An experimental study on combined effects of high-speed railway noise and vibrations on activity disturbances

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ABSTRACT

This experimental study was carried out to examine the combined effects of high-speed (Shinkansen) railway noise and vibrations on activity disturbances. Participants were ten women and ten men (18–22 years) with normal hearing ability. The Shinkansen railway noise and vibrations used as stimuli were recorded near the Hokuriku Shinkansen railway. The audio stimuli had L_{Amax} values of 50, 60, and 70 dB, whereas the vibration stimuli had three types (none, intermediate, and high) of vertical vibrations. The participants were exposed to these combined stimuli while they engaged in 30-second activity tasks (reading and thinking). The results indicated that there were significant differences in subjects' evaluations of vibration cognition between all of the vibration stimuli during the reading task. In contrast, during the thinking task, we observed no differences between the none and intermediate vibration conditions in the 60 and 70 dB conditions. We observed significant differences in evaluations of activity disturbance between the none and high vibration conditions in the 50 and 60 dB conditions during the reading task and between the none and intermediate or high vibration conditions in the 50 dB condition during the thinking task.

Keywords: High-Speed Railway, Shinkansen, Disturbance, Noise, Vibration, Experiment

1. INTRODUCTION

The first high-speed (Tokaido Shinkansen) railway opened between Tokyo and Shin-Osaka, Japan in 1964. Currently, it operates at a maximum speed of 285 km/h. When the high-speed rail network was extended in 1975, the Sanyo Shinkansen started running between Shin-Osaka and Fukuoka. In 2015, the Hokuriku Shinkansen opened between Nagano to Kanazawa (Ishikawa prefecture) as the Seibi Shinkansen. This is one of the five Seibi Shinkansen lines recognized by the Japanese government in 1973. These are controlled at a maximum speed of 260 km/h. Even today the Shinkansen rail network in Japan is being extended.

In Japan, environmental quality standards for Shinkansen Superexpress railway noise were established by the Ministry of the Environment in 1975. The standard is 70 dB or less (peak noise level) in areas used mainly for residential purposes. A vibration guideline of 70 dB was recommended by the Environment Agency in 1976.

Sone et al. (1) conducted the first social surveys about the Shinkansen railway noise in areas along the Tokaido and Sanyo Shinkansen lines. The results were compared with the results of aircrafts noise measurements. They discussed the application of several noise indices for evaluation of Shinkansen noise annoyance levels. Yano et al. (2) showed that noise and vibration annoyance caused by the Sanyo Shinkansen railway was greater than that from conventional railways in Fukuoka. Yokoshima et al. (3) indicated, after meta-analysis, that vibration annoyance related to high sound pressure level (SPL) was greater than that of low SPL. The authors (4) also revealed that respondents along the Nagano Shinkansen railway indicated significantly greater noise annoyance in residential areas at a vibration

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level of 50 dB or more, than that for less than 50 dB. Using structural equation modeling, it was shown that noise annoyance was influenced not only by physical exposure but also by disturbances of activity caused by the Nagano Shinkansen railway (5). Öhrström et al. (6) showed, both in experimental and field studies, that general annoyance due to railway noise increases in the presence of simultaneously occurring vibrations from multiple trains.

To better understand this phenomenon, it is necessary to establish the quantitative relationships of noise and vibration with annoyance and activity disturbance. With this in mind, the objective of this study was to investigate experimentally, the combined effects of noise and vibration in relation to activity disturbance.

2. EXPERIMENT

2.1 Apparatus

The experiment was conducted in a simplified anechoic room (2,800 x 2,800 mm) with controlled air temperature (21 °C) and light level (500 lx). Figure 1 shows a two-axis (vertical and horizontal) vibration system (San-Esu SPT2DV-9K-12L2-1T) in this room. Only the vertical axis was used in this study. The seat height was 835 mm from floor, and it was 900 × 900 mm. Two speakers (ECLIPSE TD508MK3) were placed in front of the participants at ear level to deliver sounds.

Figure 1 – Vibration equipment

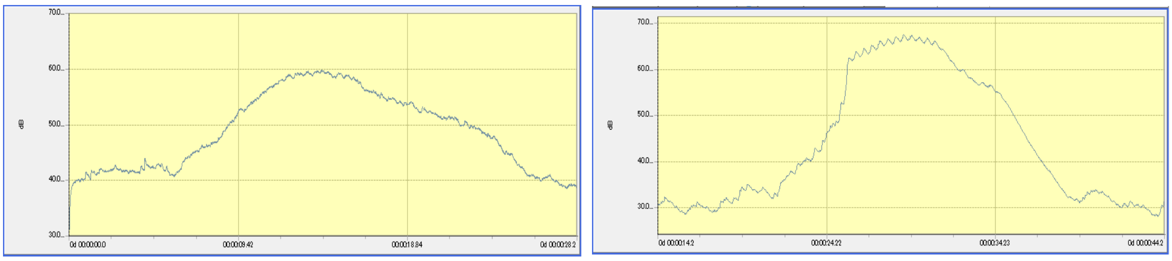
2.2 Stimuli

Participants were exposed to adjusted sounds and vibrations recorded outside near the Hokuriku Shinkansen railway. Figure 2 shows the noise and vibration measurements. The microphones for noise measurement were used with sound level meters (RION NL-32 and NL-31), and the pickups for vibration measurement were used with a vibration level meter (RION VM-53A). Data recorders (RION DA-20) were used for recording them. As a vibration measure unit, the Japanese Industrial Standard (JIS) Z 8735, “Methods of Measurement for Vibration Level,” defines “vibration level”, differently from in the indices given in ISO2631-1. The vibration level is defined as twenty times the logarithm to the base 10 of the ratio of the root-mean-square vibration acceleration, to the reference (10^{-5} ms^{-2}). Each of the three types of stimuli used in the experiments, were created based on these. The passing time of the Hokuriku Shinkansen was about 20 s, so the time for one stimulus “set” was 30 s in this experiment. The sound stimuli were adjusted so that the maximum noise levels, 50, 60, and 70 dB at the ears of participants. In this work, we regarded the maximum-based index of vibration level (L_{vmax}) as vibration exposure. The vibration stimuli were presented in three conditions: none, intermediate, and large. Intermediate and large stimuli were 65 and 75 dB, respectively. These correspond to 0.018 and 0.043 [ms^{-2}] of MTVV respectively (7, equation 1). Nine combinations were made from these stimuli.

$$10 \log \left(\frac{MTVV}{10^{-5}} \right)^2 = 1.77 + L_{Vmax} \qquad (1)$$

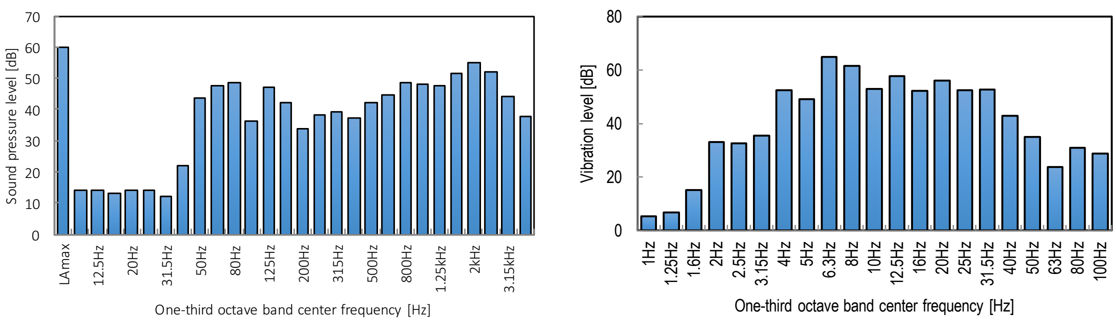
Figure 3 shows an example of the time constant of stimuli: (a) noise at 60 dB and (b) vibration at intermediate level. Figure 4 shows spectra of the noise (a) and the vibration (b) stimuli. The predominant sound frequencies occurred in band at 63 and 80 Hz, and at about 2 kHz. Those of vibrations were bands at about 6.3 and 8 Hz. The participants were randomly exposed to these nine combinations.

Figure 2 – The Hokuriku Shinkansen railway noise and vibration measurement



(a) Time history of noise (60dB) (b) Time history of vibration (middle)

Figure 3 – Time history of the noise and vibration stimuli



(a) Example of noise (60dB) (b) Example of vibration (middle)

Figure 4 – Spectrum of the noise and vibration stimuli

2.3 Design and procedure

The participants in the experiment were ten women and ten men (18–22 yr; 19.7 ± 1.2 yr) with normal hearing ability. The participants were instructed to sit in a comfortable upright posture. To investigate the effects on everyday activities of the Shinkansen railway noise and vibration, the participants carried out reading and thinking (calculation) activities in the experiment. For the reading task, the participants read a light magazine that they chose. In the thinking task, the participants repeated multiplication between two columns of numbers.

A summary of the experiment on vibration was explained to the participants, who then answered a questionnaire about their personal attributes. All experiments were conducted with reading tasks first; then thinking tasks. The total experiment time was approximately 20 min. Before each task, each participant was given practice in the reading and the thinking tasks, and the method of evaluation was explained. Table 1 shows three questions from the evaluation. Each question was evaluated on the 5-point verbal scale (8). Figure 5 shows an example of the experimental conditions. The participants did their activity tasks and evaluations in the vibration experiment comfortable postures.

Table 1 – Question wordings

	Question
Q1	How did you feel noisy during the reading (thinking) task?
Q2	How did you feel vibration during the reading (thinking) task?
Q3	How much did noise and vibration from the Shinkansen railway disturb you during the reading (thinking) task?

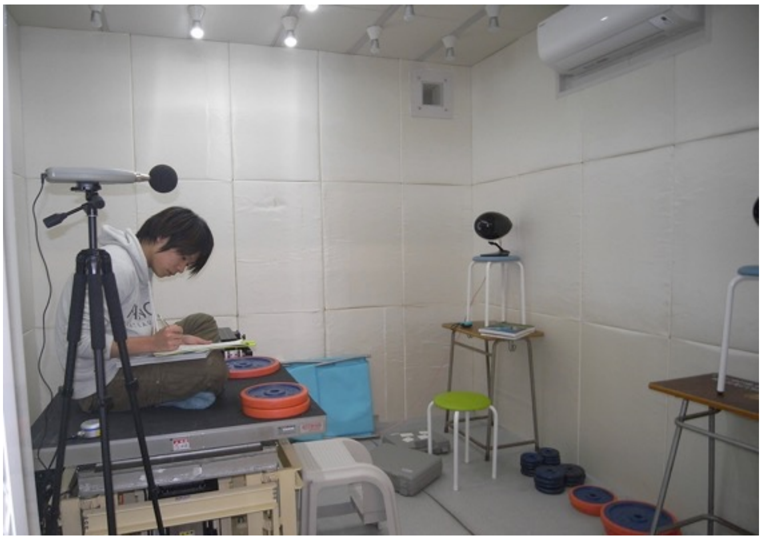
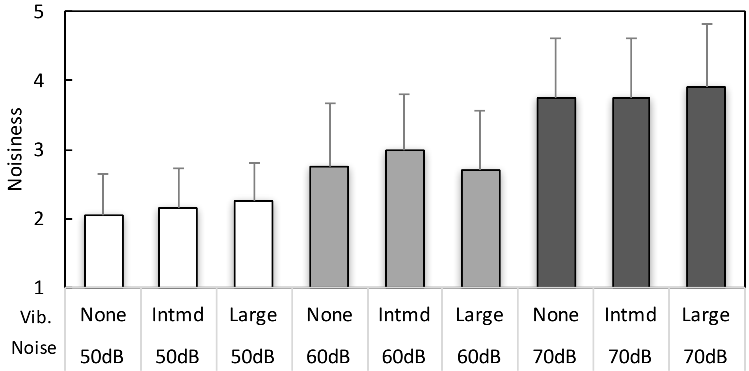


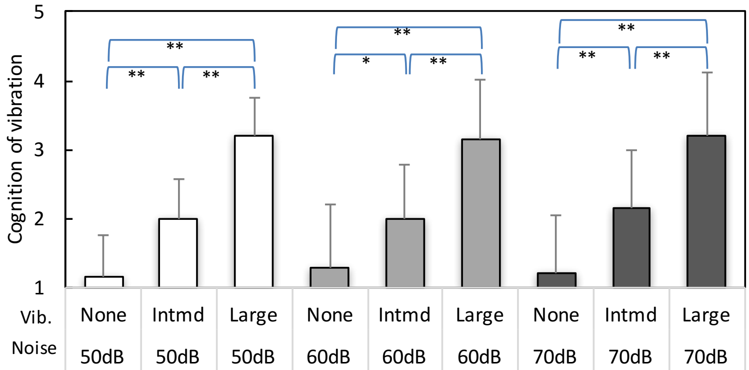
Figure 5 –Example of experiment condition

3. RESULTS AND DISCUSSION

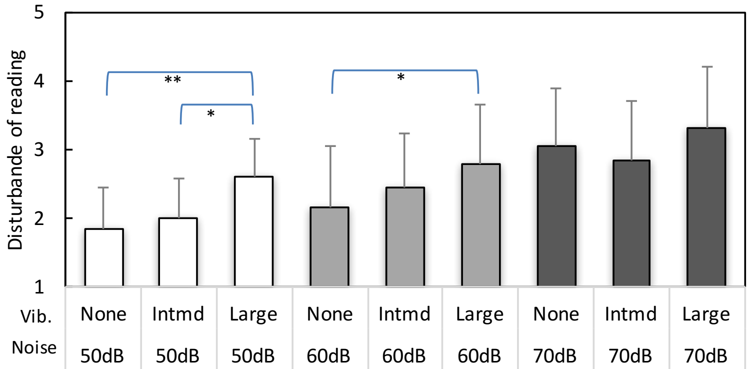
Figure 6 shows the results of the evaluation during the reading tasks. The bar indicates the average value of the evaluation and the error bar indicates the standard deviation. The Tukey's test for multiple comparison was used for the determination of significant difference. Concerning noisiness during the reading task, no difference was found between the different vibration stimuli in the same noise conditions. Given the same noise stimuli, cognition evaluations of vibration were significantly different between the different vibration stimuli. For the low noise stimuli (50 and 60 dB), significantly more responses of high levels of disturbance were given for high-level vibration stimuli in the same noise conditions. For the high noise stimulus (70 dB), there was no difference in the disturbance response between the levels of vibration stimuli.



(a) Noisiness



(b) Cognition of the vibration

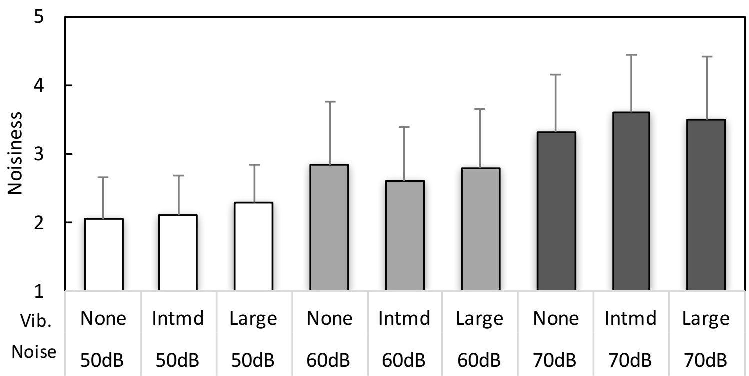


(c) Disturbance of the reading task

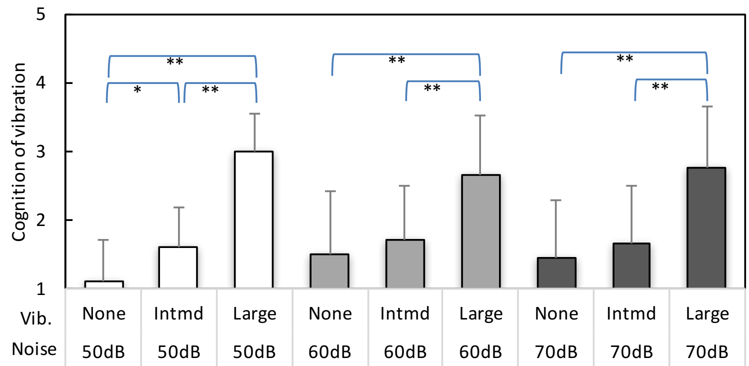
Figure 6 –The results from the reading task (*: $p<0.05$, **: $p<0.01$)

Figure 7 shows the results of the evaluation of the thinking tasks. The meaning of the bar, the error bar, and the method of the significance tests were the same as with the reading task. For the higher noise stimuli, subjects reported that high noisiness from the Shinkansen railway, while there was no reported difference between the vibration stimuli. The cognition values of the high-level vibration conditions were significantly higher than for no vibrations, or intermediate level vibrations for each level of noise stimulus. The disturbance reported for the high-level vibration stimulus was significantly greater than for other vibration stimuli (50 dB noise condition). There were no significant differences in reported disturbance between the three levels of vibration stimuli under 60 and 70 dB noise conditions, although the high-level vibration stimuli were reported to cause slightly higher disturbance. The number of calculations written on the task paper had large variation among the participants. In other words, it could not be determined by the results if the high-level noise or vibration conditions led to a fewer calculations than would have occurred under low-level noise or no vibration conditions.

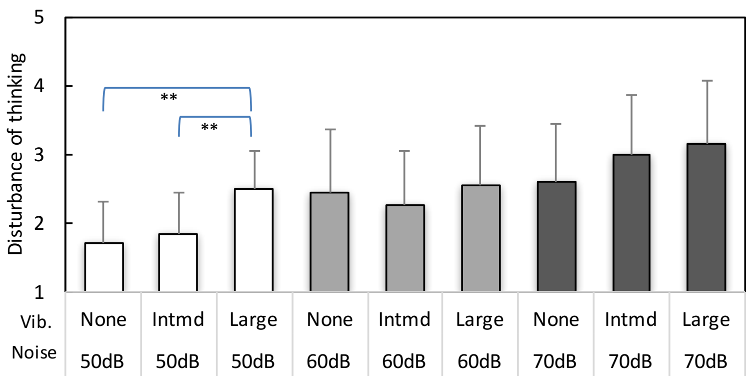
In the tasks of both reading and calculation, the reported level of disturbance was not different according to the different levels of vibration stimuli, under the 70 dB noise condition. When the noise stimulus was too strong, it was not possible to determine the combined effect of noise and vibration on activity disturbance. Moreover, under the 60 dB noise conditions, disturbance of the reading task by high-level vibration stimulus was significantly greater than for the no-vibration condition. There was no difference in calculations was greater than under the same condition. Probably the degree of the concentration required for mathematical calculation was greater than that for the reading task, and it is possible that the degree of concentration affects the level of disturbance of the activity.



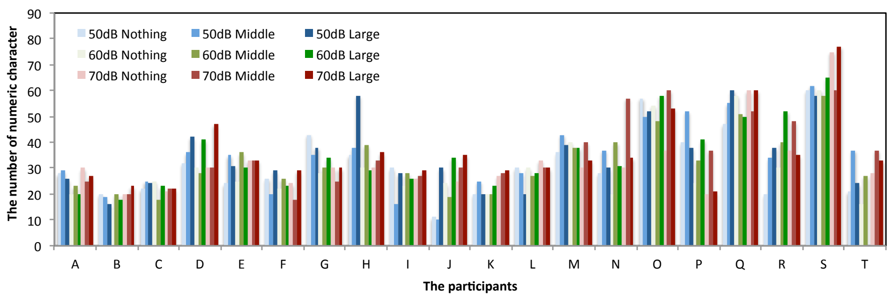
(a) Noisiness



(b) Cognition of the vibration



(c) Disturbance of the thinking task



(d) The number of numeric character

Figure 7 –The results from the thinking task (*: p<0.05, **: p<0.01)

4. CONCLUSIONS

We observed significant differences in subjective evaluations of activity disturbance between the two vibration conditions (no vibrations and high-level vibrations) under the 50 and 60 dB noise conditions during the reading task, and between “no vibration” and intermediate or high-level vibration conditions under the 50 dB noise condition during the calculation task. In a word, this study indicated that a combined effect of noise and vibration on activity disturbance did exist in an environment of low-level noise.

Further research is necessary to investigate the effect of the number (of events) of noise and vibration stimuli. We also intend to study the effects from both vertical and horizontal vibration (simultaneous) on cognition and disturbance.

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