Effects of Shoe Design and Top-piece Materials on Noises Made by Women's Shoes

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Abstract: The purpose of this study was to investigate the effects of shoe design and top-piece materials on footstep noise during walking. Footstep noise level and frequency analysis of 10 healthy young women were compared during walking in different shoes. The results of a field investigation on women's footstep noises showed that footstep noise level during climbing down indoor metal stairs was extremely high, about 90 dB, regardless of shoe design. Wear trial indicated that the footstep noise level for flip-flop sandals was the highest among test shoes, followed by mules and then sling-back sandals. Attaching an instep strap to mules significantly reduced the footstep noise level. Examining the effects of top-pieces, we concluded that the harder the top-piece, the louder the footstep noise level. In particular, footsteps noise level was the highest when the top-piece became detached from the heel, exposing the metal reinforcement spigots.

Key word: women's shoes; footstep noise; shoe design; top-piece

1. Introduction

In Japan, people have recently begun to complain that the high-pitched noises made by women's shoes on train station platforms and escalators cause them discomfort [1].

Studies on shoe footstep noises have been conducted mostly from the viewpoint of floor materials [2-4]. To the best of our knowledge, there have been no studies investigating the effects of design and top-piece material on the noises made by women's shoes.

In order to clarify the cause of this noise, the present study evaluated footstep noises on different stair materials. In addition, noises made when subjects climbed down indoor plastic tile stairs while wearing shoes with different designs and top-piece materials were measured, and the pleasantness of footstep noises was assessed by sensory evaluations.

2. Materials and Methods

2.1 Shoes

As shown in Photo 1, the following five types of sandals, which were shown to be worn often in summer and were likely to generate noise, were used: mules with 5-cm stiletto heels (5M); mules with 7-cm heels (7M); sling-back sandals with the same design as 7M (7S); flip-flop sandals with 1.5-cm heels (flip-flop); and 5M mules with instep straps (100% polyurethane, commercially available) (5M+S).

2.2 Subjects

Subjects were 10 healthy young women aged 20 - 22 years. Subjects wore the test shoes without socks.

2.3 Measurements

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2.3.1 Footstep noise level and frequency analysis

Using a sound level meter (Rion, NL-22) and a 1/3 octave real-time analysis card, footstep noise levels (A-weighted) were measured and frequency analyses were carried out. FAST (specified number: 125 ms) was used for time-weighted analysis of footstep noise levels. Footstep noise levels were corrected by ISO 1996-2. Footstep noises were measured 1 m away from the subject at 90 cm off the floor. Subjects were instructed to walk normally and wore each shoe three times.

2.3.2 Sensory evaluation of the pleasantness of footstep noises

Subjects assessed the pleasantness of footstep noises by sensory evaluations using the following five grades: 5) very pleasant, 4) pleasant, 3) neutral, 2) unpleasant and 1) very unpleasant.

2.3.3 Gait analysis

For gait analysis, a digital video camera was used to capture subjects' gait from the side at a rate of 1/120 sec.

2.4 Field investigation of footstep noise

In order to clarify the current state of footstep noise, footstep noises produced when walking on the following six floor types while wearing various types of shoes were measured: temporary metal stairs (indoors and stations), escalators and stone stairs (indoors and station building), porcelain tile stairs (outdoors), plastic tile stairs (indoors) and concrete stairs (outdoors and footbridges). Footsteps were measured while climbing down the stairs. In addition to the five shoes shown in Photo 1, 5 M shoes in which the top-piece was detached from the heel to expose the reinforcing metal spigots were also used.

2.5 Differences in footstep noise among different shoe designs

The effects of shoe design, such as shoe heel height and instep strap, on footstep noise were investigated. Shoes are shown in Photo 1. Subjects were instructed to walk up and down plastic tile stairs (30 cm tread and 12 cm rise) or on a flat floor in a quiet indoor room. Footstep noise levels were measured and frequency analyses were performed.

5M 7M 7S flip-flop 5M+S

Photo1. Type of shoes

5M: mules with 5-cm stiletto heels, 7M: mules with 7-cm heels, 7S: sling-back sandals with the same design as 7M, flip-flop: flip-flop sandals with 1.5-cm heels, 5M+S: 5M mules with instep straps.

2.6 Differences in footstep noise among different top-piece materials

The effects of top-piece materials on footstep noise were investigated. The following three top-piece materials with different degrees of hardness were used: hard urethane (hardness A29 and D39, hard top-piece), soft urethane (hardness A86, soft top-piece) and synthetic rubber (hardness A74, rubber top-piece). In addition to these, shoes with exposed metal spigots were also used. These top-pieces were used with 5M shoes. The hardness of the top-pieces was measured according to ISO7619. The footstep noise measurement methods, subjects and stair types were the same as those described above.

2.7 Statistical analysis

For the assessment of differences in footstep noise produced by different shoe designs, two-way ANOVA was performed on shoe design and walking mode. Differences in footstep noise among different top-piece materials were evaluated by two-way ANOVA. Post hoc comparisons were performed using Fisher's multiple comparison tests. Sensory evaluations of the pleasantness of footstep noises were analyzed by one-way ANOVA and multiple comparison tests.

3. Results and Discussion

3.1 Field investigation of footstep noise

As shown in Figure 1, for indoor metal stairs, footstep noise levels were approximately the same for all shoes, at roughly 90 dB. These noise levels are similar to those heard in busy plants and subway cars (with windows open). For all shoe types tested, footstep noise levels were high while walking on escalators. Irrespective of stair type, footstep noise levels for shoes with exposed metal spigots were the highest, at about 90 dB.

Figure 2 shows the results for frequency analysis of stair type and shoe design. Even at comparable levels, footstep noises in different frequency domains clearly varied among different combinations of stair and shoe types. When walking on metal or porcelain tiles, the footstep noise level in the high frequency domain at ≥3kHz was high for metal spigot.

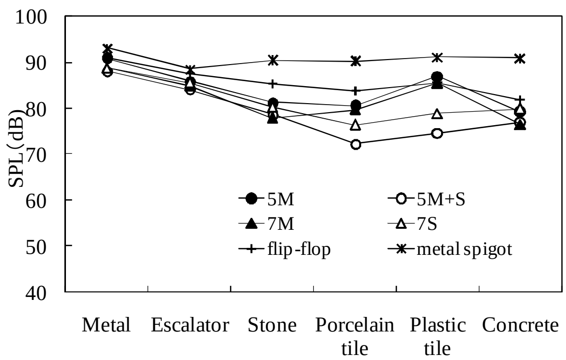


Fig. 1 Footsteps noise level for each stair type and shoe design (climbing down stairs)

3.2 Differences in footstep noise levels among different shoe designs

The results indicated that shoe design and walking mode were significant factors ($p < 0.01$), thus clarifying that these factors affect footstep noise level (Figure 3). When climbing down stairs, footstep noise levels were high for all shoes, at 70 - 80 dB, and significant differences existed ($p < 0.01$) between climbing down stairs and walking on a flat floor or climbing up stairs (Figure 3).

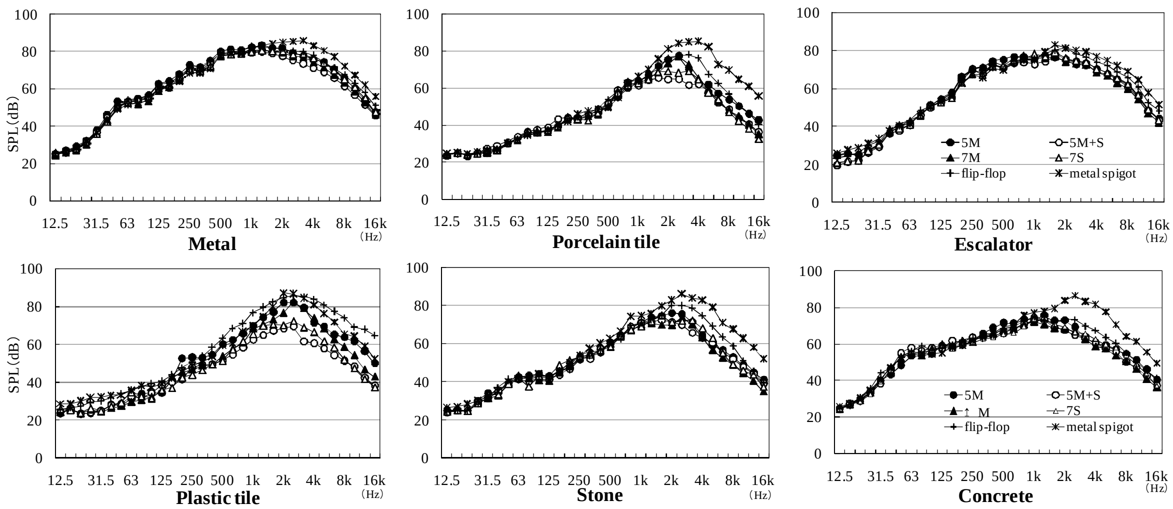


Fig. 2 Frequency analysis of stair type and shoe design (climbing down stairs)

With regards to shoe design, footstep noise level was significantly higher for flip-flops than for the other shoes ($p < 0.01$). As shown in Photo 2, because a thong passing between the toes is the sole support for flip-flop sandals, the human heel is likely to come out of the shoe while walking, and the entire heel then hits the floor when stepping down, generating a loud noise.

As for instep straps, significant differences were seen between footstep noise levels for 5M and 5M+S. In particular, attaching instep straps decreased footstep noise levels by about 6 dB while climbing down stairs. The reason for this is that the human heel remains firmly inside the shoe during walking.

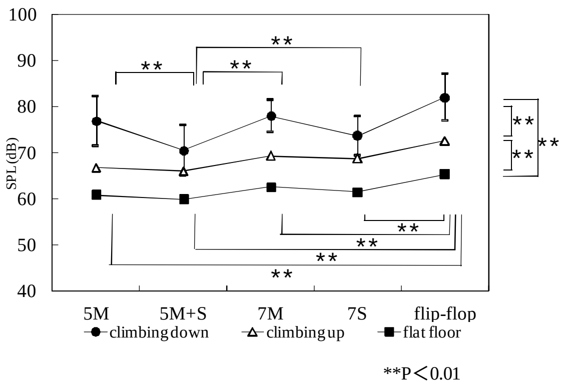


Fig. 3 Effects of shoe design and walking mode on footstep noise level

Photo 2 Walking motion at flip-flop sandals

As shown in Figure 4, while climbing down stairs, the footstep noise level in the high-frequency domain for flip-flops was significantly higher than that for the other shoes, whereas the footstep noise level in the high-frequency domain for 5M+S was lower than that for the other shoes, further demonstrating the noise-lowering effects of instep straps.

The results of sensory evaluations of the pleasantness of footstep noises (Figure 5) revealed that shoe design significantly affected subjects' perceptions of footstep noises ($p<0.01$).

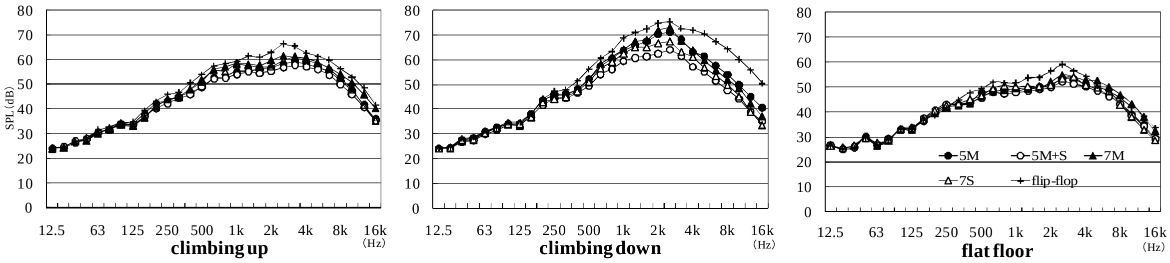
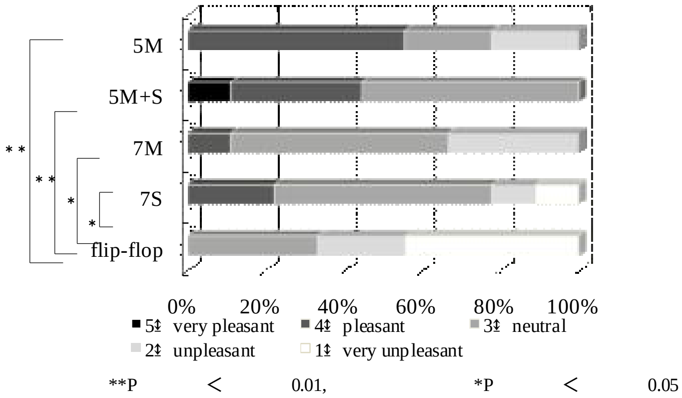
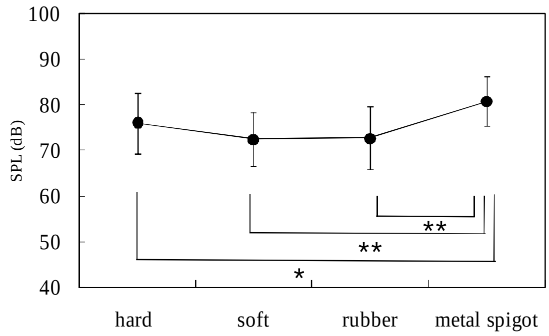


Fig. 4 Frequency analysis on shoe design and walking mode

Multiple comparison tests revealed significant differences between flip-flop sandals and the other shoes—many subjects rated the noises made by flip-flop sandals "unpleasant" or "very unpleasant".

When comprehensively analyzing the results of frequency analysis and footstep noise level, subjects appeared to perceive the footstep noises made by flip-flop sandals as ear-ringing noises.





**P<0.01, *P<0.05

Fig. 5 Sensory evaluations on the pleasantness of footstep noises

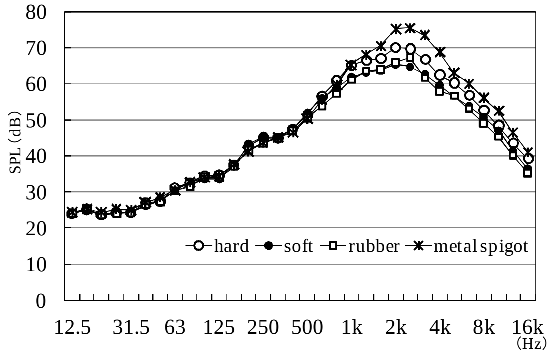
Fig. 6 Effects of top-piece material on footstep noise level (climbing down stairs)

3.3 Differences in footstep noises among different top-piece materials

As shown in Figure 6, top-piece material significantly affected footstep noise level ($p < 0.01$). Significant differences were observed between shoes with exposed metal spigots and those with both hard and soft top-pieces ($p < 0.01$). The footstep noise level of shoes with exposed metal spigots was the highest among shoe types tested. Although softer top-pieces more effectively cushion impact and absorb noise, the resistance of soft top-pieces to abrasion is low, meaning that metal reinforcement spigots may become exposed after continual wear. It is thus necessary to define a certain standard for top-piece materials with respect to both abrasion resistance and noise level.

The peak frequency for the soft top-piece was 2 kHz, slightly lower than the other top-pieces (Figure 7). When the metal spigots were exposed, footstep noise levels in the high-frequency domain were higher than for the other shoes.

The results of sensory evaluations of top-piece materials and the pleasantness of footstep noises (Figure 8) suggest that top-piece materials had significant effects on footstep noise pleasantness ($p < 0.01$). In addition, there were significant differences in footstep noise level between shoes with exposed metal spigots and the other shoes ($p < 0.01$). Shoes with exposed metal spigots received the



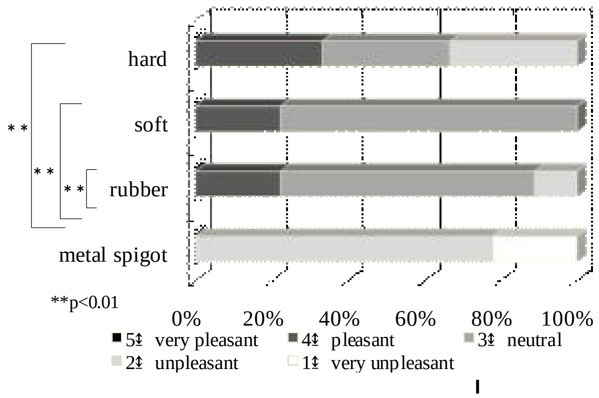


Fig. 7 Frequency analysis of top-piece material (climbing down stairs)

Fig. 8 Sensory evaluations of top-piece materials and the pleasantness of footstep noises

poorest sensory evaluations—78% and 22% of subjects evaluated the noise produced by shoes with exposed metal spigots as “unpleasant” and “very unpleasant”, respectively. In contrast, none of the subjects disliked the footstep noise made by shoes with the soft top-piece.

The results of the present study suggest that footstep noises in the high-frequency domain are high-pitched and become unpleasant when the top-piece wears out and the metal reinforcement spigots are exposed.

4. Conclusions

Subjective evaluation of top-piece material was investigated to clarify the cause of footstep noise. Footstep noise levels were measured and subjected to frequency analyses, and sensory evaluations were performed to ascertain the pleasantness of footstep noises. The results were as follows:

1) When climbing down indoor metal stairs, footstep noise levels were very high (about 90 dB) regardless of shoe design. When the top-piece was worn out, exposing the metal reinforcement spigots, footstep noise levels were high in the high-frequency domain (3 kHz).

2) Footstep noise levels while climbing down stairs were higher than when climbing up stairs or walking on a flat floor.

3) As for shoe design, the footstep noise level for flip-flop sandals was the highest, because the human heel tended to come out of the shoe during walking. With mules, footstep noise levels could be decreased by attaching instep straps.

4) In general, it is considered that the harder the top-piece, the louder the footstep noise level.

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