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ORIGINAL ARTICLE

Shuzo Sueyoshi · Yoshifumi Miyazaki · Takeshi Morikawa

Physiological and psychological responses to prolonged light floor-impact sounds generated by a tapping machine in a wooden house

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Abstract We investigated the physiological and psychological responses of nine normal men to the prolonged light floor-impact sounds of 60dBA and 80dBA generated by a tapping machine in a two-story wooden house. Blood pressure was measured, and a sensory evaluation was also conducted using the semantic differential method. The results obtained were as follows: (1) the increase in systolic blood pressure immediately after exposure to the light floor-impact sounds depended on the level of the sounds, (2) the variations in feelings due to the prolonged light floor-impact sounds were identified by factor analysis, and (3) the subjects showed no difference in "comfortable" feeling for the prolonged light floor-impact sounds of 60dBA and 80dBA, but differences in the variation of the systolic blood pressure were detected.

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

Introduction

It is important to consider sound-insulating performance in order to improve comfort in a dwelling environment. In particular, the insulation of floor-impact sounds affects the dwelling comfort in wooden buildings which are usually lighter and less rigid than other buildings such as reinforced concrete buildings.

There are two kinds of impact sources for testing the floor-impact sound insulation of buildings defined by Japanese Industrial Standard, JIS A 1418: 2000. One is a light and hard impact source, that is, the tapping machine specified in ISO 140/7, and the other is a heavy and soft one, that 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,[1,2] and heavy floor-impact sounds generated by dropping an automobile tire.[3–6]

We have also examined the physiological and psychological effects of prolonged light floor-impact sounds generated by the tapping machine on humans.[5,7–9] In this study, variations in systolic blood pressure due to the prolonged light floor-impact sounds generated by the tapping machine were measured, and a sensory evaluation was also conducted 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 using physiological indexes.

Experimental

Subjects and stimuli

Nine normal men 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 maintained at 10°–15°C, 40%–60% relative humidity and about 150lx. Sitting on a chair at the center of the downstairs room, each subject was exposed to the prolonged light floor-impact sounds that were generated on the upstairs floor by using the tapping machine for 5min. Each subject underwent the same tests with different levels of the prolonged light floor-impact sound after his blood pressure had returned to the normal level. No impact sound was generated in the control test. The average background noise level was 47dBA (A-weighted sound pressure level). Including the control test, two floor-impact sound

S. Sueyoshi (✉) · Y. Miyazaki · T. Morikawa
Forestry and Forest Products Research Institute, P.O. Box 16, Tsukuba Norin Kenkyu Danchi-nai, Ibaraki 305-8687, Japan
Tel. +81-29-873-3211 (ext. 587); Fax +81-29-874-3720
e-mail: sue@ffpri.affrc.go.jp

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levels of 60 dBA and 80 dBA were generated randomly for each subject. The reasons for selecting these sound levels were as follows: 60 dBA was the minimum level at which significant changes in some physiological responses occurred,[1] while 80 dBA was the maximum level of the light floor-impact sound generated by the tapping machine in the wooden house where this experiment was conducted.

Physiological measurement

Blood pressure, which was monitored on the left middle finger (Finapres, Ohmeda, Model 2300),[10] was measured in a quiet condition for 2 min before exposure to the prolonged light floor-impact sounds generated by the tapping machine and during radiation of the sounds for 5 min.

The Student's *t*-test was used to examine the average difference of physiological responses between the average value measured for 1 min just before exposure to the prolonged light floor-impact sounds and that measured for each 1-min period during exposure to the sounds.

Sensory evaluation

After physiological measurements, sensory evaluation was conducted using the SD method while the subjects were exposed to the light floor-impact sounds. For the SD method, the following 21 adjective pairs were provided to describe the prolonged light 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[11] and adding the pair "drowsy–alert." We have already applied these adjective pairs for the sensory evaluation of light floor-impact sounds and have confirmed their validity.[1] Each pair was expressed numerically by scoring 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, systolic blood pressure increased significantly ($P < 0.05$) immediately after exposure to the light floor-impact sounds, and the initial increase of the systolic blood pressure for 80 dBA was larger than that for 60 dBA. This means that the light floor-impact sound instantly affected the autonomic nervous system of the subjects.

The systolic blood pressure for 60 dBA gradually increased after the initial rise and showed significant changes over the periods of 0–1 min, 3–4 min, and 4–5 min. On the other hand, the systolic blood pressure for 80 dBA, which appeared to level off or decrease slightly after the initial rise, showed significant changes over the periods of 0–1 min, 1–2 min, 2–3 min, and 3–4 min, but it showed no significant change over 4–5 min. Accordingly, we detected an opposite trend of the time-series changes in the systolic blood pressure for 60 dBA and that for 80 dBA. These time-series changes could not be observed in our previously reported study[1] in which we measured the physiological responses for 1 min.

The diastolic blood pressure did not show significant differences among the control and other tests. For pulse rates, there were also no significant changes through all tests.

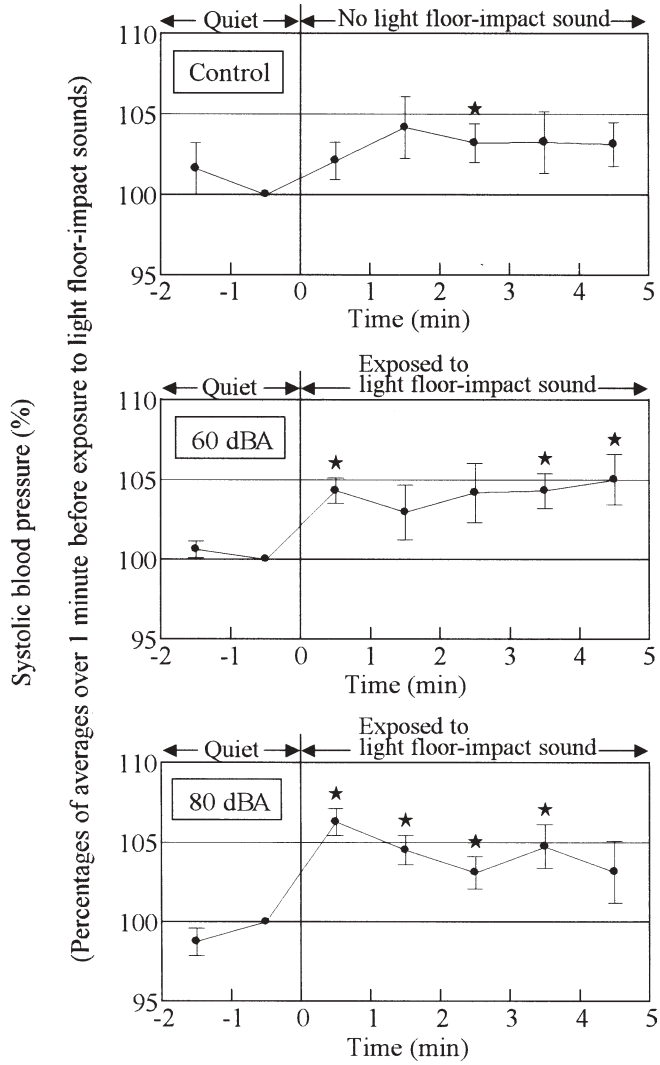

Fig. 1. Variation of systolic blood pressure as a function of time. Error bars indicate standard error. Student's *t*-test is used. Significant differences from averages over 1 minute before exposure to light floor-impact sounds are shown by *stars* ($P < 0.05$)

Sensory evaluation

Scores obtained by all of the subjects are shown in Table 1. Four factors in which an eigenvalue exceeded one were

Table 1. Construction of factors

	Factor I	Factor II	Factor III	Factor IV	Interpretation
Calm–noisy	**0.920**	0.284	0.073	0.100	Comfortable feeling
Busy–relaxed	**−0.911**	−0.110	−0.037	−0.064	
Small–large	**0.838**	0.262	0.087	0.348	
Comfortable–uncomfortable	**0.835**	0.368	0.298	0.055	
Weak–strong	**0.822**	0.310	0.090	0.239	
Agreeable–disagreeable	**0.812**	0.382	0.166	0.025	
Gentle–active	**0.791**	0.425	0.030	0.176	
Slow–fast	**0.751**	0.121	−0.230	0.079	
Safe–dangerous	**0.748**	0.530	0.140	0.190	
Tender–violent	**0.700**	0.334	0.227	0.399	
Loose–tight	**0.660**	0.385	0.212	0.290	
Soft–hard	**0.642**	0.570	−0.144	0.082	
Dull–sharp	0.208	**0.812**	−0.178	0.165	Sharp feeling
Drowsy–alert	0.254	**0.795**	0.203	0.032	
Unimpressive–impressive	0.468	**0.641**	−0.007	0.334	
Unclear–clear	0.571	**0.632**	0.057	−0.221	
Monotonous–varied	0.089	0.007	**0.903**	−0.134	Monotonous feeling
Stable–unstable	0.479	0.069	**0.701**	0.278	
Regular–irregular	−0.619	−0.161	**0.666**	0.091	
Light–heavy	0.205	0.017	−0.150	**0.906**	Light feeling
Fine–rough	0.108	0.255	0.467	**0.658**	
Eigenvalue	8.8	3.8	2.4	2.1	
Contribution (%)	42.0	18.1	11.4	9.8	

extracted. Cumulative contributions for the four factors reached 81.3%. The first factor can be interpreted as a "comfortable feeling" because the scores of calm–noisy, busy–relaxed, small–large, comfortable–uncomfortable, weak–strong, agreeable–disagreeable, gentle–active, slow–fast, safe–dangerous, tender–violent, loose–tight, and soft–hard were relatively large. The second factor shows large scores for dull–sharp, drowsy–alert, unimpressive–impressive, and unclear–clear, and so can be interpreted as a "sharp feeling". The third factor can be interpreted as a monotonous feeling because the adjective pairs of monotonous–varied, stable–unstable, and regular–irregular had large scores. The fourth factor showed large scores for light–heavy and fine–rough, and so can be interpreted as a "light feeling".

Figure 2 shows the scores of factors obtained by factor analysis. The scores of the first factor shifted from positive to negative with increasing light floor-impact sound levels. The scores of the first factor, when the subjects were exposed to the prolonged light floor-impact sounds, were significantly different from that in the control test; that is, the subjects felt uncomfortable whenever they were exposed to the prolonged light floor-impact sounds of 60 dBA and 80 dBA, but there was no significant difference between the scores for 60 dBA and 80 dBA. For the second factor, the score for 80 dBA was significantly different from that of the control test. There was no significant difference in the third and fourth factors.

The general impressions of prolonged light floor-impact sounds were as follows: the subjects felt "uncomfortable, dull, and slightly monotonous" at the sound level of 60 dBA and felt "uncomfortable and sharp" at the sound level of

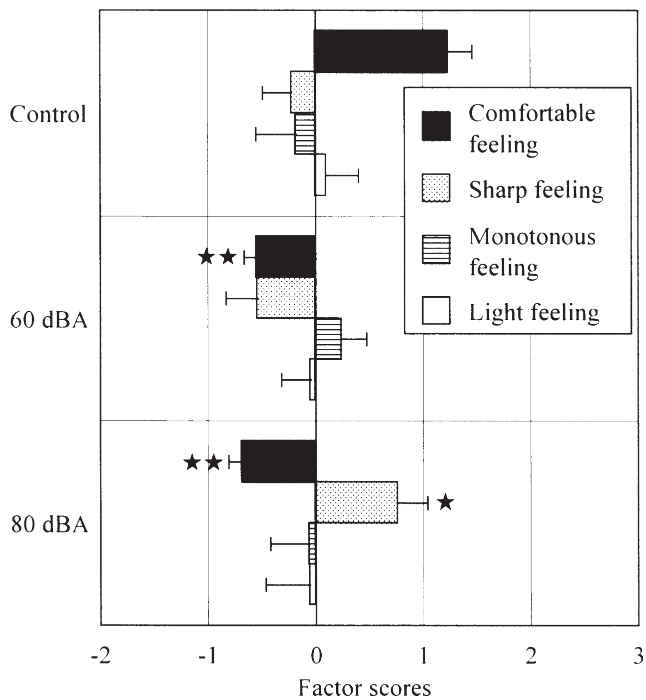

Fig. 2. Scores of four factors extracted in factor analysis by exposure to the light floor-impact sounds generated by the tapping machine. Horizontal bars are standard errors. Wilcoxon signed rank sum tests are used. Significant differences from control values are shown by *double stars* ($P < 0.01$) and *single stars* ($P < 0.05$)

80 dBA. The result of the sensory evaluation was similar to that in our previous study.[1]

Conclusions

The temporary rise in systolic blood pressure immediately after exposure to the prolonged light floor-impact sounds depended on the sound levels, and it can therefore be used as one of the physiological indexes to show an instantaneous effect of light floor-impact sounds on the autonomic nervous system of a human.

The sensory evaluation indicated that the subjects felt uncomfortable when exposed to the prolonged light floor-impact sounds of 60 dBA and 80 dBA, and that there was no significant difference in the uncomfortable feeling between these floor-impact sounds. The change in systolic blood pressure, however, showed a difference between the prolonged light floor-impact sounds of 60 dBA and 80 dBA. Therefore, we suggest that the systolic blood pressure may be used as a physiological index to evaluate the floor-impact sound insulating performance of a wooden house.

References

1. Sueyoshi S, Miyazaki Y (1995) Physiological and psychological responses to light floor-impact sounds generated by a tapping machine in a wooden house. Mokuzai Gakkaishi 41:293–300
2. Sueyoshi S, Miyazaki Y (1995) Physiological and psychological responses to light floor-impact sounds generated by a tapping machine in a wooden house (in Japanese). In: Abstracts of the 45th annual meeting of the Japan Wood Society, Tokyo, p 42
3. Sueyoshi S, Morikawa T, Miyazaki Y (1998) Physiological and psychological responses to heavy floor-impact sounds generated by dropping an automobile tire in a wooden house (in Japanese). In: Abstracts of the 48th annual meeting of the Japan Wood Society, Shizuoka, p 202
4. Morikawa T, Sueyoshi S, Miyazaki Y (1998) Physiological and psychological evaluation of floor-impact sounds in a wooden house part 2. Heavy floor-impact sounds (in Japanese). In: Summaries of technical papers of annual meeting, Architectural Institute of Japan, pp 707–708
5. Morikawa T, Sueyoshi S, Miyazaki Y (1999) Physiological evaluation of floor-impact sounds in a two-story house. In: Proceedings of Pacific Timber Engineering Conference 1:234–239
6. Sueyoshi S, Morikawa T, Miyazaki Y, Ohtsuka S (2000) Physiological and psychoacoustical analysis of heavy floor-impact sounds in a wooden house. In: Proceedings of the Seventh Western Pacific Regional Acoustics Conference 2:1049–1052
7. Sueyoshi S, Miyazaki Y (1997) Physiological responses to prolonged light floor-impact sounds generated by a tapping machine in a wooden house (in Japanese). In: Abstracts of the 47th annual meeting of the Japan Wood Society, Kochi, p 48
8. Sueyoshi S, Miyazaki Y, Morikawa T (1998) Physiological evaluation of floor-impact sound insulation of a wooden house. In: Proceedings of the Fifth World Conference on Timber Engineering 1:756–757
9. Sueyoshi S, Morikawa T, Miyazaki Y (1998) Physiological and psychological evaluation of floor-impact sounds in a wooden house part 1. Light floor-impact sounds (in Japanese). In: Summaries of technical papers of annual meeting, Architectural Institute of Japan, pp 705–706
10. Boehmer RD (1987) Continuous, real-time, noninvasive monitor of blood pressure: Penaz methodology applied to the finger. J Clin Monitor 3:282–287
11. Okuda Y, Toyokawa K, Ishii K (1980) Studies on the image of forest operations (II). On the evaluation to yarder vibrations by means of SD-method (in Japanese). Trans Jpn Forest Soc 91:511–514