Effects of noise and vibration on learning task and subjective ratings of disturbance

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Experiments on individual and combined effects of noise and vibration of low or moderate intensity were conducted concerning paired associates learning task. The experiments concerned randomly intermittent noise at 64, 74 and 79 dB(A) (re 20 μ Pa, peaks az) and continuous or intermittent vibration at 66 and 76 dB (re 10^{-5} m/s², vertical whole-body sinusoidal in 5 Hz). The learning task was evaluated by error rates in mean and standard deviation for each condition of noise and vibration. Subjective ratings of disturbance by noise and vibration were also made after the task. Sixty-four and 79 dB(A) noise produced detrimental effects on the learning. Seventy-nine dB(A) noise added with the continuous vibration indicated elimination of the effects of noise and vibration alone. Further, high disturbance did not always accompany high error rates in mean or standard deviation.

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1. INTRODUCTION

Noise and vibration in low or moderate intensity, not yet high, may cause some problems in nonoccupational environments (schools, offices or home environments etc.).^{1,2)} Earlier researches with questionnaires indicated some mental effects of noise following after annoyance, speech interference and sleep disturbance.³⁾ By the way, such mental effects may be considered to cause some effects on performance as well as physical effects of vibration. The results to date showed that noise (or vibration) produced sometimes deterioration and sometimes promotion in performance of the tasks.⁴⁻⁷⁾ Especially, individual or combined effects of noise and vibration are not clear in low or moderate intensity. Therefore, more systematical researches are required in this area.⁸⁾

This study concerned paired associates learning task, intermittent noise and vibration (continuous or intermittent). The experiments were also conducted

with three aspects; first, individual effects of noise or vibration; second, combined effects of noise and vibration; third, subjective ratings of disturbance by noise and vibration in relation to mean or standard deviation of error rates.

2. EXPERIMENTAL PROCEDURE

2.1 Noise and Vibration

Twenty-four conditions of noise and vibration were employed in this study, that contained individual and combined conditions of those.

Noise employed was broad-band intermittent noise. The noise was produced by passing through a random switch which could cut or pass signals in random intervals and durations.⁹⁾ The noise was presented at levels of 64, 74 and 79 dB(A), peaks az (re 20 μ Pa). These are designated as N₁, N₂ or N₃ respectively. Instruments to present the noise were a amplifier (SONY 1120), a loudspeaker (Mitsubishi AS 2051B) and a pink noise generator (Brüel & Kjær 1402). The loudspeaker was set in a distance

of 1.2 m from the center of a desk secured to the platform of a shaker.¹⁰⁾

Vibration employed was whole-body sinusoidal and vertical in 5 Hz. The vibration was presented continuously or intermittently at levels of 66 and 76 dB (re 10^{-5} m/s²) measured at the center of a chair secured to the platform of the shaker. Intermittent vibration was presented at intervals of 6 s with durations of 14 s that involved rise- and decay-time of 2 s respectively. Continuous vibration is designated here as CV₁ (66 dB) or CV₂ (76 dB) and intermittent vibration is designated as IV₁ (66 dB, peaks az) and IV₂ (76 dB, peaks az). Combined conditions were composed of one of N₁, N₂ or N₃ added with one of CV₁, CV₂, IV₁ or IV₂. These twelve conditions are designated as N₁+CV₁, N₂+CV₁, N₃+CV₁, N₁+CV₂, N₂+CV₂, N₃+CV₂, N₁+IV₁, N₂+IV₁, N₃+IV₁, N₁+IV₂, N₂+IV₂ and N₃+IV₂. By the way, the conditions of the vibration accompanied with noises of a cooling fan for the driver of the shaker and a oil pump that ranged from 58~60 dB(A), L_{eq} (10:00~16:00). The conditions of these noises are designated as B that continued during the electric main of the shaker being on. So conditions of B, N₁+B, N₂+B and N₃+B were also in use as experimental conditions. Control was a condition of no-vibration and a background noise in the experimental room during the main of the shaker

Fig. 1 Frequency characteristics of noise (N₁, N₂, N₃, B) and the background noise in the control (C).

being off. This is designated as C. All conditions of the noise and the vibration are indicated in Table 1 and characteristics of frequency of the noise are shown in Fig. 1.

2.2 Subjects

Six male and two female students with ages ranging from 18 to 22 years were used as subjects. They were in normal health and had normal hearing functions and normal vision. They had no previous experience with the task and the apparatus used in this study. No information about effects of noise and vibration was not given to the subjects. They were volunteers paid for their tasks. Each subjects sat on the chair with the desk which were fixed on the platform of the shaker. They experienced the vibration mainly through their buttocks via the chair.

2.3 Task

Paired associates learning (PAL) and choice reaction time task were employed as experimental task. Results about reaction time task will be reported in another paper. So results about paired associates learning are mentioned here. The task of paired associates learning was conducted in the following manner.

Each subject was required to recall each half list during 40 s with cue of presenting the other half of

Table 1 Conditions of noise and vibration.

Noise	Randomly intermittent broad-band noise. N ₁ : 64 dB(A) (re 20 μPa, peaks az). N ₂ : 74 dB(A). N ₃ : 79 dB(A). B: Background noises when the main of the shaker was made on (58~60 dB(A)).
Vibration	Vertical whole-body sinusoidal vibration. CV ₁ : Continuous vibration at 66 dB (re 10^{-5} m/s ²). CV ₂ : Continuous vibration at 76 dB. IV ₁ : Intermittent vibration at 66 dB (re 10^{-5} m/s ² , peaks az). IV ₂ : Intermittent vibration at 76 dB.
Control	C: No-vibration and background noise.
Combined conditions	N ₁ +B, N ₂ +B, N ₃ +B, N ₁ +CV ₁ , N ₁ +CV ₂ , N ₁ +IV ₁ , N ₁ +IV ₂ , N ₂ +CV ₁ , N ₂ +CV ₂ , N ₂ +IV ₁ , N ₂ +IV ₂ , N ₃ +CV ₁ , N ₃ +CV ₂ , N ₃ +IV ₁ , N ₃ +IV ₂ .

each list, after memorizing each list of ten pairs of words during a period of 40 s. This task was repeated successively with five trials in each session of each subject. Words in the lists consisted of two Japanese syllables that had non-association values from 0 to 4. Characters in each list was presented by a projector (Kodak EXTRAGRAPHIC B-2) in a size of 5 cm × 5 cm on a screen which was set in a distance of 3.5 m from the center of the desk.

2.4 Procedure

Task experiments were conducted in two days for each pair of the subjects. The subjects were assigned to four pairs before the experiments. Each pair was examined in turn for eight experimental sessions in a day. While one subject was examined on his or her task, the other one had been waiting in a next quiet room. Three sessions were held in the morning and five sessions in the afternoon. Each session was composed with 5 min of choice reaction time task and 15 min of paired associates learning task. Experimental design was planned by a block design.

3. ANALYSIS OF DATA

The paired associates learning task was evaluated with two measures of mean and standard deviation as regards error rates in each condition of each subject. The error rates mentioned above contained rates not recalled. All data in each measure were analyzed by Hayashi's Quantification Method (Type 1). Estimated values of this method are defined in the following equation.¹¹⁾

$$\alpha = \sum_{j=1}^R \sum_{k=1}^K \delta(jk) x_{jk},$$

$$\delta(jk) = \begin{cases} 1 & \text{(if a data follows } k \text{ category} \\ & \text{in } j \text{ item),} \\ 0 & \text{(if a data does follow a category} \\ & \text{besides } k) \end{cases}$$

α : outside variable

x_{jk} : estimated value of k category in j item.

In preliminary analyses for each measure of error rates, variable of "day" was not useful and then four variables were used for analytical items in this method. The variables were "noise and vibration" (NV), "subjects" (Sub), "materials for memory" (Mt) and "sessions" (Ses).

Subjects were required to rate disturbance by noise and vibration after each task in the experimental sessions. Disturbance was evaluated in a scale of

Table 2 Values in Likert's scale (L) versus the values in the subjective rating scale of disturbance (D).

Scale	Scale values				
D	1	2	3	4	5
L	1.0	2.08	3.02	3.92	5.0

five orders from 1 (disturbed not at all) to 5 (very disturbed). There was no comments at each number of the scale except 1 and 5, and it was assumed that this scale was linear with same intervals. Then, data of the subjective ratings of disturbance were also analyzed by Hayashi's Quantification Method (Type 1) with the same variables to those in the analyses of performance.

By the way, the assumption for this rating scale of disturbance was tested in preliminary analysis by Hayashi's Quantification Method (Type 2)¹²⁾ with the same items (variables) to those in the analysis by Hayashi's Quantification Method (Type 1) (used in this study). The five rank numbers in the rating scale of disturbance were used for outside categories in this preliminary analysis. Results of the preliminary analysis showed that quantified values for each conditions of noise and vibration highly correlated ($r=0.939$) to quantified values for the NV's conditions (mentioned below in this study) analyzed by the quantification method of Type 1. This suggested that the assumption for the rating scale of disturbance would be almost true. Further, this assumption was also tested in preliminary analysis by using Likert's scale.¹³⁾ Results were represented to be equal values in the both polar values of the scales. Table 2 indicates Likert's scale in relation to the subjective rating scale of disturbance. This table also suggested that the assumption for the rating scale of disturbance would be almost true. So these preliminary analyses indicated that values rated by subjects in the subjective rating scale of disturbance could be analyzed as numerical data for outside variable of Hayashi's Quantification Method (Type 1). Results of the subjective ratings of disturbance analyzed by the quantification method of Type 1, using the data not changed to Likert's scale, are showed in the following.

4. RESULTS

4.1 Variables to Explain the Task Performance

Tables 3 and 4 show intercorrelations among the

Table 3 Intercorrelations among the variables, partial correlations of each variable and multiple correlation analyzed by Hayashi's Quantification Method (Type 1) as regards mean of error rates of PAL.

Variables	Noise and vibration	Subjects	Sessions	Materials
Subjects	-0.033			
Sessions	0.025	0.043		
Materials	-0.060	0.061	-0.131	
(Partial correlation)	0.616***	0.900***	0.289**	0.657***
(Multiple correlation)	0.924***			

*** and ** show statistical significance at levels of $p < 0.001$ and $p < 0.01$ respectively.

Table 4 Intercorrelations among the variables, partial correlations of each variable and multiple correlation analyzed by Hayashi's Quantification Method (Type 1) as regards standard deviation of error rates of PAL.

Variables	Noise and vibration	Subjects	Sessions	Materials
Subjects	0.018			
Sessions	-0.218*	-0.012		
Materials	-0.188	0.041	-0.310**	
(Partial correlation)	0.674***	0.483***	0.487***	0.606***
(Multiple correlation)	0.774***			

***, ** and * show statistical significance at levels of $p < 0.001$, $p < 0.01$ and $p < 0.05$ respectively.

variables, partial correlations of each variable and multiple correlations in the analyses for each measure of error rates with Hayashi's Quantification Method (Type 1). Both of Tables 3 and 4 showed high multiple correlations ($p < 0.001$) in each analysis for the measures of mean and standard deviation of error rates. The variables (NV, Sub and Mt) indicated high partial correlations ($p < 0.001$) in these tables. While Ses indicated a high partial correlation in the analysis for the standard deviation, Ses indicated rather low partial correlation in the analysis for the mean. NV showed a highest partial correlation in the analysis for the standard deviation (sd), but NV showed a equivalent partial correlation to Mt. Sub showed a highest partial correlation in the analysis for the mean.

As regards intercorrelations among the variables, Tables 3 and 4 showed low correlations among each variable except those between NV and Ses and between Ses and Mt in the analysis for the sd. This could be considered to be due to the block design employed in this study. Tables 3 and 4 indicated in the results that the task performance could be explained by the four variables of NV, Sub, Mt

and Ses.

4.2 Effects of Noise and Vibration on the Task Performance

Figures 2~6 show quantified values for each condition of noise and vibration, when each measure of mean or sd was respectively used as outside variable in the quantification method (Type 1).

Parentheses (a) and (b) in these figures concern mean and sd of error rates respectively.

Figure 2 concerns the effects of the noise alone (N_1 , N_2 , N_3) and the conditions with B (B , N_1+B , N_2+B , N_3+B) as compared with the effects of C. N_1 and N_3 showed a higher mean of error rates than C ($p < 0.05$). N_2 showed a slightly higher mean of error rates. These indicates that the intermittent noise alone have deterioration in performance, especially N_1 or N_3 , although no differences in sd of error rates were shown in Fig. 2 among N_1 , N_2 , N_3 and C.

B showed a slightly higher mean of error rates than C and showed no difference in sd of error rates from C (see Fig. 2). But N_1+B showed a lower mean of error rates than N_1 ($p < 0.05$). N_2+B and

(a) Mean of error rates.

(b) Standard deviation of error rates.

Fig. 2 Estimated effects of noise under N_1 , N_2 , N_3 , N_1+B , N_2+B , N_3+B , B and the control (C). *C indicates statistical significance from C at $p < 0.05$. *N₁ also indicates statistical significance from N_1 at $p < 0.05$.

N_3+B also showed similar tendencies in mean of error rates to N_1+B . N_1+B and N_3+B showed no differences in sd of error rates from N_1 and N_3 respectively, while N_2+B showed a larger sd of error rates than N_2 ($p < 0.05$) or B ($p < 0.05$). By the way, N_1+B , N_2+B and N_3+B showed small differences in mean of error rates from C. Therefore, noise with B indicated tendencies of eliminating the effects of noise alone.

Figure 3 is concerned with the vibration alone (CV_1 , CV_2 , IV_1 , IV_2). CV_1 showed a higher mean of error rates ($p < 0.05$) than C. CV_2 , IV_1 and IV_2 also showed slightly higher mean of error rates. But CV_1 , CV_2 , IV_1 and IV_2 showed little differences in mean of error rates from B. The effects of the vibration alone was little, because the vibration accompanied with B (see Sect. 2.1). CV_2 and IV_2 showed smaller sd's of error rates than C or B ($p < 0.05$). So the effects of the vibration alone was appeared in sd of error rates, because CV_2 and IV_2 had higher levels of vibration than CV_1 or IV_1 respectively.

(a) Mean of error rates.

(b) Standard deviation of error rates.

Fig. 3 Estimated effects of vibration under CV_1 , CV_2 , IV_1 and IV_2 . *C indicates statistical significance from C at $p < 0.05$. *B also indicates statistical significance from B at $p < 0.05$.

Figure 4 concerns N_1 -noise added with each vibration. N_1+CV_1 showed a higher mean of error rates ($p < 0.05$), but showed a little difference in mean of error rates from N_1 or CV_1 . N_1+CV_2 , N_1+IV_1 and N_1+IV_2 showed little differences in mean from each vibration alone (CV_2 , IV_1 , IV_2) or N_1 , N_1+CV_1 and N_1+IV_2 showed smaller sd's of error rates than N_1 or each of CV_1 and IV_2 respectively ($p < 0.05$). N_1+CV_1 , N_1+CV_2 and N_1+IV_2 also showed smaller sd's of error rates than C. These results resembles to those of the vibration alone, especially in mean of error rates (see Figs. 3 and 4).

Figure 5 concerns N_2 -noise added with each vibration. N_2+CV_2 showed a slightly higher mean of error rates than CV_2 , that was statistically higher than C ($p < 0.05$). The other combined conditions relating to N_2 showed little differences in mean of error rates. As regards sd's of error rates, N_2+CV_1 showed a smaller sd than CV_1 ($p < 0.05$). N_2+IV_1 showed a larger sd than N_2 ($p < 0.05$). N_2+CV_2 and N_2+IV_2 showed smaller sd's than C ($p < 0.05$).

(a) Mean of error rates.

(b) Standard deviation of error rates.

Fig. 4 Estimated combined effects of noise and vibration under N_1+CV_1 , N_1+CV_2 , N_1+IV_1 and N_1+IV_2 . *C indicates statistical significance from C at $p < 0.05$. *N₁, *CV₁ and *IV₂ indicate statistical significance from N₁, CV₁ and IV₂ respectively ($p < 0.05$).

(a) Mean of error rates.

(b) Standard deviation of error rates.

Fig. 5 Estimated combined effects of noise and vibration under N_2+CV_1 , N_2+CV_2 , N_2+IV_1 and N_2+IV_2 . *C, *CV₁ and *N₂ indicate statistical significance from C, CV₁ and N₂ respectively ($p < 0.05$).

Figure 5 indicates that N_2+CV_2 had rather additive combined effect.

Figure 6 concerns N_3 -noise added with each vibration. N_3+CV_1 and N_3+CV_2 showed lower means of error rates than N_3 or each of CV_1 and CV_2 ($p < 0.05$). But N_3+IV_1 and N_3+IV_2 showed little differences in mean of error rates from IV_1 and IV_2 respectively. N_3+CV_1 showed a larger sd of error rates than N_3 ($p < 0.05$). N_3+IV_2 also showed a smaller sd of error rates than N_3 or IV_2 ($p < 0.05$). N_3+CV_1 and N_3+CV_2 indicated elimination of the effects of the noise alone or the vibration alone. N_3+CV_1 and N_3+CV_2 also showed rather promotion in performance.

4.3 Subjective Ratings of Disturbance

Table 5 shows intercorrelations among the variables, partial correlations of each variable and

multiple correlation in the analysis for the subjective ratings of disturbance. Table 5 showed a high multiple correlation ($p < 0.001$). The variable of NV showed a highest partial correlation ($p < 0.001$). The Sub and the Mt also showed high partial correlations ($p < 0.001$), but Ses showed rather low partial correlation ($p < 0.05$). Intercorrelations among the variables showed low correlations. These means that the subjective ratings of disturbance could be explained by these four variables.

Figure 7 shows relationships between subjective ratings of disturbance and means of error rates (%) for each condition of noise and vibration. The vertical axis represents quantified values of the ratings of disturbance (outside variable) for each condition of noise and vibration analyzed by the quantification method (Type 1). The horizontal axis also represents the quantified values of means of error rates (outside variable) for each condition of noise and vibration analyzed by the quantification

Fig. 6 Estimated combined effects of noise and vibration under N_3+CV_1 , N_3+CV_2 , N_3+IV_1 and N_3+IV_2 . *C, * N_3 and * IV_2 indicate statistical significance from C, N_3 and IV_2 respectively ($p < 0.05$).

method (Type 1) (see Sect. 4.2).

Four groups of relationship between subjective ratings of disturbance and means of error rates were observed. N_1 , N_2 , N_3 , N_1+CV_1 , N_1+CV_2 , N_1+IV_1 , N_1+IV_2 , N_2+CV_1 , N_2+CV_2 , N_2+IV_1 and N_2+IV_2 were estimated to fall under the group (a). N_1+

Fig. 7 Estimated subjective ratings of disturbance in relation to mean of error rates. Parentheses of (a), (b), (c) and (d) indicate the groups showed in Table 6. Numbers in this figure indicate the conditions in the following; 1: N_1 , 2: N_2 , 3: N_3 , 4: N_2+CV_1 , 5: N_2+CV_2 , 6: N_2+IV_1 , 7: N_2+IV_2 .

N_2+B , N_2+B and N_3+B fell under the group (b). N_3+CV_1 , N_3+CV_2 , N_3+IV_1 and N_3+IV_2 fell under the group (c). CV_1 , IV_1 and IV_2 fell under the group (d). Regression lines of each group were estimated as having same regression coefficients to each other and different constants from each other (see Tables 6 and 7). In these groupings of relationship between subjective ratings of disturbance and means of error rates, CV_2 and B were estimated to fall under the group (a). These were different tendencies from preliminary consideration of grouping that would be estimated to fall under the group (d) or (b) respec-

Table 5 Inter correlations among the variables, partial correlations of each variable and multiple correlation analyzed by Hayashi's Quantification Method (Type 1) as regards subjective ratings of disturbance in PAL by noise and vibration.

Variables	Noise and vibration	Subjects	Sessions	Materials
Subjects	-0.141			
Sessions	-0.041	-0.032		
Materials	-0.107	0.013	0.012	
(Partial correlation)	0.753***	0.653***	0.202*	0.449***
(Multiple correlation)	0.815***			

*** and * show statistical significance at levels of $p < 0.001$ and $p < 0.05$ respectively.

Table 6 Result of analysis of variance for regressions of subjective ratings of disturbance on means of error rates.

Source	SS	f	MS
Differences among constants	14.609	3	4.870***
Residual (1)	2.080	19	0.109
Differences among regression coefficients	0.235	3	0.078
Residual (2)	1.845	16	0.115

*** shows statistical significance ($p < 0.001$).

Table 7 Regression coefficient and constants of the estimated lines of subjective ratings on means of error rates.

Groups	Conditions of noise and vibration	Constants	Regression coefficients
(a)	$N_1, N_2, N_3, N_1\text{comb.}, N_2\text{comb.}$	-1.03	
(b)	N_1+B, N_2+B, N_3+B	0.06	
(c)	$N_3+CV_1, N_3+CV_2, N_3+IV_1, N_3+IV_2$	1.08	0.124
(d)	CV_1, IV_1, IV_2	-2.31	

These estimated regression lines are shown in Fig. 7. $N_1\text{comb.}$ in this table indicate the conditions of $N_1+CV_1, N_1+CV_2, N_1+IV_1$ and N_1+IV_2 . $N_2\text{comb.}$ in this table also indicate $N_2+CV_1, N_2+CV_2, N_2+IV_1$ and N_2+IV_2 .

Table 8 Results of analyses of variance for regressions of subjective ratings of disturbance on standard deviations of error rates.

Analytical group No.	Source	SS	f	MS
[1] (a), (b), (c)	Differences among constants	4.787	2	2.394***
	Residual (1)	0.946	10	0.095
	Differences among regression coefficients	0.218	2	0.109
	Residual (2)	0.727	8	0.091
[2] (d), (e)	Differences among constants	4.974	1	4.974***
	Residual (1)	0.425	6	0.071
	Differences among regression coefficients	0.00003	1	0.000
	Residual (2)	0.425	5	0.085

*** shows statistical significance ($p < 0.001$).

tively. C was estimated to fall under the group (a). As the results, it was shown that the group (c) was most disturbing in spite of indicating rather low means of error rates, especially N_3+IV_1 or N_3+IV_2 , and that the group (d) was least disturbing in spite of indicating rather high means of error rates (Fig. 7, Table 7).

Figure 8 shows relationships between subjective

Fig. 8 Estimated subjective ratings of disturbance in relation to standard deviation of error rates. Parentheses of (a), (b), (c), (d) and (e) indicate the groups estimated in Table 8. Numbers in this figure indicate the conditions in the following: 1: N_1 , 2: N_2 , 3: N_3 , 4: N_2+CV_1 , 5: CV_2 , 6: N_2+IV_1 , 7: N_2+IV_2 , 8: N_1+CV_2 , 9: N_2+CV_2 , 10: N_3+CV_2 .

Table 9 Regression coefficients and constants of the estimated lines of subjective ratings on means of error rates.

Groups		Conditions of noise and vibration	Constants	Regression coefficients
[1]	(a)	B, Bcomb., CV ₂ , CV ₂ comb.	4.58	-0.0706
	(b)	N ₁ +CV ₁ , N ₁ +IV ₁ , N ₁ +IV ₂	3.92	
	(c)	N ₃ +CV ₁ , N ₃ +IV ₁ , N ₃ +IV ₂	5.67	
[2]	(d)	CV ₁ , IV ₁ , IV ₂	-0.55	0.108
	(e)	N ₁ , N ₂ , N ₃ , N ₂ +CV ₁ , N ₂ +IV ₁ , N ₂ +IV ₂	1.11	

These estimated regression lines are shown in Fig. 8. Bcomb. in this table indicate the conditions of N₁+B, N₂+B and N₃+B. CV₂comb. in this table also indicate the conditions of N₁+CV₂, N₂+CV₂ and N₃+CV₂.

ratings of disturbance and standard deviations of error rates (%) for each condition of noise and vibration. The vertical axis represents the quantified values of the subjective ratings of disturbance (outside variable) for each condition of noise and vibration (same to those in Fig. 7). The horizontal axis also represents the quantified values of standard deviations of error rates (outside variable) for each condition of noise and vibration analyzed by the quantification method (Type 1) (see Sect. 4.2). It was also observed in Fig. 8 that five groups of relationship between subjective ratings of disturbance and sd's of error rates. The groups of (a), (b) and (c) were estimated as having same regression coefficients to each other, and the groups of (d) and (e) were also estimated as having same regression coefficients (see Table 8) that were different from the coefficient of the group of (a), (b) and (c) (see Table 9). B, N₁+B, N₂+B, N₃+B, CV₂, N₁+CV₂, N₂+CV₂ and N₃+CV₂ fell under the group (a). N₁+CV₁, N₁+IV₁ and N₁+IV₂ fell under the group (b). N₃+CV₁, N₃+IV₁ and N₃+IV₂ fell under the group (c). CV₁, IV₁ and IV₂ fell under the group (d). N₁, N₂, N₃, N₂+CV₁, N₂+IV₁ and N₂+IV₂ fell under the group (e). The conditions in the group of (a), (b) or (c) indicated that subjective ratings of disturbance increased in proportion to decreasing sd's of error rates, while the conditions in the group of (d) or (e) indicated that subjective ratings of disturbance increasing in proportion to increasing sd's of error rates (Fig. 8). C was estimated to be not belonged to the groups mentioned above in Fig. 8.

5. DISCUSSION

The results to date in the effects of noise and

vibration are inconclusive, because of difficulties in the experimental control of the variables affecting on the task performance. Therefore, it is difficult to summarize simply the effects of noise and vibration.^{14,15} Nevertheless, some suggestive results were obtained in this study.

The main variables affecting on the task in this study were NV (noise and vibration), Sub (subjects), Mt (materials for memory) and Ses (sessions) (Tables 3 and 4). The results in the analyses by Hayashi's Quantification Method (Type 1) showed that these variables did not correlate to each other in mean and standard deviation (sd) of error rates, except Ses in sd of error rates (Tables 3 and 4). Ses in sd of error rates showed correlation to NV and Mt, but showed a rather low partial correlation. Therefore, the estimated mean and standard deviation of error rates in each condition of noise and vibration can be considered to be fairly clear effects of noise and vibration, although the levels of noise or vibration were rather low or moderate. The results in Table 5 also showed that the estimated subjective ratings of disturbance were clear effects of noise and vibration. Many earlier researchers employed such experiments as the subjects were tested on the set task under the conditions of noise and quiet.⁴⁻⁶ In such experiments, equal capabilities for performance between two groups of subjects can be not always matched, though they are randomly selected in a larger group.¹⁴ So each subject was examined under 2/3 of all conditions of noise and vibration under the block design in this study. Then Tables 3~5 indicated reasonable results as mentioned above.

N₁ and N₂ produced clearly detrimental effects in mean of error rates as compared with the control.

N_2 also indicated the same tendency to N_1 and N_3 . Yoshida demonstrated that the noise at equivalent levels to those in this study produced the promotive effects on the same task.⁹⁾ Although the durations for memorization and recall was longer in the previous study⁹⁾ than in this study, the mean error rates of all data were equivalent. The durations were employed, because the subjects in this study indicated higher performance and less error in preliminary training tests. Reason for this discrepancy (detrimental or promotive) would be that distraction and arousal were different between intermittent and continuous noise. The intermittent noise in this study was randomly varying in intervals and durations and was unfamiliar to the subjects. So the intermittent noise produced the detrimental effects on the task.¹⁶⁾ It is suggested that distraction would not appear in the same scalar dimension to arousal, and that arousal would be multidimensional.^{8,9)}

CV_1 indicated clearly detrimental effects, but CV_2 , IV_1 and IV_2 indicated no effects or little deterioration in performance (Fig. 3). These effects would be mainly due to B, because the effects of the vibration alone indicated the effects near to B (Fig. 3). Reason for this may be that the intensity of the vibration was too low.¹⁷⁾ Nevertheless, the vibration when it was added with noise indicated the different effects from the effects of the conditions with B (Figs. 4~6). Especially, $N_3 + CV_1$ and $N_3 + CV_2$ indicated rather promotive effects on performance. It seems that N_3 (higher intensity) masked the effects of B and the vibration (CV_1 , CV_2). The other combined conditions indicated similar effects of the vibration alone, although $N_2 + CV_2$ indicated rather additive effects (Figs. 3~6). It seems that the effects of dominant stressor appeared in the combined conditions as well as in the vibration alone. $N_2 + CV_2$ showed rather additive effects (Fig. 5). Such effects were also shown in the previous paper.⁹⁾ Therefore, it is inconclusive about the combined effects.¹⁸⁾ But additive effects of the combined conditions would appear in balancing the effects of each stressor. It is suggested combined stressors may probably change arousal from the arousal of each stressor (noise and vibration) in balancing or filtering each arousal of noise and vibration in accordance with demand of the task.

As regards subjective ratings of disturbance, interest results were observed (Figs. 7 and 8). The disturbance indicated the clear proportion to mean or standard deviation of error rates in each of some

groups respectively. CV_1 , IV_1 and IV_2 showed high error rates in mean in spite of low disturbance. N_3 added with the vibration showed rather low error rates in mean against showed high disturbance, especially $N_3 + IV_1$ and $N_3 + IV_2$. These indicates that high error rates does not always accompany high disturbance. So it should be taken account for such relationships between error rates and disturbance when some conditions of noise and vibration will be compared in performance. By the way, Fig. 8 showed two tendency in relationship between the standard deviation and the disturbance. The noise or vibration alone, except the conditions with B, showed increasing standard deviation of error rates as increasing disturbance. But the combined conditions as well as the conditions with B showed decreasing standard deviation of error rates as increasing disturbance. So it is suggested that some concentration in performance may produced higher disturbance and that it may show high error rates in mean and small standard deviations of error rates.

In summary, it was observed that N_1 and N_3 produced detrimental effects and that N_2 indicated the same tendency to N_1 or N_3 . It was also observed that $N_3 + CV_1$ and $N_3 + CV_2$ indicated elimination of each effect of the noise and the vibration alone. Further, it was demonstrated that high disturbance did not always accompany high error rates in mean or standard deviation of the paired associates learning task.

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REFERENCES

- 1) A. T. Purcell and R. H. Thorne, "An alternative method for assessing the psychological effects of noise in the field," *J. Sound Vib.* **55**, 533-544 (1977).
- 2) J. W. Sargent and W. A. Utley, "The disturbance caused to school teachers by noise," *J. Sound Vib.* **70**, 557-572 (1980).
- 3) J. Lambert, F. Simonnet, and M. Vallet, "Patterns of behaviour in dwellings exposed to road traffic noise," *J. Sound Vib.* **92**, 159-172 (1984).
- 4) N. D. Weinstein, "Effect of noise on intellectual performance," *J. Appl. Psychol.* **59**, 548-554 (1974).
- 5) W. E. Teichner, E. Arees, and R. Reilly, "Noise and human performance: A psychological approach,"

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- Ergonomics 6, 83-97 (1963).
- 6) C. R. Johansson, "Effects of low intensity, continuous and intermittent noise on mental performance and writing pressure of children with different intelligence and personality characteristics," *Ergonomics* 26, 275-288 (1983).
- 7) J. L. Wheale and N. M. O'Shea, "Noise and the performance of a four-choice psychomotor task," *Ergonomics* 25, 1053-1064 (1980).
- 8) M. Loeb, "Noise and performance: Do we know more now?" *ASHA-Reports* 10, 303-321 (1980).
- 9) T. Yoshida, "Effects of noise and vibration on choice reaction time task and paired associates learning task," *J. Acoust. Soc. Jpn. (E)* 7, 315-323 (1986).
- 10) K. Yamazaki, "Effects of whole body vibration on human performance and physiological functions (Report 1)," *Bull. Railw. Labour Sci. Res. Inst.* 29, 41-51 (1975) (in Japanese).
- 11) S. Yasuda, *Social Statistics* (Maruzen, Tokyo, 1967), p. 189 (in Japanese).
- 12) S. Yasuda, *Social Statistics* (Maruzen, Tokyo, 1967), p. 194 (in Japanese).
- 13) T. Takagi, *Studies on Quantification in Psychology* (Tokyo-Daigaku-Shuppankai, Tokyo, 1969), p. 199 (in Japanese).
- 14) K. D. Kryter, *The Effects of Noise on Man* (Academic Press, New York, 1970), p. 550.
- 15) G. R. J. Hockey, "Effects of noise on human work efficiency," *Handbook of Noise Assessment*, ed. by D. N. May (Van Nostrand Reinhold Comp., New York, 1978), Chap. 14, p. 335.
- 16) A. J. Eschenbrenner, Jr., "Effects of intermittent noise on the performance of a complex psychomotor task," *Hum. Factors* 13, 59-63 (1971).
- 17) B. K. N. Rao and C. Ashley, "Effect of whole body low frequency random vertical vibration on a vigilance task," *J. Sound Vib.* 33, 119-125 (1974).
- 18) C. S. Harris and R. W. Shoenberger, "Combined effects of broad-band noise and complex waveform vibration on cognitive performance," *Aviat. Space Environ. Med.* 51, 1-5 (1980).