Combined effects of low frequency vertical vibration and noise on whole-body vibration sensation

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ABSTRACT

The operators of vehicles and construction work machines experience a variety of vibration and noise stimulation from the surrounding environment. It has been reported that vibration and sound stimuli, such as vibration music therapy and background music, have the psychological and physiological effects of mitigating tiredness and tension. The purpose of this study is to determine the effect of musical sound and noise on whole-body vibration sensation such as changes in sensation strength or uncomfortable sensation of vibrations. We studied low frequency vertical vibration generated in vibration environments including vehicles. We hypothesized that uncomfortable sensation of vibration could be reduced by adding sound to the vibration environment and comforting musical sounds to the sound stimulation. The vibration sensation when the subjects were simultaneously exposed to vibration and sound stimulation was measured by using a psychological method. From the experimental results, it was found that the vibration sensation strength has a maximum at a vibration frequency of 8 Hz. Also, the tendency of the vibration sensation to increase and decrease in response to the uncomfortable sensation of vibration was different with musical sound and noise.

Keywords: Whole-body vibration sensation, Sound stimuli, Vibrational environment, Vibration acceleration level, Psychological response

1. INTRODUCTION

We experience a variety of vibration stimulations in everyday environments. In previous research on the effect of whole-body vibration on the human body, the psychological responses when the human body was exposed to sinusoidal vibration in the vertical or horizontal direction have been investigated (1-4). Humans are generally exposed to both vibration and noise, which are generated simultaneously, when travelling in vehicles such as automobiles and trains. Therefore, an evaluation of the vibration sensation based on the combined effect of vibration and noise is needed.

There have been studies using a psychological method for the combined effect of noise and vibration (5, 6). In a study by Howarth and Griffin (7), the noise and vibration in buildings caused by nearby railways were reproduced in the laboratory, and the evaluation experiment was conducted with twenty-four subjects. As a result, it was shown that when railway noise and railway-induced building vibration occur together, the overall annoyance depends on the magnitudes of both stimuli. Huang et al. (8) exposed the subject to noise and vibration in the vertical direction, which were recorded inside a car, and evaluated the judegments of discomfort caused by the noise and the vibration by using the magnitude estimation method. It was shown that the judgement of vibration is more affected by noise than the judgement of noise is affected by vibration.

The objective of this study is to determine the effect of sound stimulation on whole-body vibration sensation by simultaneously exposing subjects to vibration and sound stimulation. The effect of sinusoidal vibration in the vertical direction from vehicles on the human body was examined through psychological measurement. The vibration and sound stimuli that we experience daily provide both uncomfortable and comfortable sensations. Moreover, vibration and sound stimuli, such as vibration music therapy and back-ground music, show that there is a psychological and physiological effect of mitigating tiredness and tension (9). For this research, we assumed that the uncomfortable sensation of vibration could be reduced by adding sound to a vibration environment

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and comforting musical sound to the sound stimuli. We describe the relationships between the vibration sensation and the physical quantity of vibration, the musical sound and noise stimuli respectively.

2. DESCRIPTION OF EXPERIMENTAL METHOD

2.1 Apparatus and Subjects

The evaluated vibration was the vertical whole-body vibration intended for simulating a vehicle's low frequency vibration. Vertical whole-body vibration was generated using an electrodynamics vibration table. A subject sat on a legless chair fixed to the vibration table, and the subjects were exposed to whole-body vibration in the vertical (Z-axis) direction at the hip. The noise stimuli were applied to both ears through headphones. When the subjects were not exposed to the noise, the effect of background noise was reduced by using earmuffs. Fifteen healthy university students with normal hearing participated in our experiment. The subjects were 15 men aged 21.3±0.7 years with a body weight of 56.3±8.5 kg.

2.2 Vibration and Noise Stimuli Conditions

Table 1 lists the vibration stimuli conditions. The kind of vibration used in this experiment was sinusoidal as shown in Figure 1. Ten vibration stimuli conditions were created by combining four different frequencies and three vibration acceleration levels (VAL). Figure 1 shows the sinusoidal vibration waveforms, which are acceleration waveforms obtained from the servo acceleration detector installed in the vibration table.

The noise stimuli conditions used in this study are listed in Table 2. The average cycle was the mean value of the fluctuation count at the noise level per second, and this was calculated by the zero-crossing method. The noise stimuli categories were white noise (WN) containing no discernible meaning and musical sounds from “Carmen Prelude to Act 1” and “Air on the G strings” as shown in Figure 2. The white noise was a steady noise and a fluctuating noise that changes an average cycle. Fifteen noise stimuli conditions were created by combining five different noise stimuli with three equivalent sound levels (L_{Aeq}).

Table 1 – Vibration stimuli conditions

Frequency, Hz	Vibration acceleration level (VAL)*, dB
2	90, 100
4	80, 90, 100
8	80, 90, 100
16	90, 100

*Reference 10^{-6} m/s^2

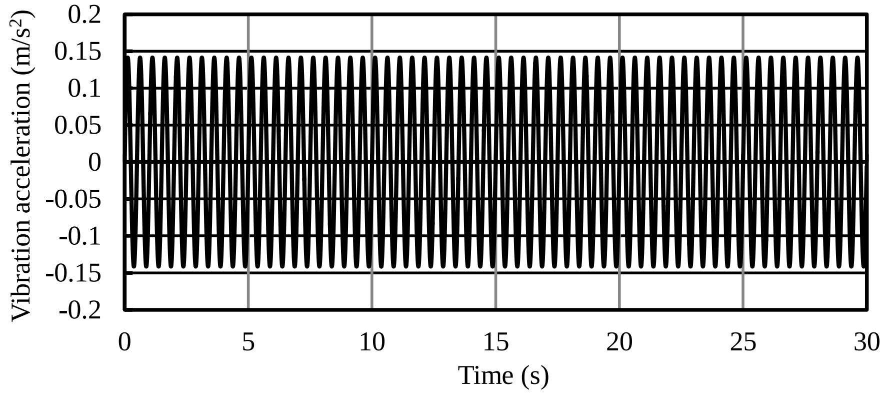


Figure 1 – Example vibration waveform (2 Hz sinusoidal vibration)

Table 2 – Noise stimuli conditions

Noise stimuli category	Average cycle, s	Equation sound level ($L_{Aeq, T=30s}$), dB
Music A*	1.3	
Music B**	0.5	
White noise (WN)	-	50, 60, 70
Fluctuating white noise A (FWN-A)	1.5	
Fluctuating white noise B (FWN-B)	0.5	

* "Air on the G strings"
** "Carmen Prelude to Act 1"

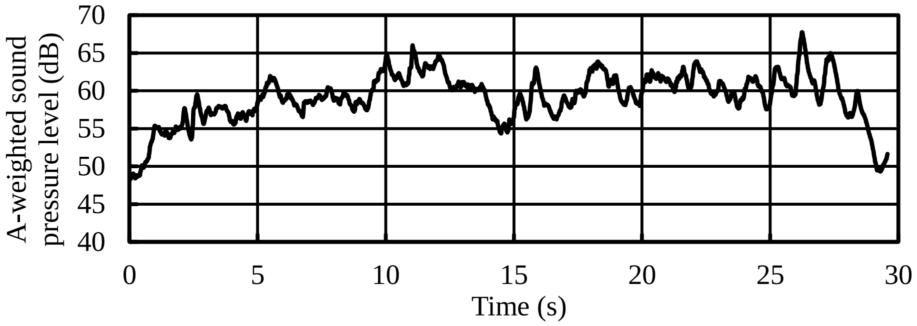


Figure 2 – Example noise waveform (Music A: "Air on the G strings")

2.3 Measurement method of Psychological Response

The vibration sensation measured by this study is the sensation strength and the uncomfortable sensation of the vibration. The method used for measuring the sensation strength of the vibration was Stevens' magnitude estimation (the ME method). The subjects estimated how strong the vibration stimulation was on a scale of 1 to 100; "1" is minimum, and "100" is maximum. The uncomfortable sensation of the vibration was measured in terms of a seven-point Likert scale when the subjects were exposed to vibration and noise.

2.4 Experimental Procedure

The experimental timing chart is shown in Figure 3. The experimental duration of one set was 120 seconds. The exposure time of simultaneous vibration and noise stimulation was 30 seconds, and the time for answering the questionnaire was set to 90 seconds. The number of experimental sets for one subject was 150 comprising the 10 types of vibration stimuli listed in Table 1 and the 15 types of noise stimuli listed in Table 2. To lessen the burden on the subjects, the experiment time duration of one test was set to one hour (30 sets of 120 seconds equals 3600 seconds). That is, each subject took the experiment five times in one hour (30 sets). Each subject was exposed to the stimuli under randomly assigned experimental conditions.

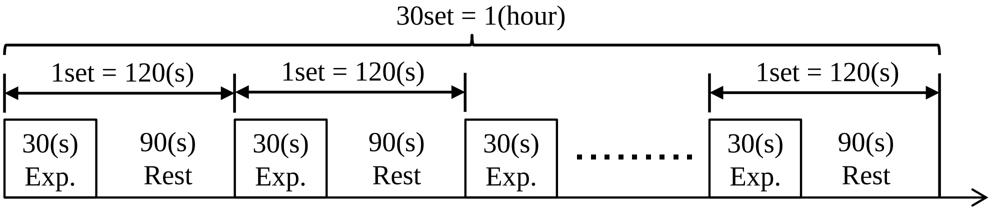


Figure 3 – Experimental timing chart

3. RESULTS AND DISCUSSIONS

3.1 Effect of Noise on Vibration Sensation Strength

Figure 4 shows the relationship between vibration sensation strength and vibration frequency obtained using the ME method. The vibration sensation strength in Figure 4 is the arithmetic mean value. As shown in this figure, the vibration sensation strength has a maximum at a vibration frequency of 8 Hz. Moreover, by comparing the vibration sensation strength under the vibration alone condition and that under the noise to the vibration stimuli conditions, we found that there was no difference in the vibration sensation strength.

Figure 5 is a graphical representation of the relationship between vibration sensation strength and vibration acceleration level. The vibration sensation strength increased with increasing vibration acceleration level. As shown in Figure 5(a) and (b), a similar tendency was shown when the vibration frequency was changed.

Figure 6 shows the relationship between vibration sensation strength when the equation sound level was changed and the vibration acceleration level. From this result, the equation sound level has been found to have little effect on the vibration sensation strength.

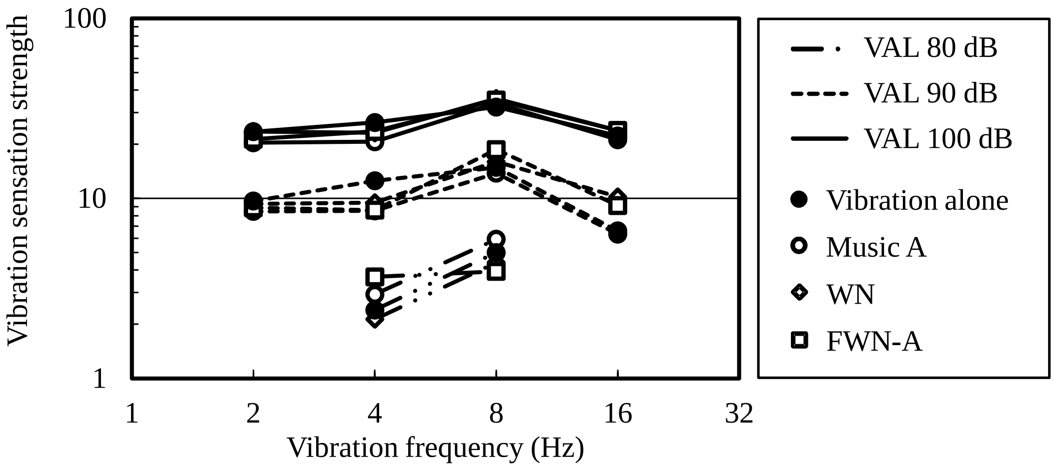
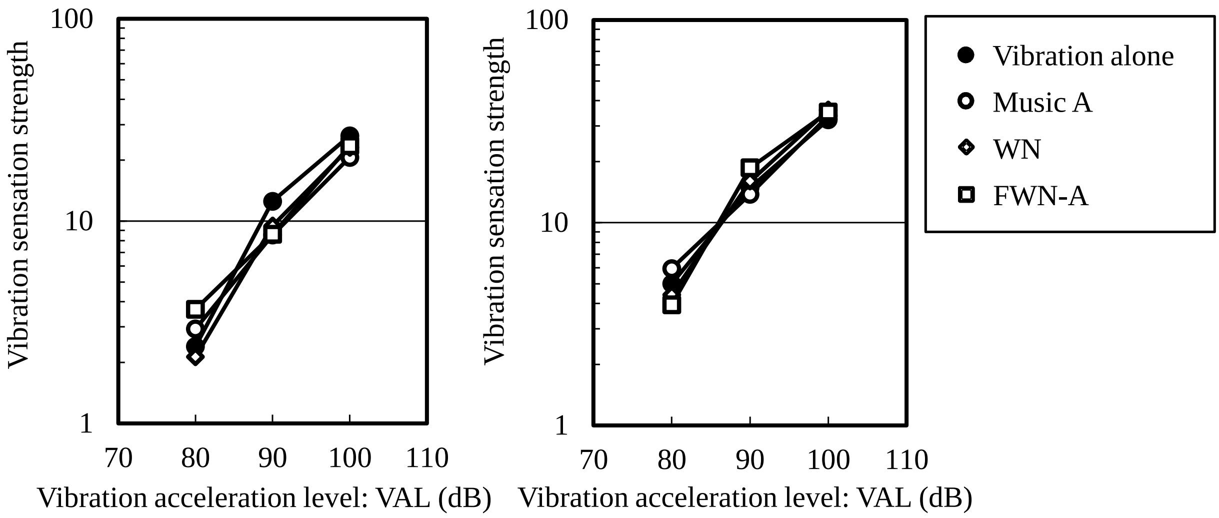


Figure 4 – Relationship between vibration sensation strength and vibration frequency (L_{Aeq} 60 dB)



(a) Vibration frequency of 4 Hz (b) Vibration frequency of 8 Hz

Figure 5 – Relationship between vibration sensation strength and vibration acceleration level (L_{Aeq} 60 dB)

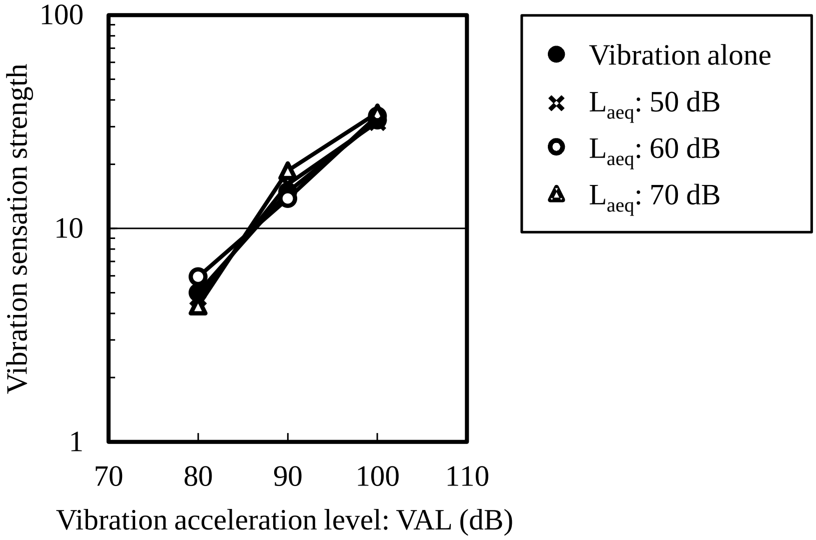


Figure 6 – Relationships between vibration sensation strength and vibration acceleration level, equation sound level respectively (Vibration frequency of 8 Hz, Music A)

3.2 Effect of Noise on Uncomfortable Sensation of Vibration

Figure 7 shows the relationship between uncomfortable sensation of vibration and vibration frequency. As shown in this figure, the uncomfortable sensation of vibration was almost constant for all measured vibration frequency conditions when the subjects were exposed to vibration and noise stimuli at the same time.

Figure 8 shows the relationship between uncomfortable sensation of vibration and vibration acceleration level. It was found that the uncomfortable sensation of vibration increased with increasing vibration acceleration level. Moreover, the decrease in the uncomfortable sensation with music A was larger than that with the vibration alone condition and other noise stimuli (WN, FWN-A, and FWN-B). By comparing the results of music A and B, there was no difference in the uncomfortable sensation of vibration in the average cycle.

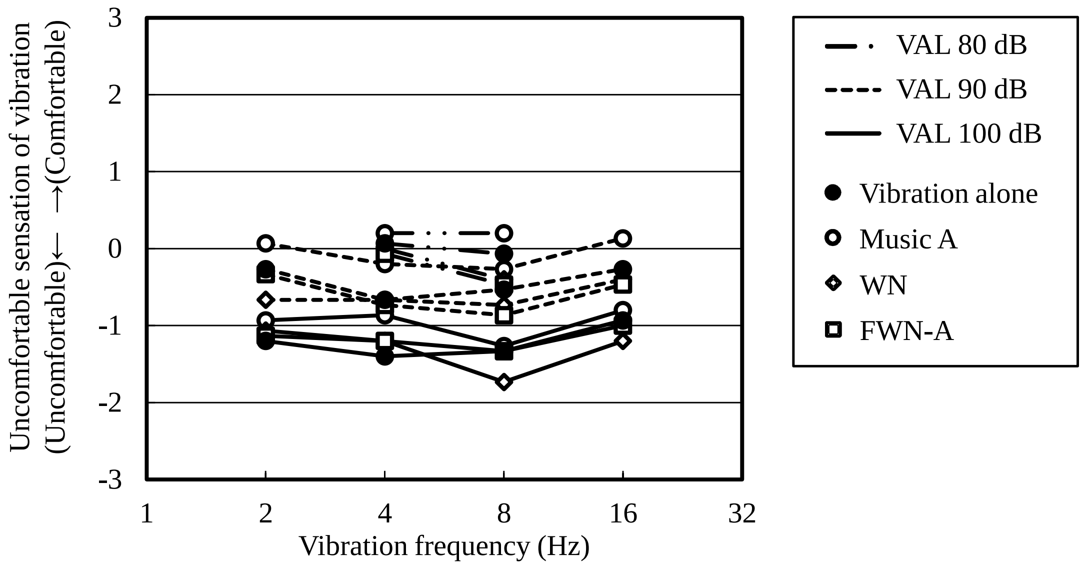
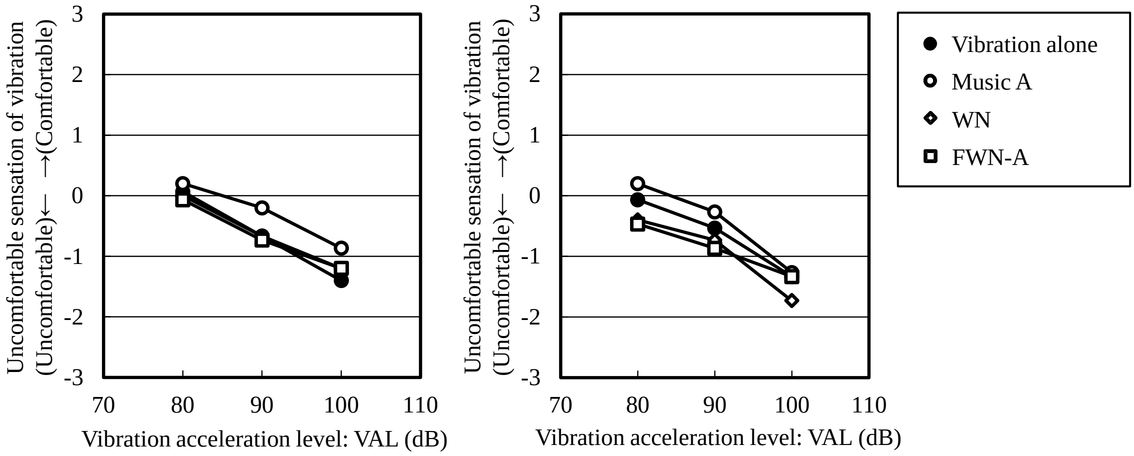


Figure 7 – Relationship between uncomfortable sensation of vibration and vibration frequency



(a) Vibration frequency of 4 Hz (b) Vibration frequency of 8 Hz

Figure 8 – Relationship between uncomfortable sensation of vibration and vibration acceleration level (L_{Aeq} 60 dB)

4. CONCLUSION

In this research, we experimentally examined the effect of the noise stimuli on the vibration sensation. The conclusions are summarized as follows:

(1) The vibration sensation strength has a maximum at a vibration frequency of 8 Hz, and that increased with increasing vibration acceleration level. The noise stimuli conditions (category, average cycle and equation sound level) have been found to have little effect on the vibration sensation strength in the range of the measured vibration frequency.

(2) The uncomfortable sensation of vibration in the same vibration acceleration level with the same condition was almost constant for all measured vibration frequency conditions. The decrease in the uncomfortable sensation by music tended to be larger than that of the other noise stimuli conditions. It was thought that the uncomfortable sensation of vibration decreased when the subject was exposed to vibration and music compared to being exposed to vibration alone.

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