SoniFootsteps: Movement-Triggered Footstep Sounds to Modulate Body-Weight Perception, Gait and Emotion

SUPPLEMENTARY MATERIAL

1 Supplementary Methods

1.1 Questionnaire on Body feelings

Participants were asked to answer the question "How did you feel during the experience?" from 1 to 9, selecting accordingly a figure from each of 3 different scales. Each scale showed different kind of feelings: happy/positive vs unhappy/negative, aroused/excited vs unaroused/calm, dominant/important vs submissive/awed (slightly frightened). From 1 (Unhappy, Negative), to 9 (Happy, Positive). From 1 (Unaroused, Calm), to 9 (Aroused, Excited). From 1 (Submissive, Awed), to 9 (Dominant, Important). Then they were asked to select, from 1 to 7 the number they thought that best expressed their level of agreement with the sentences below. "During the experience I felt:" Slow/Quick, Light/Heavy, Weak/Strong, Crouched, Stooped/Elongated, Extended. Very Feminine/Very Masculine. Participants were then asked in which extent they agreed with the following statements, from 1 (I strongly disagree), to 7 (I strongly agree). During the experience it seemed like the sounds I heard were produced by my own footsteps/ body. During the experience it seemed the feeling of my body was less vivid than normal. During the experience the feelings about my body were surprising and unexpected. During the experience it seemed like I could really tell where my feet were.

1.2 Post-Experiment Questionnaire

At the end of the experiment participants were asked to complete the following statements:

- "During the experience the footsteps I heard were:" From 1 (Not in sync with my walking), to 7 (In sync with my walking).
- "I find the sound of the footsteps were:" From 1 (Not plausible (realistic) at all), to 7 (Totally plausible (realistic)).
- Then they were asked to select, from 1 to 7 the number they thought that best expressed their level of agreement with the sentence below.
- "After the experience I feel perceptually exhausted." From 1 (Totally Disagree), to 7 (Totally Agree).

1.3 Feedback Interview

Participants were also asked to answer the following questions

- "Are there any techniques or algorithms you commonly use that could be employed to improve the performance of the system?"
- "Regarding the devices and sounds we used, what did you like and what would you do differently?"

1.4 Recording Hardware Configuration

Recordings were conducted in an anechoic environment. To record the footstep sounds we used two sets of wired binaural microphones (SOUNDMAN OKM-II), with a frequency response of 20 Hz–20 kHz, a sensitivity of approximately

Author's Contact Information:, 4m4r000@gmail.com.

7 mV/Pa, and an impedance of 2.2 kΩ. Designed for in-ear placement, they support a maximum sound pressure level (SPL) of 120 dB and operate on plug-in power (1.5 V-10 V) via a 3.5 mm TRS stereo mini-jack. We also used a handheld portable recorder (ZOOM h4n), in four-channel configuration. One set of microphones was positioned at the tip of the shoes and the other one in the walker's ears. The files were recorded with a 16-bit resolution and 44100 Hz sampling rate. A mobile application with a flashing-screen metronome functionality was used to provide a synchronized visual tempo cue (80, 100, 120 bpm) during the recordings.

1.5 Materials and Recording Setup

Two different ground materials were used: wood (MDF) planks, positioned on the floor of the anechoic environment to form a runway measuring 480 cm in length and 80 cm in width, and marble tiles (40 x 40 x 4 cm), which were placed on top of the wooden runway. Further, two types of shoes were used: leather dress shoes (EU sizes 42 and 46) and sandals with hard rubber soles (EU size 42). To simulate increased body weight and create varied weight recording conditions, participants wore a fitness weight set that added 5 kg of extra mass.

The choice to include sandals with hard-rubber soles as footwear and wood (MDF) as the walking surface was made to replicate the materials setup used in [1]. Three people, weighing approximately 50, 60 and 70 kg, participated in the sound recordings. Each of them performed eight recording sessions: four while wearing the 5 kg weights (sandals on marble, sandals on wood, shoes on marble, and shoes on wood), and the same four without the additional weight. This approach allowed us to cover the following weight ranges: 50-55 kg, 55-60 kg, 60-65 kg, 65-70 kg, 70-75 kg and 75-80 kg.

To prevent introducing any additional sound sources into the recordings, participants synchronized their footsteps using a visual metronome on a smartphone, which emitted a screen flash at each beat. The recording consisted of five 1-minute phases: walking in place at 80 bpm, walking normally at 80 bpm, walking in place at 100 bpm, walking normally at 100 bpm, and walking in place at 120 bpm. We only recorded walking in place at 120 bpm due to the limited path length, as walking at this tempo along the short distance would have resulted in unnaturally short steps.

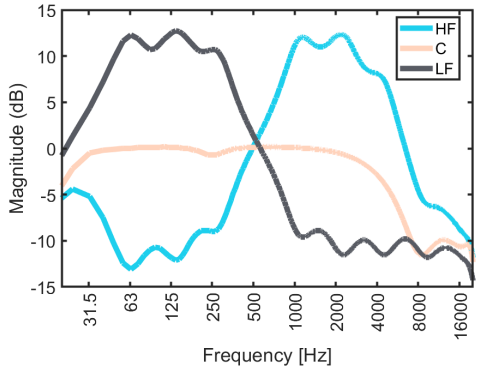

Fig. 1. Frequency response of the High Frequency (HF), Low Frequency (LF) and Control (C) filters.

1.6 Sound Selection and Processing

After the recording sessions, we went through all the tracks and selected the candidate sounds for the study. Specifically, we focused on the walking pace and decided to exclude 80 bpm, 120 bpm and walking-in-place recordings. This decision

was made considering that, in the study, we wanted participants to walk at a "natural" speed, which we defined as a pace that people typically use in everyday walking scenarios. We felt that 80 bpm and 120 bpm might not represent this natural pace, and walking-in-place recordings were excluded to avoid any artificial constraints. Although studies involving similar prerecorded sounds like [3] have used a 120 bpm walking pace, they only involved the walking-in-place activity, which is different from the walking scenario we aimed to replicate. We decided to incorporate background noise into the footsteps tracks to make the listening experience more realistic and less frustrating. To do so, we recorded the background noise at the study location and added it to the sound processing system.

The recordings were composted of four channels (two for the microphones placed in the ears and two for those placed on the shoes). Ultimately, we decided to perform the piloting using only the foot-located microphones for the following reasons. Firstly, in the footsteps recordings with the microphones in the ears, the footstep sound level was lower than with the foot-located microphones, and this, after amplifying the signal, generated a perceivable click at the footstep pairs joints. Secondly, considering the the influence of height differences between the individuals who produced the recorded sounds and the participants in the study. Finally, to remain consistent with previous studies [1, 4] that use the feet as microphone locations.

The same filters developed for the SoniWeight Shoes device [1], as described in [2], were used to equalize the prerecorded footstep sounds, obtaining: an HF version and a LF version, simulating the acoustic characteristics of a lighter and a heavier body, respectively. In HF, higher frequency bands (1-4 kHz) were amplified by 12 dB, while lower frequencies (83-250 Hz) were attenuated by 12 dB. In contrast, LF inverted this pattern. Figure 1 shows the frequency response of the two filters, along with the Control condition (referred to as C).

References

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