Experimental study on combined effect of Shinkansen railway noise and vibration on daily activities: A case of reading and calculation tasks

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Abstract: Two laboratory experiments were conducted to investigate the combined effect of Shinkansen (high-speed) railway noise and vibration on daily life. In Experiment 1, stimuli noise and vibration recorded outdoors were used, and in Experiment 2, those recorded indoors were used. Twenty participants were exposed to 18 stimuli comprising 9 pairs of noise and vibration in Experiment 1, whereas 20 different participants were exposed to 22 stimuli comprising 11 such pairs in Experiment 2. The results indicated that there was significant activity disturbance from the combined effect of noise and vibration; however, the influence of vibration stimuli at 65 dB or less did not disturb reading.

Keywords: Combined effect, Noise, Vibration, Disturbance, Shinkansen railway

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1. INTRODUCTION

The first Shinkansen (high-speed) railway, the Tokaido Shinkansen line, opened between Tokyo and Shin-Osaka, Japan, in 1964. Currently, it runs with a maximum speed of 285 km/h. When the high-speed rail network was extended in 1975, the Sanyo Shinkansen line began operating between Shin-Osaka and Fukuoka, and it runs with a maximum speed of 300 km/h. In 2015, the Hokuriku Shinkansen line opened between Nagano and Kanazawa (Ishikawa prefecture) as a Seibi Shinkansen (new Shinkansen) line. This is one of the five Seibi Shinkansen lines planned by the Japanese government in 1973. They are controlled to operate at a maximum speed of 260 km/h. Today, the Shinkansen rail network in Japan is still being extended.

In Japan, environmental quality standards for Shinkansen Superexpress railway noise were established by the Environment Agency in 1975. The standards are 70 dB or less (peak noise level) in areas used mainly for residential purposes and 75 dB or less in other areas. A vibration guideline of 70 dB was recommended by the Environment Agency in 1976. These environmental quality standards and recommendations provide standard and guideline values respectively; therefore, those in which noise and vibration environments have been assessed comprehensively are necessary.

Sone et al. [1] conducted the first social surveys on the community response to Shinkansen railway noise in areas along the Tokaido and Sanyo Shinkansen lines in 1972. The results were compared with those of aircraft noise. They discussed the application of several noise indices to evaluate Shinkansen noise annoyance. Yano et al. [2] demonstrated that each annoyance due to noise and vibration from the Sanyo Shinkansen railway was greater than that from conventional railways in Fukuoka prefecture. Yokoshima et al. [3] confirmed, after a meta-analysis, the combined effects of vibration/noise exposure on noise/vibration annoyance. Morihara et al. [4] also revealed that respondents along the Nagano Shinkansen railway evaluated significantly greater noise annoyance in residential areas at a vibration level of 50 dB or more than that for under 50 dB. Öhrström et al. [5] showed, both in experiments and field studies, that general annoyance due to

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railway noise increases in the presence of simultaneously occurring vibrations from multiple trains. Howarth and Griffin [6] conducted an experimental study on the total annoyance caused by simultaneous noise and vibration from railways. The vertical vibration stimuli were recorded in houses during the passage of trains nearby. The sound stimuli comprised broad-band random noise that was refined to a spectrum resembling that of train noise. The results indicated that total annoyance was more accurately predicted by using the combined noise and vibration stimuli than by using either noise or vibration alone. Lee and Griffin [7] demonstrated that the total annoyance caused by combined noise and vibration was considerably greater than the annoyance of the dominant source from high-speed trains.

The results of previous studies indicate the importance of the mutual effects of noise and vibration from railways on annoyance. Therefore, it is necessary to investigate the effects of simultaneous exposure to noise and vibration from Shinkansen railways on an actual living environment. Considering this, the objective of this study was to investigate the combined effects of noise and vibration on daily activity disturbance experimentally.

2. METHODS

It is said that annoyance is difficult to evaluate experimentally; therefore, we decided to verify the combined effect of noise and vibration by examining how it interfered with reading and thinking (calculation) tasks. Information on these disturbances was also collected through a social survey [4]. These two tasks were selected because body functions that may be susceptible to vibration are involved in accomplishing them—visual function in both tasks and hand and arm control, particularly in the calculation function. Moreover, another reason for selecting these two tasks included the assumption that the cognitive process and information processing required for these two tasks might be different. An apparent difference was that the calculation task required responses based on cognition and information processing, which were not needed in the reading task. The experiments were divided into two parts. In Experiment 1, noise and vibration stimuli recorded outdoors were used, and in Experiment 2, recordings made in a house near a Shinkansen railway were used. These experiments were conducted with the approval of the ethics committee of the National Institute of Technology, Ishikawa College.

2.1. Apparatus

The laboratory experiment was conducted in a simplified anechoic room (2,800 × 2,800 mm). Sound stimuli were presented through two speakers (ECLIPSE TD508MK3) placed in front of the participants at ear level. Vertical vibration was generated by a two-axis (vertical and horizontal) vibration system (San-ESu SPT2DV-9K-12L2-1T) in the room. The seat was 835 mm from the floor, and its size was 900 × 900 mm. Participants sat on the seat without a backrest or cushion.

2.2. Stimuli

Participants were exposed to adjusted sounds and vibrations recorded outdoors and indoors near the Hokuriku Shinkansen railway. The microphones for noise measurement were used with sound level meters (RION NL-32 and NL-42), and the pickups for vibration measurement were used with a vibration level meter (RION VM-53A). Data recorders (RION DA-20) were used to record the measurements. As a measurement unit for vibration, the Japanese Industrial Standard (JIS) Z 8735, “Methods of Measurement for Vibration Level,” defines “vibration level” differently from the indices provided in ISO 2631-1. The vibration level \( L_v \) (Eq. (1)) is defined as 20 times the logarithm to base 10 of the ratio of the root-mean-square vibration acceleration \( a \) to the reference acceleration \( 10^{-5} \text{ms}^{-2} \).

\[
L_v = 20 \log \left( \frac{a}{10^{-5}} \right)
\]  

Indoor recording was conducted at the center of the second floor of a typical wood-frame residential house. The time during which the noise from Shinkansen trains was louder than the background noise was approximately 20 s, so the time for one stimulus “set” was 30 s in this experiment. The sound stimuli were adjusted to reach maximum noise levels of 50, 60, and 70 dB at the ears of the participants in Experiment 1. In this work, we regarded the maximum index of the vibration level \( L_{v_{\text{max}}} \) as the vibration exposure. The vibration stimuli were presented under three conditions, no stimuli, intermediate stimuli, and large stimuli, in Experiment 1. The intermediate and large stimuli were 65 and 75 dB, respectively. These values of \( L_{v_{\text{max}}} \) were converted to maximum transient vibration values (MTVVs) of approximately 0.022 and 0.069 \([\text{ms}^2]\), respectively, in accordance with the following empirical equation reported by Shimoyama et al. [8]:

\[
10 \log \left( \frac{\text{MTVV}}{10^{-5}} \right)^2 = 1.77 + L_{v_{\text{max}}}
\]  

Nine combinations of these stimuli were made. The sound stimuli in Experiment 2 were no stimuli, 50 and 60 dB \( L_{v_{\text{max}}} \), and the vibration levels were zero, 55, 60, and 65 dB \( L_{v_{\text{max}}} \). These vibration levels corresponded to MTVVs of 0.007, 0.012, and 0.022 \([\text{ms}^2]\), respectively. Thus, 11 different combinations were used.

In the two experiments, each noise or vibration stimulus was produced from records of field measurements.
with magnitudes close to the target magnitudes described above. Figure 1 shows the spectra of the noise (a) and vibration (b) stimuli in Experiment 1. The dominant sound frequencies occurred in the bands at 63 and 80 Hz, and at approximately 2 kHz. It was confirmed that the differences in sounds near the dominant frequency were less than 3 dB at heights from 60 to 80 cm on the seat and at positions 20 cm from the center in four directions. The dominant vibration frequencies were bands at approximately 6.3 Hz and from 20 to 31.5 Hz. Figure 2 shows the spectra of the noise (c) and vibration (d) stimuli in Experiment 2. The dominant sound frequencies that occurred in Experiment 2 resemble the stimuli of Experiment 1. The sound pressure levels of noise stimuli in Experiment 2 at frequencies less than 250 Hz were greater than those in Experiment 1. This is because a woofer was introduced in Experiment 2. The dominant frequency of vibrations was at bands of approximately 50 Hz. These differed between the two experiments. The participants were randomly exposed to these nine or eleven combinations.

2.3. Design and Procedure

Ten men and ten women aged between 18 and 22 years (19.7 ± 1.2 years) participated in Experiment 1, and ten men and ten women aged between 19 and 20 years (19.5 ± 0.5 years) participated in Experiment 2. No participants took part in both experiments. All participants were diagnosed as having no hearing problems during their regular health check.

Before the start of the experiment, which continued for approximately 30 min, the experiments were described to the participants, and then the participants were instructed to sit on the seat in a comfortable upright posture. All nine possible paired combinations of three levels of noise and three levels of vibrations in Experiment 1 were presented in random order to each participant after practice. Eleven paired combinations of two levels of noise and three levels of vibrations (not including the absence of stimuli) were used in Experiment 2. During the experiments, the participants performed the activity tasks of reading magazines and calculations (multiplication of two digit numbers). After one session, the participants answered three questions regarding noise, vibration, and activity disturbance. Table 1 shows the questions and evaluation scales. These evaluation scales were based on a five-point verbal scale for noise annoyance [9].

3. RESULTS AND DISCUSSION

3.1. Experiment 1

We used two-way ANOVA to analyze the two main
effects of noise and vibration, and the effect of the interaction between noise and vibration stimuli. Tukey’s test for multiple comparisons was used to determine the significant difference during the noise or the vibration stimuli. SPSS Statistics 25 was used for these analyses.

Table 2 shows the results of two-way ANOVA for the reading tasks in Experiment 1. The interactive effect between noise and vibration stimuli was not significant in any of evaluations. It was shown that the conditions of noise and vibration had only significant effects on the noisiness and the perception of vibration, respectively. The main effects of both noise and vibration stimuli significantly influenced the reading tasks. Table 3 shows the results of multiple comparisons, and Fig. 3 shows the average values of the disturbance evaluation during the reading tasks. There was a significant difference in the reading disturbance between the noise stimulus of 70 dB and other stimuli at the significance level of 1%. Significantly more responses of high levels of disturbance were given for vibration stimuli at 75 dB than for the other vibration stimuli at the significance level of 1%.

Table 4 shows the results of two-way ANOVA for the calculation tasks in Experiment 1. The interactive effect between noise and vibration stimuli was not significant. It was shown that the conditions of noise and vibration had only significant effects on the noisiness and the perception of vibration, respectively. Two main effects, noise and vibration, were significantly effective for calculating disturbance. Table 5 shows the results of multiple comparisons, and Fig. 4 shows the average values of the disturbance evaluation during the calculation tasks. There was a significant difference between 50 dB and other noise stimuli, in addition, as well as 60 and 70 dB noise stimuli. The disturbance reported for the 75 dB vibration stimulus...
was significantly greater than for other vibration stimuli (zero and 65 dB vibration stimuli).

3.2. Experiment 2

Table 6 shows the results of two-way ANOVA for the reading tasks in Experiment 2. The interactive effect between noise and vibration stimuli was not significant in any of the evaluations. It was shown that the conditions of noise and vibration had significant effects on the noisiness and the perception of vibration, respectively. Only the noise stimuli affected the reading disturbance at the significance level of 1%. Table 7 shows the results of multiple comparisons, and Fig. 5 shows the results of the evaluation during the reading tasks in Experiment 2. For the reading disturbance, a significant difference was found between no stimuli and 60 dB noise stimuli at the significance level of 1%. There were no significant differences in the other noise stimuli and all vibration stimuli.

Table 8 shows the results of two-way ANOVA for the calculation tasks in Experiment 2. The interactive effect between noise and vibration stimuli was not significant in any of the evaluations. It was shown that the conditions of noise and vibration had significant effects on the noisiness and the perception of vibration, respectively. The main effects of both noise and vibration stimuli significantly influenced the calculation tasks at the significance levels of 1%, and 5%, respectively. Table 9 shows the results of multiple comparisons, and Fig. 6 shows the results of the

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**Table 6** Significance of main and interactive effects for reading tasks in Experiment 2.

| Source     | Noisiness | Perception of vibration | Disturbance of reading task |
|------------|-----------|-------------------------|----------------------------|
| Noise      | 0.000     | 0.286                   | 0.001                      |
| Vibration  | 0.884     | 0.000                   | 0.164                      |
| Noise × Vibration | 0.672     | 0.925                   | 0.884                      |

**Table 7** Results of multiple comparisons for reading disturbance in Experiment 2.

| Noise stimuli | Mean Difference | Std. Error | Sig.    |
|---------------|-----------------|------------|---------|
| No stimuli−50 | 0.22            | 0.137      | 0.238   |
| No stimuli−60 | 0.48            | 0.137      | 0.001   |
| 50−60         | 0.26            | 0.127      | 0.099   |

| Vibration stimuli | Mean Difference | Std. Error | Sig.    |
|-------------------|-----------------|------------|---------|
| zero−55           | 0.10            | 0.164      | 0.922   |
| zero−60           | 0.04            | 0.164      | 0.995   |
| zero−65           | 0.18            | 0.164      | 0.680   |
| 55−60             | 0.06            | 0.146      | 0.973   |
| 55−65             | 0.29            | 0.146      | 0.210   |
| 60−65             | 0.22            | 0.146      | 0.428   |

**Table 8** Significance of main and interactive effects for calculation tasks in Experiment 2.

| Source     | Noisiness | Perception of vibration | Disturbance of calculation task |
|------------|-----------|-------------------------|---------------------------------|
| Noise      | 0.000     | 0.466                   | 0.002                           |
| Vibration  | 0.091     | 0.000                   | 0.034                           |
| Noise × Vibration | 0.118     | 0.611                   | 0.668                           |

**Table 9** Results of multiple comparisons for calculating disturbance in Experiment 2.

| Noise stimuli | Mean Difference | Std. Error | Sig.    |
|---------------|-----------------|------------|---------|
| No stimuli−50 | 0.16            | 0.131      | 0.428   |
| No stimuli−60 | 0.46            | 0.131      | 0.001   |
| 50−60         | 0.30            | 0.121      | 0.039   |

| Vibration stimuli | Mean Difference | Std. Error | Sig.    |
|-------------------|-----------------|------------|---------|
| zero−55           | 0.25            | 0.156      | 0.366   |
| zero−60           | 0.21            | 0.156      | 0.550   |
| zero−65           | 0.13            | 0.156      | 0.848   |
| 55−60             | 0.05            | 0.140      | 0.986   |
| 55−65             | 0.38            | 0.140      | 0.035   |
| 60−65             | 0.33            | 0.140      | 0.083   |
evaluation during the calculation tasks in Experiment 2. There were significant differences in the disturbances of the calculation tasks between 60 dB and the other noise stimuli. For the vibration stimuli, the disturbance with the 65 dB vibration stimulus was significantly greater than that with 55 dB at the significance level of 5%.

3.3. Discussion

We examined the effects of simultaneous exposure to noise and vibration on the noisiness, the perception of vibration, and disturbance of reading and calculation tasks. The interactive effects between noise and vibration stimuli in all the evaluations were not significant in either Experiment 1 or 2. The noisiness was affected by the noise stimuli but not the vibration stimuli. On the other hand, the perception of vibration was affected by the vibration stimuli but not the noise stimuli. The disturbance of the calculation tasks was affected by both noise and vibration stimuli, that is, a combined effect was observed in these experiments. In other words, an increase in noise causes a greater disturbance of the calculation tasks, and moreover, an additional increase in vibration causes an even greater disturbance. However, the disturbance of the reading tasks was not statistically affected by the changes in vibration stimuli in the range between 55 and 65 dB in Experiment 2, whereas significant differences were found in the disturbance of reading between 75 dB and other vibration stimuli in Experiment 1. Only in the calculation tasks was a significant difference found between 50 and 60 dB for noise stimuli and between 55 and 65 dB for vibration stimuli. It can be considered that the calculation task was more susceptible to noise and vibration stimuli than the reading task because of the high load involved in visualizing, thinking, and moving the hands.

In Experiments 1 and 2, the participants who were exposed to the same noise and vibration stimuli had similar disturbance of reading ratings, but the evaluation of the disturbance of calculation was slightly higher in Experiment 2 than in Experiment 1. The difference in the frequency characteristics of noise and vibration stimuli may have influenced the evaluation of the disturbance of calculation, but it was not clear which was affected in this study.

Lee and Griffin [7] evaluated annoyance caused by noise and vibration through a laboratory experiment. To compare the results of social surveys and laboratory experiments, it is necessary to conduct subjective evaluation experiments, including the evaluation of annoyance, in an environment closer to an actual living environment. Further research must be consideration the effect of the number (of events) of noise and vibration stimuli, as well as the effects of both vertical and horizontal vibrations (simultaneously). We evaluated relatively young participants; however, if participants were older, the task load would be different, and their evaluations of noise and vibration might differ.

4. CONCLUSIONS

Through two-way ANOVA, we revealed that the combined effects of noise and vibration were significant for daily activity disturbances. That is, to evaluate the effects of noise and vibration from the Shinkansen railway in an actual living environment, it is necessary to consider the effects of both noise and vibration in terms of a quantitative relationship between noise and vibration effects. However, under a vibration stimulus of 65 dB, the influence of the vibration was not significant for the disturbance of reading.

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