REM was steeper at the noise peak level in the second half of the all-night sleep than the first half, with Y(%) = 0.246X - 6.54, and 0.606X -25.8 for the first and second halves, respectively. The percentage of shift to shallower stages from Stage 3 observed was also higher in the second half of the all-night sleep than the first half, although such change was not significant (Y(%) = 1.787X-36.9, and 1.126X-26.3 for the first and second halves, respectively) (Table 1).

Habituation to passing truck noise was assessed by separating the data collected during the twelve nonconsecutive nights into four sets: 2nd to 3rd nights, 4th to 6th nights, 7th to 9th nights and 10th to 12th nights (Tables 2 and 3). Decrease in the percentage of shift to shallower stages from Stage 2 immediately after noise exposure of 50 dBA was significant by the Cochran-Armitage test but not significant in the cases immediately after noise exposure of 45, 55, and 60 dBA. Decrease in the change of stage from Stage REM immediately after noise exposure was significant only at 45 dBA.

Discussion

Defining "threshold" as peak level causing stage shift to shallower stages in this study may be inappropriate, since the relationship between peak level and percentage of shift to shallower stages was essentially linear. In fact, the definition has practical meaning for most people sleep under a background noise of 30 dBA. However, it may also be inaccurate since it was

Table 1 Percentages of shift to shallower stages from Stages 2, 3, and REM by the passing truck noise.

Peak sound	Stage 2				Stage 3				REM Stage			
level measured ‡	Number of events	All night	First half	Second half	Number of events	All night	First half	Second half	Number of events	All night	First half	Second half
Control	1158	5.2	5.2	5.2	134	42.5	37.6	64.0	344	7.6	11.0	6.3
45 dBA	590	11.5+	9.1*	13.8+	67	50.8	44.6	81.8	181	2.8*	5.2	1.6
50	602	14.6+	11.2+	17.7+	78	62.8*	54.0	78.6	151	4.6	3.1	5.0
55	643	15.6+	11.9+	19.8+	70	60.0+	56.3*	100.0	222	6.8	7.6	6.3
60	609	22.3+	16.0+	29.2+	52	80.8+	75.7+	93.3	197	10.2	8.1	11.4

Note: Chi-square test was applied.
First half: the first half of a night (till 3 a.m.); second half: the second half of a night (after 3 a.m.)
‡ A-weighted sound level. *$p < .05$, +$p < .01$

Table 2 Percentages of shift to shallower stages from Stage 2 by the passing truck noise shown in quarters.

Peak sound	Experiment nights							
	2nd and 3rd		4th to 6th		7th to 9th		10th to 12th	
level measured ‡	f	%	f	%	f	%	f	%
45 dBA	8/ 96	8.3	21/152	13.8	19/170	11.2	20/172	11.6
50*	19/ 95	20.0	28/155	18.1	20/172	11.6	21/180	11.7
55	20/110	18.2	29/168	17.3	24/181	13.3	27/184	14.7
60	22/100	22.0	37/161	23.0	43/183	23.5	34/165	20.6

Note: Cochran-Armitage test was applied.
f: number of shallow epochs per noise exposure events
‡ A-weighted sound level. * $p<.05$ in gradient

Table 3 Percentages of change to the other stages from Stage REM by the passing truck noise shown in quarters.

Peak sound	Experiment nights							
	2nd and 3rd		4th to 6th		7th to 9th		10th to 12th	
level measured ‡	f	%	f	%	f	%	f	%
45 dBA*	3/ 29	10.3	0/ 45	0	2/ 53	3.8	0/ 54	0
50	2/ 27	7.4	2/ 34	5.9	2/ 46	4.3	1/ 44	2.3
55	1/ 28	3.6	3/ 64	4.7	8/ 64	12.5	3/ 66	4.5
60	2/ 32	6.3	8/ 47	17.0	5/ 50	10.0	5/ 68	7.4

Note : Cochran-Armitage test was applied.
f: number of shallow epochs per noise exposure events
‡ A-weighted sound level. * $p < .05$ in gradient and total

determined based only on statistical differences, and consequently it could have been under- or over- estimated to some extent. More precise estimation may be possible by using a greater number of subjects.

A linear level-response relationship between four noise peak levels and shallow epoch percentage from Stages 2, 3 and REM was observed. The percentage of shift to shallower stages from Stage 2 was significant in peak noise of 45 dBA and over. Minimum effective noise in Stage 2 may possibly be less than 45 dBA, and in Stage 3, between 45 and 50 dBA.

Based on the level-response relationship between noise peak level and percentage of shift to shallower stages is examined, control data could not be plotted. Thirty dBA as the background level differs from 30 dBA as the noise peak level. Such relationship is applicable to only four peak levels. The "threshold" is determined by statistical comparison of the percentage of shift to shallower stages of control data with that of noise peak which, in this study, was highest in Stage REM, followed by that in Stage 3 and 2.

Significant change in the percentage that shifted to shallower stages from Stage 2 lasted for 1 to 2 minutes and from Stage 3 for 3 to 6 minutes, depending on the peak. Thus, when a person sleeps in Stage 3 and hears passing truck noise of 60 dBA, sleep becomes shallower and will not recover for more than 6 minutes theoretically.

Thiessen examined the relationship between peak level of passing sound in dBA and percentage of shift to shallower stages and waking[10] and noted a linear correlation up to 80 dBA. The percentage of shift to shallower stages without arousal was 38% at 50 dBA and 73% at 70 dBA, in both young and old subjects. Griefahn established an equation for the level-response relationship between sound level and percentage of shift to shallower stages.[11] However those results cannot be compared with the ones obtained in the present study since sleep stage right before noise exposure was not specified.

The percentage of shift to shallower stages from Stage 2 was twice the percentage of change in Stage REM. The percentage of shift to shallower stages from Stage 2 and changed epoch percentage from REM in response to noise exposure of 60 dBA were 22.3% and 10.2%, respectively. Stevenson and McKellar noted significant correlation between the probability of shift in the level of sleep stage and sound level.[12] The data of six subjects showed the probability of stage shift by the exposure of 60 dBA to be 20%, which is consistent with the present data.

The percentage of shift to shallower stages in response to noise was less in slow wave sleep compared with Stage 2 or REM in the study by Di Nisi et al.[13] However, Bach et al. found that the percentage of sleep stage change due to noise exposure is higher in Stage 3 than Stage 2 or REM.[14] In such cases, traffic noise with peak levels higher than 80 dBA of 5 to 10 seconds duration made sleep stage change from Stage 2 at 10%, Stage 3 at 20% and Stage REM at 5%. The same was also noted here in this study, and the percentage of shift to shallower stages from Stage 3 was nearly 4 times that of Stage 2. The percentage of shift to shallower stages from Stage 3 in response to noise exposure of 60 dBA was 75.7% in the first half and that increased in the second half. The fact that the arousal effect by exposure to noise impedes slow wave sleep maintenance and results in sleep stage change,[15] can partially explain this.

Eberhardt and Akselsson recommended to divide Stage 2 into three sub-stages because it constitutes about 50 % of all-night sleep and contains drowsy and slow wave sleeps.[16] All-night sleep data were halved in this study and percentage of shift to shallower stages from Stage 2 was determined for each half. Eberhardt and Akselsson did the same because Stage 2 with delta waves of less than 20% per epoch are predominant in the first half of sleep, and no delta wave is predominant in the second half. The percentage of shift to shallower stages from Stage 2 was less in the first half of the night. This could not be explained by the amount of slow wave component, as in the case of Stage 3 of this study. Stage REM frequently appeared and was stable in the second half of the night. There was no change in this component in Stage REM, and thus the percentages in both the first and second half of the night were the same.

In the study by Di Nisi et al.,[17] there was no habituation to noise exposure during sleeping. However, stage shift from Stage REM at 45 dBA and the percentage of shift to shallower stages from Stage 2 at 50 dBA ($p < 0.05$) were noted in this study. The interval of noise exposure was 15 minutes and one cycle consisted of eight exposures, requiring two hours. Intervals between stimuli were constant, though the sound level was varied. Since a significant level is not high enough and coherence with noise peak level is not clear, this result should be interpreted with caution.

Habituation during a single night was difficult to evaluate here due to change in the characteristics of Stage 2 which showed a slow wave component in the first half and disappeared in the most part of the second half of the night. In addition, stage 3 was predominant in the first half and the number of sampling times was insufficient in the second half. Furthermore, stage REM was predominant in the second half and the number of sampling times was insufficient in the first half.

Conclusion

The transient effects of passing truck noise on stages 2, REM and 3 were examined. The following results were obtained:

1) The percentage for shallower stages from Stage 2 significantly increased by exposure to 45, 50, 55 and 60 dBA noise compared to the non-exposed control.
2) The percentage of shift to shallower stages from Stage 3 significantly increased at 50, 55 and 60 dBA noise compared to the control.
3) The minimum effective sound level for the percentage of change in Stage REM was greater than 60 dBA.
4) Responses to noise exposure in Stage REM was less sensitive than in Stage 3.

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References

1) Öhrström E, Rylander R. Sleep disturbance effects of traffic noise: a laboratory study on after effects. J Sound Vib 1982; **84**, 87-103.
2) Wilkinson RT, Allison S. Effects of Peaks of Traffic Noise During Sleep on ECG and EEG. In: Milan GR, ed. Noise as a Public Health Problem, Proceedings of the Fourth International Congress. Turin: Edizioni Tecniche a cura del Centro Ricerche e Studi Amplifon, 1983; 957-63.
3) Kawada T, Suzuki S. Transient and all-night effects of passing truck noise on the number of sleep spindle. Jpn J Psychiatr Neurol 1994; **48**, 629-34.
4) Okuma T. Sleep —Physiology and Clinical Problems—. Tokyo: Igaku Shoin, 1977; 69-70 (in Japanese).
5) Kawada T, Naganuma S, Aoki S, Suzuki S. Instantaneous changes in sleep stage due to the sound of a passing truck. Jpn J Hygiene 1992; **47**, 952-7 (in Japanese).
6) Kawada T, Suzuki S. Instantaneous change in sleep stage with noise of a passing truck. Percept Motor Skills **80**:1031-40.
7) Rechtschaffen A, Kales A. A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects. Washington DC: Public Health Series, US Government Printing Office, 1968.
8) Rechtschaffen A, Verdone P. Amount of dreaming: effect of incentive, adaptation to laboratory, and individual differences. Percept Motor Skills 1964; **19**, 947-58.
9) Agnew HW Jr, Webb WB, Williams RL. The first night effect: an EEG study of sleep. Psychophysiol 1966; **2**, 263-6.
10) Thiessen GJ. Disturbance of sleep by noise. J Acoust Soc Am 1978; **64**, 216-22.
11) Griefahn B. Research on Noise-disturbed Sleep since 1973. In: Tobias JV, Jansen G, Ward WD, eds. Noise as a Public Health Problem, Proceedings of the Third International Congress. Maryland: ASHA Reports, No. **10**. 1980; 377-90.
12) Stevenson DC, McKellar NR. The effect of traffic noise on sleep of young adults in their homes. J Acoustic Soc Am 1989; **85**, 768-71.
13) Di Nisi J, Muzet A, Weber L. Cardiovascular responses to noise: effects of self-estimated sensitivity to noise, sex and time of the day. J Sound Vib 1987; **114**, 271-9.
14) Bach V, Libert JP, Tassi P, Wittersheim G, Johnson LC, Ehrhart J. Cardiovascular responses and electroencephalogram disturbances to intermittent noises: effects of nocturnal heat and daytime exposure. Eur J Appl Physiol 1991; **63**, 330-7.
15) Muzet A, Naitoh P, Townsend RE, Johnson LC. Body movements during sleep as a predictor of stage change. Psychon Sci 1972; **29**, 7-10.
16) Eberhardt JL, Akselsson KR. The disturbance by road traffic noise of the sleep of young male adults as recorded in the home. J Sound Vib 1987; **114**, 417-34.
17) Di Nisi J, Muzet A, Ehrhart J, Libert JP. Comparison of cardiovascular responses to noise during waking and sleeping in humans. Sleep 1990; **13**, 108-20.

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