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ORIGINAL ARTICLE

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Physiological and psychological responses to a heavy floor-impact sound generated by dropping an automobile tire in a wooden house

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Abstract We investigated the physiological and psychological responses of ten healthy male volunteers to a single heavy floor-impact sound generated by dropping an automobile tire from heights of 50, 100, and 150 cm in a wooden house. Blood pressure and peripheral blood flow were measured simultaneously, and sensory evaluation was conducted using the semantic differential method. The results obtained were as follows: (1) the systolic blood pressure increased and the peripheral blood flow decreased when the subjects heard the heavy floor-impact sound; (2) the heavy floor-impact sound caused the subjects to feel uncomfortable, but there was no significant change in "sharp" and "monotonous" feelings; and (3) for the heavy floor-impact sound for 100 cm and that for 150 cm, the subjects showed no difference in "comfortable" feeling, but we detected differences in the variations of both the systolic blood pressure and the peripheral blood flow.

Key words Heavy floor-impact sound · Physiological response · Psychological response · Wooden house

Introduction

Sound insulating performance is one of the most important factors in terms of comfort in a dwelling environment. The insulation of floor-impact sounds has particular importance for dwelling comfort in a wooden building, which is usually lighter in weight and lower in stiffness than other buildings like a reinforced concrete building.

There are two kinds of impact sources for testing the floor-impact sound insulation of buildings defined by Japanese Industrial Standard, JIS A 1418-1, 1418-2: 2000. One is a light and hard impact source, which is the tapping machine specified in ISO 140-7, and the other is a heavy and soft one, which is an automobile tire.

We have investigated the sound insulating performance of a wooden house by measuring physiological and psychological responses to light floor-impact sounds generated by the tapping machine,[1–6] and heavy floor-impact sounds generated by dropping an automobile tire.[6–9]

In this study, we adopted the techniques of physiological measurements that have been recently improved,[10–12] and measured autonomic nervous activities in response to a single heavy floor-impact sound generated by dropping an automobile tire. We also conducted sensory evaluation using the semantic differential (SD) method. Comparing the physiological responses and the sensory evaluation, we discuss the possibility of evaluating the floor-impact sound insulating performance of a wooden house by using physiological indexes.

Experimental

Subjects and stimuli

Ten healthy male volunteers of 24–29 years of age participated in the physiological and psychological experiments as subjects. These experiments were conducted in a Japanese-style room in an experimental two-story wooden house. The downstairs room was kept at 25°C, 60% relative humidity, and 10 lx during the physiological measurements by turning the room light off. After that, the room light was turned on for the sensory evaluation.

Sitting on a chair at the center of the downstairs room, each subject was exposed to the single heavy floor-impact sound that was generated on the upstairs floor by using the automobile tire specified in JIS A 1418-2: 2000. Each subject underwent the same tests with different levels of the

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heavy floor-impact sound after his blood pressure and peripheral blood flow returned to the normal level. The heights from which the automobile tire was dropped were 50, 100, and 150 cm, and the maximum sound pressure levels of all passes were 88, 91, and 93 dBC (C-weighted sound pressure level), respectively. No impact sound was generated in the control test. The control test and the heavy floor-impact sound tests from 50, 100, and 150 cm were randomly conducted.

Physiological measurement

Blood pressure was measured on the left middle finger (Finapres, Ohmeda, Model 2300).[13] Peripheral blood flow was simultaneously measured on the left index finger (Omegaflow, Neuroscience, FLO-C1).[14,15] These physiological responses were measured in a quiet condition for 30 s before exposure to the single heavy floor-impact sound generated by dropping the automobile tire and for 60 s after exposure to the heavy floor-impact sound.

Student's *t*-test was used to examine the average difference of physiological responses between the average over the 10 s immediately before exposure to the heavy floor-impact sound and each value measured every 1 s after exposure.

Sensory evaluation

After the physiological measurements, sensory evaluation tests for the single heavy floor-impact sound were conducted using the SD method. The following 21 adjective pairs were provided to describe the heavy floor-impact sounds: "safe–dangerous," "stable–unstable," "tender–violent," "weak–strong," "small–large," "loose–tight," "gentle–active," "comfortable–uncomfortable," "busy–relaxed," "unclear–clear," "slow–fast," "fine–rough," "dull–sharp," "light–heavy," "soft–hard," "calm–noisy," "monotonous–varied," "regular–irregular," "unimpressive–impressive," "drowsy–alert," and "agreeable–disagreeable." These pairs were determined by modifying the adjective pairs used for the sensory evaluation of vibration during operation of a yarder[16] and adding the drowsy–alert pair. We have already applied these adjective pairs to the sensory evaluation of light floor-impact sounds and have confirmed their validity.[1] Each pair scored from one to seven on a seven-step scale, and elementary factors were determined by factor analysis using the principal factor method and the rotation varimax method.

Results and discussion

Physiological responses

As shown in Fig. 1, the systolic blood pressure instantly increased after exposure to the single heavy floor-impact sound generated by dropping the automobile tire from heights of 50, 100, and 150 cm. After reaching the maximum in every case, the systolic blood pressure returned to the normal level in 20 s. After that, the systolic blood pressure for the 50-cm and 100-cm tests leveled off, whereas that for 150-cm test significantly increased by about 5% and did not return to the normal level within 60 s.

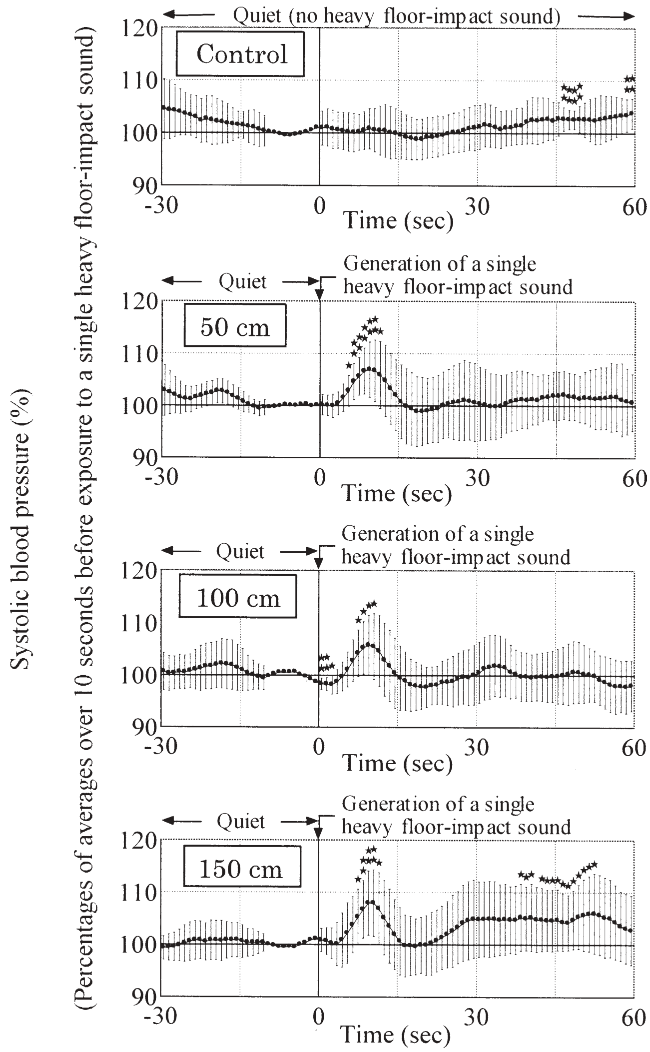

Fig. 1. Variation of systolic blood pressure as a function of time. *Error bars* indicate standard deviation. Student's *t*-test is used. Significant differences from the averages of readings over 10 s before exposure to a single heavy floor-impact sound are shown by *double stars* ($P < 0.01$) and *single stars* ($P < 0.05$)

Figure 2 shows the change in the peripheral blood flow as a function of time. The peripheral blood flow decreased concomitantly like mirror images of systolic blood pressure ($P < 0.01$). Those for tests at 50, 100, and 150 cm similarly decreased immediately after exposure to the heavy floor-impact sound and reached the minimum in 10 s. After that, the peripheral blood flow for the 50-cm test took about 15 s and that for the 100-cm test took about 40 s to return to the normal level, while that for the 150-cm test varied significantly ($P < 0.05$) for about 50 s after exposure to the heavy floor-impact sound.

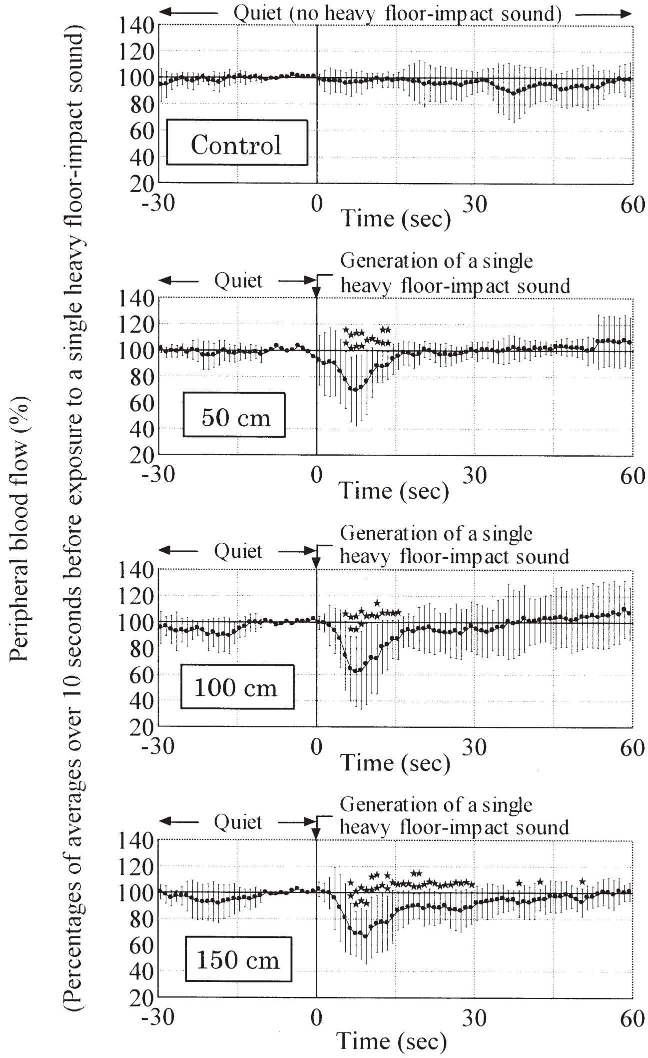

Fig. 2. Variation of peripheral blood flow as a function of time. *Error bars* indicate standard deviation. Student's *t*-test is used. Significant differences from the averages of readings over 10 s before exposure to a single heavy floor-impact sound are shown by *double stars* ($P < 0.01$) and *single stars* ($P < 0.05$)

These physiological responses can be observed as a typical stress reaction that is known as the "fight or flight reaction." This means that when a situation is perceived as dangerous, the muscles need more oxygen, to either fight or run away. Therefore, the arterial blood pressure increases in order to supply more blood to the muscles. To enable this to be done quickly, the blood vessels in the relevant areas dilate to let the blood in, resulting in the heart beating faster to pump it through. Blood vessels to the skin are constricted, reducing any potential blood loss.

Sensory evaluation

Scores obtained by all of the subjects are shown in Table 1. Three factors in which an eigenvalue exceeded one were extracted. Cumulative contributions for the three factors reached 84.6%. The first factor can be interpreted as a "comfortable feeling" because the scores for small–large, weak–strong, tender–violent, safe–dangerous, calm–noisy, comfortable–uncomfortable, light–heavy, agreeable–disagreeable, gentle–active, unimpressive–impressive, loose–tight, busy–relaxed, drowsy–alert, stable–unstable, fine–rough, soft–hard, and unclear–clear are relatively large. The second factor shows large scores for dull–sharp and slow–fast, so it can be interpreted as a "sharp feeling." The third factor can be interpreted as a "monotonous feeling" because the adjective pairs of regular–irregular and monotonous–varied have large scores.

Figure 3 shows the factor scores of heavy floor-impact sound tests extracted by factor analysis. For the first factor, scores for the 50-cm, 100-cm, and 150-cm tests were significantly different from the score of the control test, but not significantly different from each other. The scores of the second factor shifted from minus to plus with increasing height of the test, but there was no significant difference among the scores. There was also no significant difference in the third factor. These results indicated that the subjects felt "uncomfortable" on hearing the heavy floor-impact

Table 1. Construction of factors

	Factor I	Factor II	Factor III	Interpretation
Small–large	0.951	0.181	0.142	Comfortable feeling
Weak–strong	0.936	0.210	0.185	
Tender–violent	0.926	0.218	0.168	
Safe–dangerous	0.924	0.178	0.191	
Calm–noisy	0.916	0.173	0.260	
Comfortable–uncomfortable	0.911	0.151	0.260	
Light–heavy	0.897	0.150	0.215	
Agreeable–disagreeable	0.871	0.122	0.340	
Gentle–active	0.857	0.293	0.291	
Unimpressive–impressive	0.853	0.285	0.197	
Loose–tight	0.853	0.362	0.241	
Busy–relaxed	−0.845	−0.120	−0.093	
Drowsy–alert	0.776	0.044	0.211	
Stable–unstable	0.729	0.253	0.383	
Fine–rough	0.713	0.309	0.207	
Soft–hard	0.696	0.562	0.071	
Unclear–clear	0.567	0.565	0.371	
Dull–sharp	−0.041	0.893	0.108	Sharp feeling
Slow–fast	0.479	0.731	0.171	
Regular–irregular	0.158	0.142	0.921	Monotonous feeling
Monotonous–varied	0.356	0.163	0.838	
Eigenvalue	12.5	2.7	2.6	
Contribution (%)	59.3	13.0	12.3	

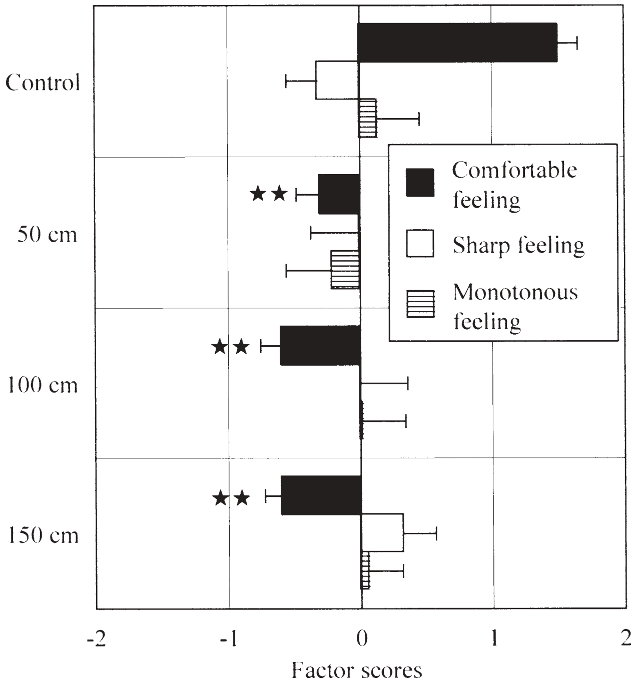

Fig. 3. Scores of three factors extracted in factor analysis by exposure to a single heavy floor-impact sound. *Horizontal bars* are standard errors. Wilcoxon signed rank sum tests are used. Significant differences from control values are shown by *double stars* ($P < 0.01$)

sound for the 50-cm, 100-cm, and 150-cm tests and seemed to feel "sharp" when hearing the heavy floor-impact sound for the 150-cm test.

Conclusion

The sensory evaluation indicated that the subjects felt uncomfortable when they heard the heavy floor-impact sound for the 50-cm, 100-cm, and 150-cm tests, and that there was no significant difference in the uncomfortable feeling among these heavy floor-impact sounds. The physiological responses, however, showed a difference between the heavy floor-impact sounds for the 50-cm and 100-cm tests, and that for the 150-cm test. Therefore, we suggest that physiological indexes may be used to evaluate the performance of the floor-impact sound insulation of a wooden house.

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