PERCEPTION OF IMPACT SOUNDS THROUGH WOODEN FLOORS WAS EXPLAINED BY FREQUENCIES 100–3150 Hz – PSYCHOACOUSTIC EXPERIMENT ON ANNOYANCE

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ABSTRACT

The most popular single-number quantities (SNQs) of impact sound insulation in Europe are $L'_{n,w}$ and $L'_{nT,w}$. They are based on measurements within 100–3150 Hz. Recently, it was proposed that the measurements should be extended down to 25 Hz for wooden floors, and $L'_{nT,w}+C_{I,25}$ should replace $L'_{nT,w}$. The purpose of this study is to analyze which of the two SNQs, $L_{n,w}$ or $L_{nT,w}+C_{I,25}$, predicts the annoyance of natural impact sounds better for wooden floors. We conducted a psychoacoustic experiment, where 52 participants rated the annoyance of 75 impact sounds. As stimuli, five types of natural impact sounds were used. They were recorded for 15 different wooden floors built in an impact sound insulation laboratory, where also their SNQs were measured. Based on correlation analysis, $L_{n,w}$ explained annoyance of natural impact sounds equally well or better than $L_{n,w}+C_{I,25}$, depending on impact sound type Therefore, based on perception, it seems to be sufficient to conduct measurements within 100–3150 Hz for wooden floors and assess their sound insulation using $L'_{nT,w}$ or $L'_{n,w}$.

Keywords: impact sound insulation, psychoacoustics, single-number quantities

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1. INTRODUCTION

Impact sound insulation of floors is frequently described in Europe by single-number quantities (SNQs) $L'_{nT,w}$ or $L'_{n,w}$. They are based on impact sound pressure levels (SPLs) within 100–3150 Hz. Sweden and Finland conduct measurements down to 50 Hz, and their SNQ is $L'_{nT,w}+C_{I,50}$. Recently, it was proposed that the measurements should be extended down to 25 Hz, and $L'_{nT,w}+C_{I,25}$ should replace $L'_{nT,w}$ [1]. The proposal was based on a residential survey. Residential surveys conducted in apartment buildings suffer from uncontrolled uncertainties (stimulus level, presence degree of neighbor upstairs, respondents' living styles). Subjective annoyance ratings are confounded by non-acoustic situational and social factors. Therefore, the research proposing extended frequency range down to 25 Hz needs a psychoacoustic counterpart before the proposal could be considered.

It is extremely important use such SNQ that it ranks floors in the same order as people subjectively rank them. Objective ranking is based on measurements using tapping machine as a stimulus (ISO 10140-3, ISO 16283-2, ISO 717-2). However, subjective ranking in residential apartment is based on natural impact sounds that residents produce. Therefore, natural impact sounds should be used in experimental studies. Instead, rubber ball (soft/heavy impact source of ISO 10140-3 and ISO 16283-2) has been developed to resemble running children. Therefore, it is reasonable to use rubber ball also in experimental studies.

The purpose of our psychoacoustic experiment was to analyze which of these two SNQs ($L_{n,w}$ or $L_{n,w}+C_{I,25}$)

predicts the annoyance caused by natural impact sounds better for wooden floors.

2. MATERIALS AND METHODS

2.1 Floors and stimuli

The first part of the research involved sound insulation tests for 30 different wooden floor constructions according to ISO 10140 and ISO 717. They are reported in the open data described by closer in Ref. [2].

The $L'_{nT,w}$ requirements in Europe vary within 48–68 dB [3]. Therefore, the floors used in psychoacoustic experiment were chosen to cover that range sufficiently so that the results can be applied throughout the Europe. Out of the data of Ref. [2], fifteen wooden floors were chosen.

Two different load-bearing slabs (described in Fig. 1) were used in these floors. They consisted of the slab, different suspended ceilings, floating floors, or both. All floors had laminate covering. The impact sound insulation performances of the floors are shown in Fig. 1 and Table 1.

The experimental sounds consisted of recordings made for 15 wooden floors. On each floor, five natural impact sound types were presented and recorded:

- RB: rubber ball drop (2.5 kg, 25 cm drop height)
- SB: steel ball drop (33 g, 25 cm drop height)
- W: walking on 120 bpm pace (4.3 km/h)
- J: jumping in place with 140 bpm pace
- C: chair pushing (4.3 km/h).

These impacts were recorded in the same sound insulation laboratory, where the floors were built for sound insulation testing. However, the receiving room was transformed to a sound-absorbing space (RT under 0.50 s) during each recording to resemble living room acoustics. The SPL of background noise was under 16 dB L_{Aeq} (under hearing threshold). Recording was made using a condenser microphone and digital recorder in two positions of the room (A and B) to enable two psychoacoustics experiments A and B. This paper focuses on Experiment A.

The sound samples used in the psychoacoustic experiment were approximately 3–4 seconds long. Sound types W, J, and C were presented with their original paces. Sound types RB and SB were presented so that the same impulse was repeated at a pace of 60 bpm.

The recorded levels of sound types RB and J were, on average, high compared to three others. Therefore, the levels of all RB and J recordings were reduced by 10 dB and 5 dB, respectively, for the psychoacoustic experiment to avoid the saturation of annoyance responses.

The sounds were presented in the psychoacoustic laboratory. The SPL of background noise in the laboratory was 14 dB L_{Aeq} (under hearing threshold) being smaller than the faintest stimulus (Fig. 2). The sounds were presented to the participants using headphones, which had nearly flat frequency response within 20–3150 Hz. The frequency response of headphones was compensated using 1/3-octave band filtering. Playback level was measured using head-and-torso simulator. The levels were adjusted so that the measured level was within 1.5 dB L_{Aeq} from the target level measured in the impact sound laboratory.

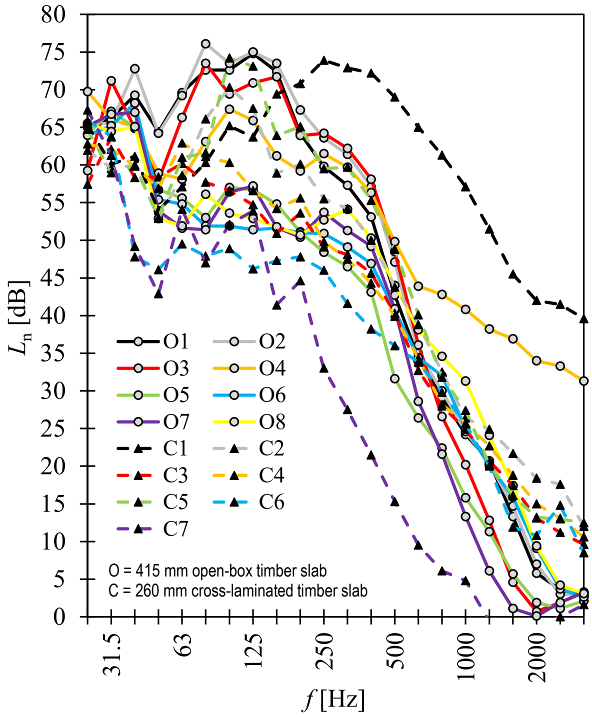

Fig. 1. Normalized impact SPL, L_n, as a function of frequency, f, for the 15 wooden floors.

2.2 Psychoacoustic experiment

The psychoacoustic experiment involved 52 normal-hearing participants. The experimental plan was approved by TUAS ethics committee.

The experiment involved five parts: hearing threshold test, familiarization to sounds, rehearsal or rating, Experiment A (75 sounds), and Experiment B (75 sounds). This paper contains only results of Experiment A.

The task was to rate the annoyance of each sound using an 11-step rating scale (0 Not at all, 10 Extremely much). The

participants had to listen to each sound for 8 seconds before the annoyance rating was enabled.
The list of 75 sounds consisted of 5 clusters (due to 5 sound types) to avoid too chaotic variation of impact sound types. The order of 5 clusters and 15 sounds within each cluster was randomized between participants.

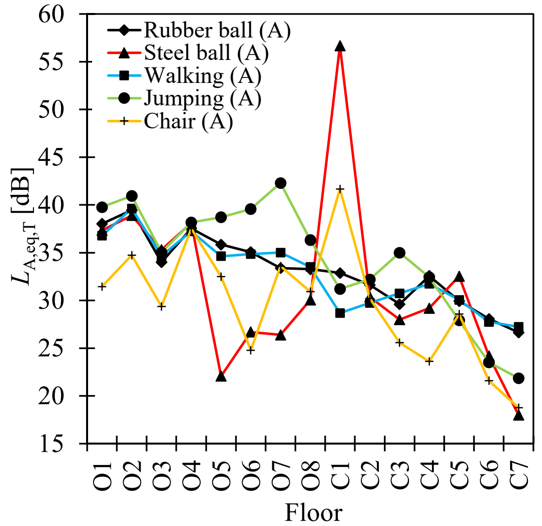

Fig. 2. The A-weighted SPL of experimental sounds in Experiment A for the 5 sound types and 15 floors.

Table 1. The single-number values of 15 floors.

Floor	$L_{n,w}$ [dB]	$L_{n,w} + C_{I,25}$ [dB]
O1	61	66
O2	63	67
O3	60	64
O4	56	60
O5	46	56
O6	44	57
O7	47	57
O8	46	56
C1	65	65
C2	55	59
C3	45	54
C4	47	55
C5	60	63
C6	39	53
C7	38	54

The analysis describing the association between mean annoyance of all participants and single-number values of the 15 floors was made using Pearson's correlation coefficient, r_P. This was made separately for each sound type. Coefficient values exceeding 0.64 are statistically significant (p<0.01, 2-way analysis). Mean of 52 participants was justified since the responses were normally distributed except for the most extreme annoyance ratings (close to 0 or 10).

3. RESULTS

The results are shown in Table 2. The analysis method is depicted for one sound type in Fig. 3.

Table 2. Pearson's correlation coefficient explaining the association between the annoyance and single-number values of 15 floors.

Sound type	$L_{n,w}$	$L_{n,w} + C_{I,25}$
Rubber ball	0.86	0.84
Steel ball	0.80	0.71
Walking	0.69	0.68
Jumping	0.59	0.57
Chair	0.75	0.64

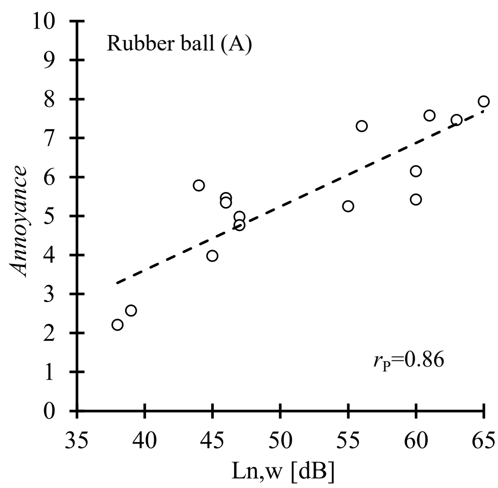

Fig. 3. An example of correlation analysis. The association between the mean annoyance (N=52) caused by rubber ball drop and normalized weighted impact SPL, $L_{n,w}$, for the 15 wooden floors.

4. DISCUSSION

$L_{n,w}$ explained annoyance of natural impact sounds equally well or better than $L_{n,w}+C_{I,25}$, depending on impact sound type. The finding is against Ref. [1] suggesting the opposite. Since our experimental setup is almost free from uncertainties related to stimulus level (each participant heard the same sounds), the scientific evidence of these results is very strong. However, it is possible that different result is obtained in the next experiment. Since our study and Ref. [1] contradict, it is important to have further research in this field.

Although the wooden floors have poor impact sound insulation below 100 Hz, and the linear SPL of natural impact sounds (except for SB) was mostly higher below 100 Hz than above it (not shown in this paper), annoyance perception of natural impact sounds could still be explained by impact SPLs above 80 Hz. This may be caused by the fact that hearing sensitivity (equal-loudness curves of ISO 226) reduces stronger towards low frequencies than the SPLs of impact sounds increase. A psychoacoustic follow-up analysis on this should be made to better understand the perceptional reasons for our finding.

Based on perception, it seems to be sufficient to conduct impact sound insulation measurements within 100–3150 Hz for wooden floors and assess their sound insulation using $L_{n,w}$. In field conditions, the counterparts are $L'_{nT,w}$ and $L'_{n,w}$.

Our experimental method of assessing the superiority of the two SNQs was strong since the experiment contained a large span of wooden floors, large number of natural impact sounds with extremely different spectra, large number of participants, highly controlled recording environment, and a qualified psychoacoustic laboratory with its equipment. In addition, all floors had laminate covering providing constant friction. This is very important to obtain comparable chair pushing sounds. These factors lead to the fact that the stimulus was very well controlled. The participants could focus on the stimulus with very high attention. Therefore, the outcomes of the experiment should reflect the perception of natural impact sounds transmitted by wooden floors to the best possible precision.

The volume of the receiving room of the sound insulation test laboratory was 76 m^3. In that environment, the following relationship holds: $L'_{nT} = L_n - 3.1$ dB. With the floors of this study, flanking transmission was absent since the lowest measurable $L_{n,w}$ of the laboratory was 24 dB. However, the SPLs are the most important for annoyance perception in psychoacoustic experiment: it does not matter whether the SPL origins from direct or flanking transmission. Therefore, the results are applicable also to field conditions.

We deliberately focused on wooden floors. The results only concern wooden floors within 38–65 dB $L_{n,w}$ (or 35–62 dB $L'_{nT,w}$). It would be useful to conduct a similar experiment also using a steel-reinforced concrete as a load-bearing slab to see how the results deviate from this experiment.

5. CONCLUSIONS

$L_{nT,w}$ explained annoyance of natural impact sounds on wooden floors equally or better than $L'_{nT,w}+C_{I,25}$. Based on perception, it seems to be sufficient to conduct impact sound insulation measurements of wooden floors within 100–3150 Hz and assess their sound insulation using $L'_{nT,w}$ or $L'_{n,w}$.

6. ACKNOWLEDGMENTS

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