Association between hearing threshold and low-frequency walking sounds on concrete floors

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ABSTRACT

The sufficient frequency range to be measured for the rating of impact sound insulation of floors has been a relevant research question since the 1960's when the lower limit of the measured frequency range was set at 100 Hz. It has been long recognized that walking sounds at frequencies lower than 100 Hz might have a significant effect on the experienced impact sound insulation of floors. Recently, it has been suggested that the frequency range to be measured for the rating of impact sound insulation should be enlarged down to 20 Hz. This suggestion is based on studies concerning wooden buildings. It is not known whether audible low-frequency walking sounds are generated by walking on concrete floors. The purpose of this preliminary study was to produce sound spectra of several living impact sound sources, and to compare them with hearing thresholds. The spectra of different sound sources were measured in a laboratory. The results show that low-frequency living sound spectra exceeding the hearing threshold exist only at 40 Hz and occasionally at 31,5 Hz frequency band in the case of walking with socks on concrete floors.

1. INTRODUCTION

It has been long recognized that walking on floors often generates low-frequency impact sounds below 100 Hz which was set as the lower limit of the measured frequency range in the standardized impact sound insulation measurements in the 1960's [1, 2]. Already in the 1960's, it was also shown that these low-frequency impact sounds might have a significant effect on the experienced impact sound insulation of floors [3–6]. Already in the formulation phase of the standardized measurement method, there was discussion on the lowest frequency band to be measured [7–9]. The frequency range for achieving sufficient association between the physical sound pressure levels (SPL) and the perceived impact sound insulation has been a relevant research question ever since [2, 10–14].

During the last decade, research on impact sound insulation has mainly concentrated on wooden floors [15–20]. It has been suggested that the measured frequency range should be enlarged even

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down to 20 Hz [19, 20]. It has also been shown that low-frequency impact sounds at the frequency range from 50 to 100 Hz are generated also by walking on concrete floors [21, 22], but it is not known whether those sounds are generated also in the lowest frequency range down to 20 Hz. The purpose of this preliminary study was to study sound spectra of several living impact sound sources and find out how they are related to the hearing threshold in the lowest frequency range. The results presented in this paper are based on studies carried out in 2012. The experimental setup has been described in articles and papers, but the results have earlier been reported down to 50 Hz only [14, 21, 22, 23].

2. MATERIALS AND METHODS

2.1. Studied floors

The impact sound measurements were carried out at a laboratory, where the bearing structure of the floor separating the vertically adjacent source and receiving rooms was a 265 mm thick concrete hollow core slab (400 kg/m^2). The measured reverberation times of the receiving room corresponded well with those of typical furnished rooms in Finnish dwellings [24]. Therefore, the sound spectra measured in the receiving room can be considered to correspond well with the typical spectra in residential dwellings.

In the laboratory, all the floor coverings were installed in the same place on the slab. The size of each floor covering was 3.0 x 4.0 m^2. The study was conducted using a wide range of floor coverings for covering the typical impact sound insulation spectra found in dwellings. Eight different floor coverings on the bearing slab were used (Table 1). The weighted sound reductions in impact sound pressure levels ΔL_w [dB] and dynamic stiffnesses s' [MN/m^3] have also been shown in Table 1. Measurements were also carried out without a floor covering (F1). The measured weighted impact sound pressure levels $L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$ of the studied floors have been shown in Table 1. The impact sound pressure levels L_{eq} generated by the tapping machine have been shown in Figure 1.

Table 1: Structural layers of the floor types denoted with letter F and a number 1–9 and their impact sound insulation properties [14]. The values of $C_{I,50\text{-}2500} < 0$ have not been taken into account.

Denotation	Structural layers of the floor covering	$L'_{n,w}$	$L'_{n,w} + C_{I,50\text{-}2500}$
Floor F1	No covering	80 dB	80 dB
Floor F2	Cushion vinyl, ΔL_w = 2 dB	78 dB	78 dB
Floor F3	Cushion vinyl, ΔL_w = 21 dB	59 dB	59 dB
Floor F4	Multilayer parquet and soft underlay, ΔL_w = 20 dB	60 dB	60 dB
Floor F5	Wall-to-wall carpet, ΔL_w = 21 dB	59 dB	59 dB
Floor F6	Wall-to-wall carpet, ΔL_w = 37 dB	43 dB	47 dB
Floor F7	Multilayer parquet 14 mm Soft underlay 2 x plasterboard 15 mm (30 kg/m^2) Mineral wool 13 mm, s' = 16.1 MN/m^3	51 dB	56 dB
Floor F8	Multilayer parquet 14 mm Soft underlay 2 x plasterboard 15 mm (30 kg/m^2) Mineral wool 50 mm, s' = 11.5 MN/m^3	44 dB	53 dB
Floor F9	Multilayer parquet 14 mm Soft underlay 4 x plasterboard 15 mm (60 kg/m^2) Mineral wool 50 mm s' = 11.5 MN/m^3	42 dB	48 dB

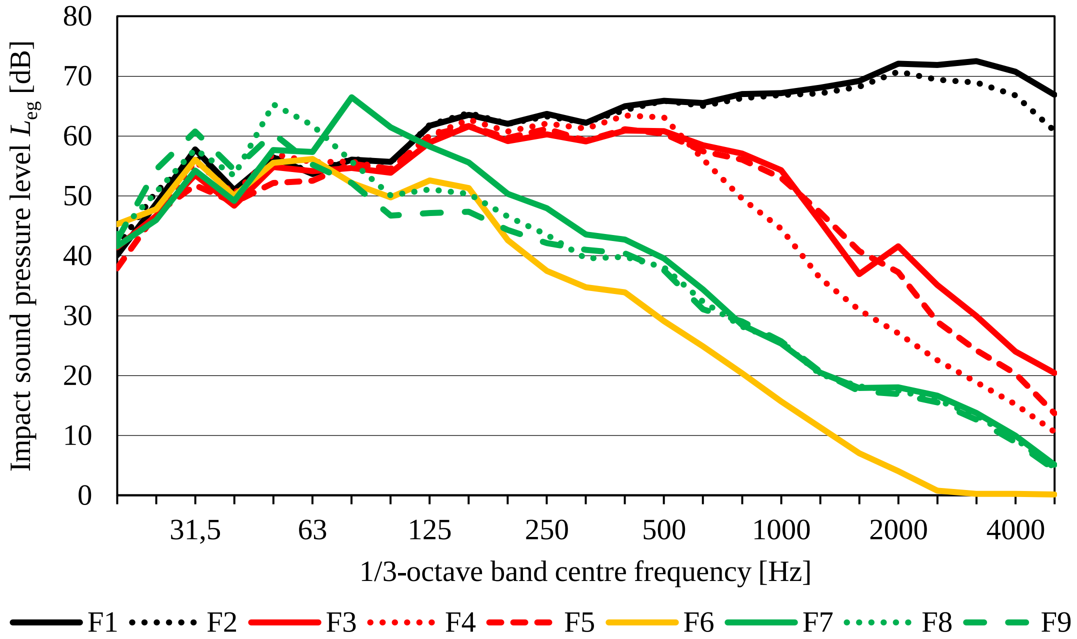

Figure 1: Impact sound pressure levels generated by the tapping machine
in the frequency range from 20 to 5000 Hz.

2.2. Generation of the living impact sounds

Impact sounds are different living sounds directed at floors, especially in dwellings. Examples of sources of the living impact sounds are walking on the floor, falling objects, moving furniture and children playing. The present standardized single-number quantities expect that the main impact source is walking with hard-heeled shoes. This sound type does not necessarily reflect the most typical impact sounds in all countries [14–16, 20, 25]. Therefore, each of three male walkers W1, W2 and W3 (Table 2) wore hard-heeled shoes, socks, and soft-heeled shoes (S1, S2, S3, respectively). The same footwear was used through the test series. Each walker walked along a rectangular and an hourglass-shaped track on each floor. The SPLs were recorded in the receiving room at two microphone positions as a function of time with time weighting FAST. The measurement and walking duration were 40 seconds. Each measurement was repeated twice. As walker W1 appeared to be the loudest of the three, only measurement results of W1 will be shown later.

Table 2: Dimensional analysis of the walkers. The shoe sizes correspond to the European measures.

Walker	**Age**	**Mass**	**Height**	**Shoe size**
W1	22	86 kg	188 cm	46
W2	40	125 kg	191 cm	44
W3	23	91 kg	183 cm	42

In addition to walking, two other impact sounds were studied. The first represented one possible sound spectrum caused by playing children: a so-called super ball (weight 45 g) made of synthetic rubber and being very elastic was thrown towards the floor at the centre point of the floor covering (S4). The bouncing was repeated so that the ball was turned back towards the floor from the same height (1 meter). Furthermore, the sound produced by moving a wooden chair was measured. The sound was generated as follows: first, a walker pulled the chair out from under a table, then the person moved to the front of the chair and moved it towards the table, sat down on the chair, stood up, pushed the chair away from the table and finally pushed the chair back under the table (S5). The living impact sounds studied in our research will be denoted as follows:

- S1 – Walking by W1 with hard shoes
- S2 – Walking by W1 with socks
- S3 – Walking by W1 with soft shoes
- S4 – Super all bouncing
- S5 – Chair moving (on floor F6 chair moving was not possible)

Every step, super ball drop and chair moving generates slightly different sound spectrum. In our study, the purpose was to define the typical momentary maximum spectrum for the living impact sounds. For this reason, the momentary maximum spectra were selected from the time-varying sound pressure levels by calculating $L_{A,F}(t)$ as a function of time. In the case of walking, the typical number maxima were 50-60 per each measurement. The measured spectra of all the momentary maxima of two repeated positions resulted in a sample of spectra based on maximum A-weighted SPLs. The sample size for each walking consisted typically of 200–250 momentary maxima. From these maxima, the typical spectra for each sound source were calculated as energetic average of the whole sample of the spectra (Figure 2). The generation of the living impact sound and calculation of the spectra have been described in more detail in an earlier article [21]. The measurement data has been described as a whole in [26].

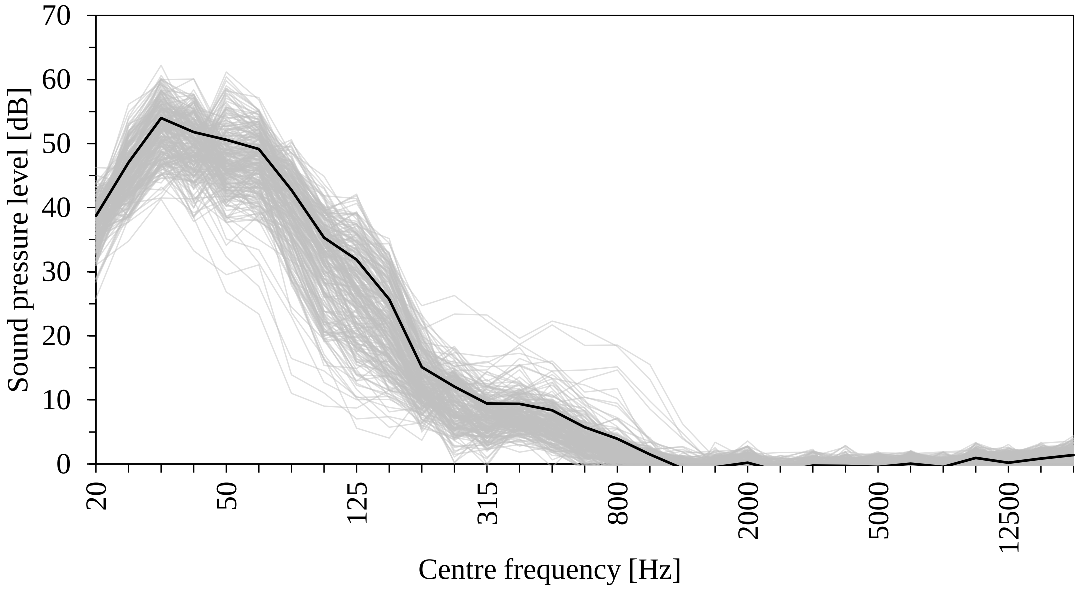

Figure 2: An example of the variation of the momentary maxima $L_{A,F}(t)$ generated by walker W1 wearing socks walking on floor F4. The energetic average $L_{A,F,max}$ representing a typical step sound is shown with a black line.

2.3. Comparison of the living impact sounds with the hearing threshold

It is usually expected that the experienced loudness of a time-varying sound is determined by the loudest momentary spectrum [27–29]. In our study, the object was to find out whether the living impact sounds can be audible i.e. whether their sound pressure levels exceed the hearing threshold. The hearing conditions of living impact sounds from upstairs in a room cannot be considered diffuse as the location of the sound source usually can be recognized. Therefore, the maximum SPLs $L_{A,F,max}$ at 1/3-octave bands will be compared in this preliminary study with the hearing threshold (HT) according to ISO 226-2003 [30].

3. RESULTS AND DISCUSSION

The maximum SPLs $L_{A,F,max}$ for each floor type F1–F9 and sound type S1–S5 have been shown in Figure 3. In the figure, the hearing threshold [30] has also been given. The studied frequency range was from 20 to 5000 Hz, even though it is obvious that at the higher frequencies above 1000 Hz, the walking sounds were not usually audible (especially floors F3–F9).

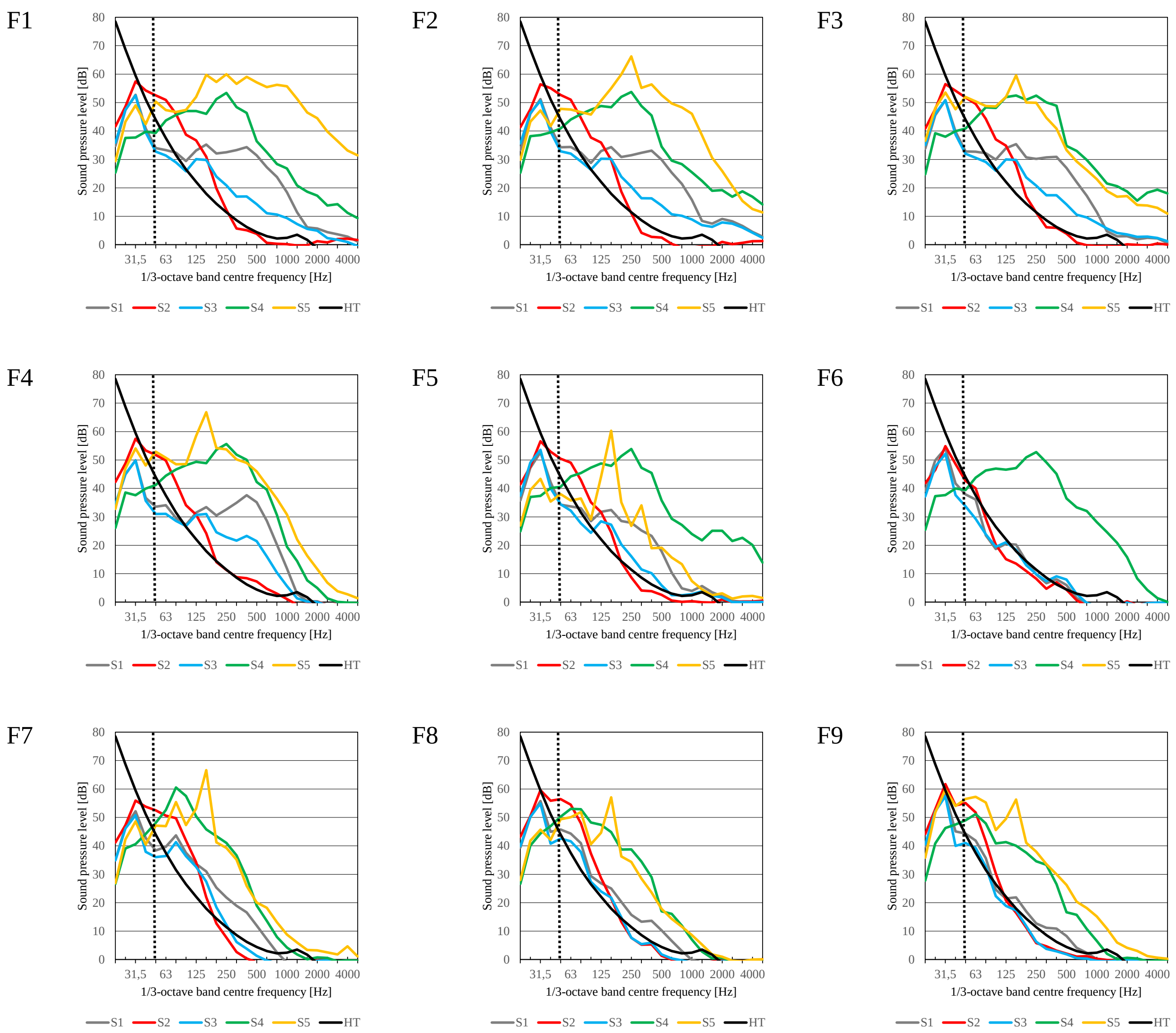

Figure 3: The maximum sound pressure levels $L_{A,F,max}$ for each floor type F1–F9 and sound type S1–S5 compared with the hearing threshold (HT). The vertical black dotted line shows the frequency band of 50 Hz.

Figure 2 shows that the sounds S1, S3 and S4 did not exceed the hearing thresholds at frequency bands lower than 50 Hz. This indicates that these sounds (walking with hard shoes or soft shoes and super ball bouncing) are not necessarily audible below 50 Hz. In most cases, the sound S5 (chair moving) also stayed below the hearing threshold. Only exception was chair moving on floor F9, when the hearing threshold was exceeded at 31,5 and 40 Hz frequency bands. The reason for this might be that moving the chair excited the resonance frequency of the floating floor which was in this frequency range.

The only sound type exceeding the hearing threshold in the low-frequengy range in most cases was S2 (walking with socks). Except the floor type F6, SPLs from walking with socks exceeded the hearing threshold at 40 Hz in eight cases of nine. They exceeded the hearing threshold also at 31,5 Hz in the cases of floors F8 and F9. This indicates that walking with socks on concrete floors might be a significant sound source independent on the floor type, which has been shown in earlier articles, too [14, 21, 22]. A suggestion of enlarging the frequency range down to 40 Hz would, however, require psychoacoustical experiments in the similar way as has been carried out in [22].

Figure 2 shows that in some cases, the maximum sound pressure levels of a single step might be about 5 dB larger than the energetic averages shown in Figure 3. It is therefore possible that sometimes the audibility of the walking sounds might differ from the audibility of the energetic averages, i.e. individual steps or knocks to the floor could be heard. However, for sounds S1, S3 and S4 the energetic averages are 5–10 dB lower than the hearing threshold so the situation might not change if the sounds are louder than the energetic averages. The situation might change in the cases of sounds S5 and especially S2.

On the bases of Fig. 3, some observations on SPLs of walking sound at frequencies over 100 Hz can be done. In the cases of floors F1–F5, walking with shoes generated sounds exceeding the hearing threshold at mid-frequencies. Walking with socks generated audible sounds from 40 up to 250 Hz (except F6). In the vase of F6, F8 and F9, walking with shoes generated sounds near to the hearing threshold in the whole frequency range.

4. CONCLUSIONS

Our preliminary study shows that none of the five sound types directed to the nine floor types did not exceed the hearing threshold at frequency bands 20 or 25 Hz. Sound types S1, S3 and S4 did not exceed the hearing threshold at 31,5 and 40 Hz frequency bands either. It can thus be concluded that these three living impact sounds were not audible at the lowest frequency bands in this experimental study. However, walking on socks generated sounds exceeding the hearing threshold in eight cases of nine at 40 Hz and in two cases also at 31,5 Hz. This might indicate that walking with socks on concrete floors is an important sound source and it might be worth to be studied further. This sound type might also have a significant effect on the subjective experience of impact sound insulation between dwellings.

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