How does the choice of the sound reproduction system affect the perceptual evaluation of impact sound insulation?

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Abstract
In listening test design, the choice of the sound reproduction system is often one of the least regarded issues and is guided dominantly by convenience, availability, or financial constraints. The influence of this choice on the results of listening tests specific for room and building acoustics has been made the topic of broader research. This paper presents the preliminary results of the study made within this framework on a listening test based on loudness matching, designed for subjective evaluation of impact sound insulation. The listening configurations considered in the study are: mono signal from four overhead speakers and a subwoofer; a 2nd order Ambisonics system; mono signal on uncalibrated headphones; mono signal on calibrated headphones with a flat frequency response; mono signal on a hybrid system using headphones and a subwoofer; a binaural Ambisonics system. The listening test is performed on all configurations and the differences in the obtained results are discussed.

Keywords: ambisonics, headphones, listening tests, impact noise, sound reproduction systems.

1 Introduction

Science and engineering use listening tests as a tool for getting information about the perception of different auditive phenomenons, and while there are many well-studied practices and standards for many listening tests [1], the influence of the choice of the sound reproduction system for perceptual evaluation of impact sound insulation is still not encompassed in a standard. This article presents the methodology and results of a preliminary listening test that tackles this question and is a continuation of the work presented in [2] and [3].

2 Methodology

Since the field of perceptual evaluation of impact sound insulation is still fairly young, its method is still being developed and there is no standard that could be used. For the base experiment, the methodology of [3] and [4] has been used with an added level of complexity by varying sound reproduction system used in the test.
Recorded signals used in this test have been measured and recorded in laboratory conditions. Objective impact noise parameters have been measured for each of the different floor constructions ($L_{n,w}$, $L_{n,w}+C_{I,50-2500}$) as well as the recordings of a heel-walking person [5] for each of the floors. Floors (coded in the analysis as CON1, BSP4, HBDS, HBD7) have been paired by matching their $L_{n,w}+C_{I,50-2500}$ single number quantity, and the listeners had to compare the perceived loudness of heal-walking noises for each floor.

Additionally, each of the floor pairs has been played over a set of different sound reproduction systems, to see how their choice influences the variability of the test results. In this experiment, six different sound reproduction systems have been tested.

3 Setup

The listening test is separated into two segments with regards to the master sound reproduction system (chosen randomly which one is first for each participant): one part is conducted via headphones (with 28 listening pairs), and another part is conducted via a 16.2 multi-channel loudspeaker system (14 listening pairs).
During the part with 16.2 multi-channel loudspeaker system participants listened to:
1-1) mono signal from four overhead speakers or a subwoofer and
2-2) 2nd order Ambisonics system
During the headphones part of the test the participants listened to four different headphones setups:
3-3) mono signal on uncalibrated headphones
4-4) mono signal on calibrated headphones with a flat frequency response
5-5) mono signal on a hybrid system using headphones and a subwoofer
6-6) a binaural Ambisonics system
The listening test has been developed in Max 8 programming environment and the user interface can be seen in figure 1. Participants were instructed to play the "Reference" walking stimuli and the "Sample" stimuli and to match their loudness. They were able to change the level of the sound sample in 1dB or 3dB increments. Once they matched the loudness they press "Next pair" button which sets a new pair of stimuli to be tested. Each floor configuration has been tested one time as a reference, and another time as a sample, and the second time with their places switched (eg. BSP4-HBDS and HBDS-BSP4). For analysis purposes, both cases were merged by inverting half of the listening pair results.

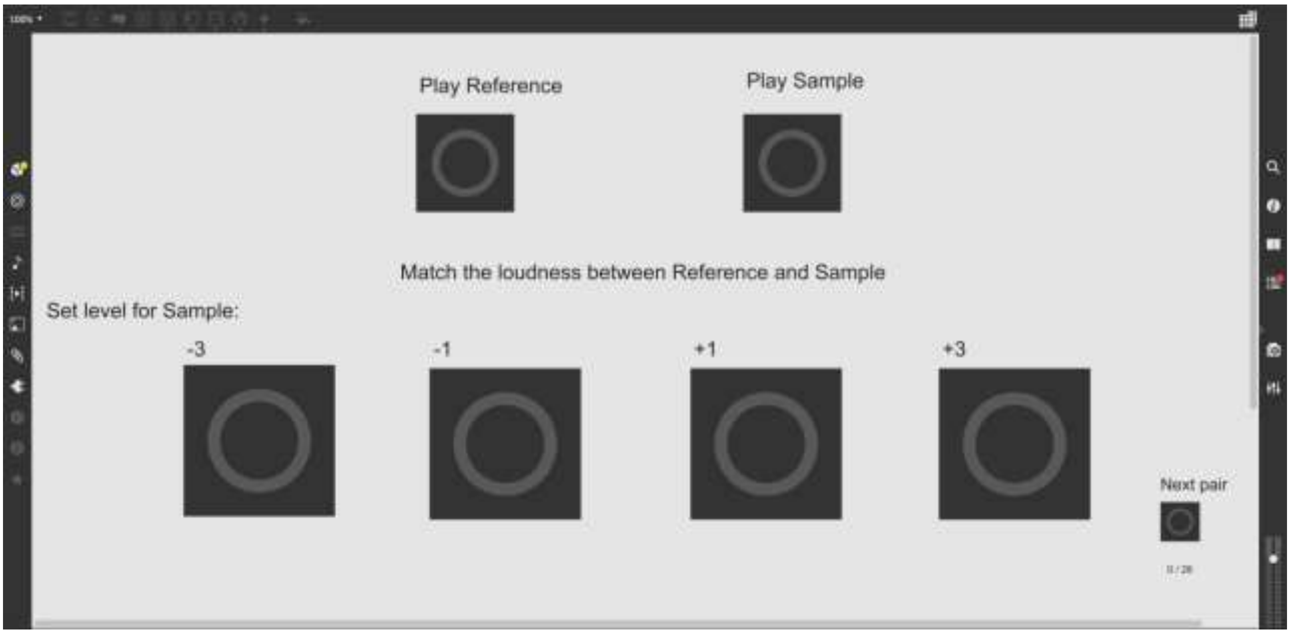

Figure 1 – Graphical user interface of the listening test.

IEM plug-in suite is used for 1-1 and 6-6 sound reproduction system configurations [7]. StereoEncoder with 70° elevation and continuously changing azimuth from 0° to 360°, as well as AllRADecoder and DistanceCompensator for decoding the ambisonics signal to 16.2 sound reproduction system, and

BinauralDecoder for decoding the signal to headphone system. Sonarworks Reference 4 has been used for frequency calibration of headphones.
Ten people participated in this preliminary test, 3 female and 7 male participants, with their ages ranging from 24 to 59.

4 Results

The results are shown in figures 2.-10. and table 1. Each figure presents a frequency graph with answers in 1dB steps on x-axis. A test pair where the same floor configuration is the reference and the sample (CON1-CON1) can be seen for each sound reproduction system in figures 2-8. Figures 9-11 show the same type of sound reproduction system but for different floor listening pairs. Table 1. presents the overview of the results in form of averages and standard deviations for all three listening pairs and all six different sound reproduction systems.

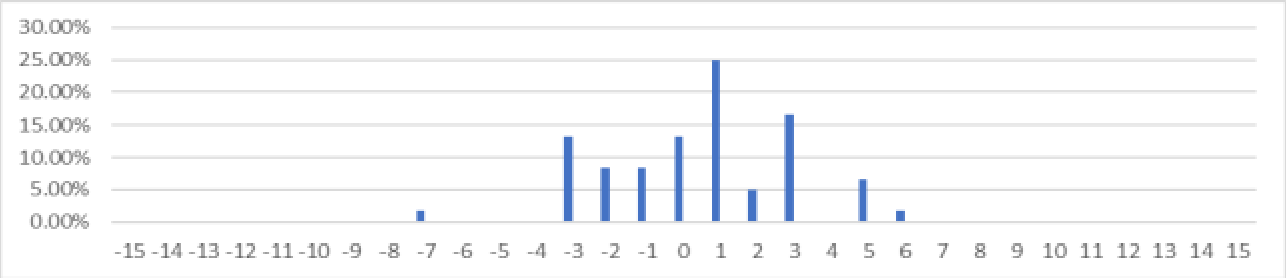

Figure 2 – CON1-CON1; All systems.

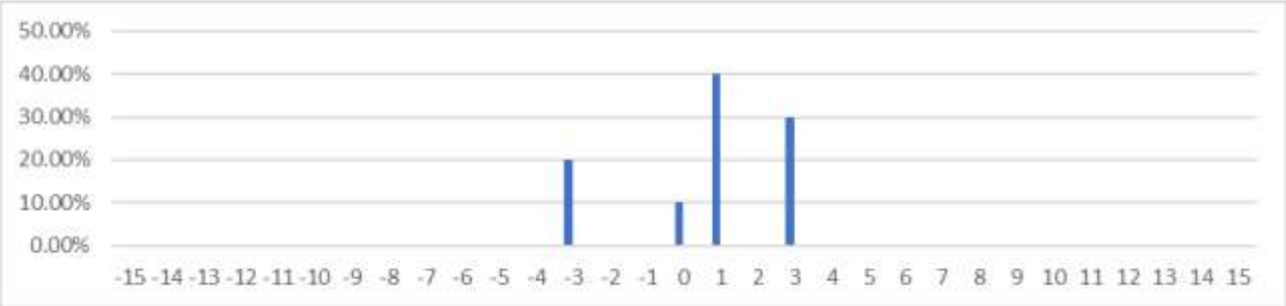

Figure 3 – CON1-CON1; mono signal from four overhead speakers and a subwoofer.

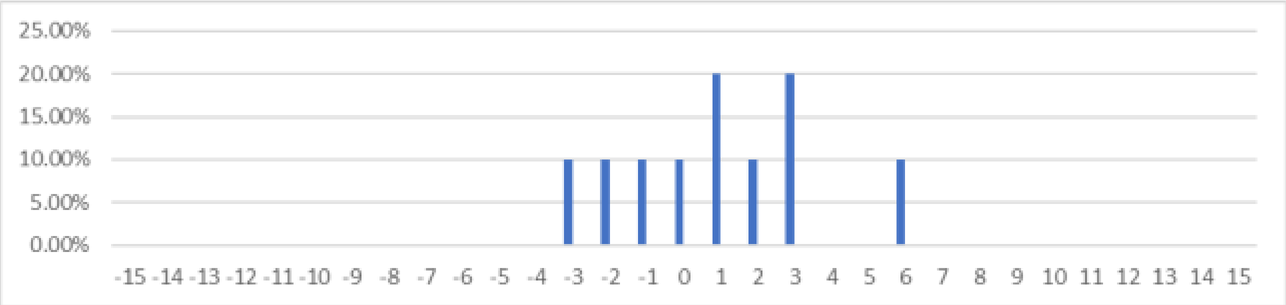

Figure 4 – CON1-CON1; 2nd order Ambisonics system.

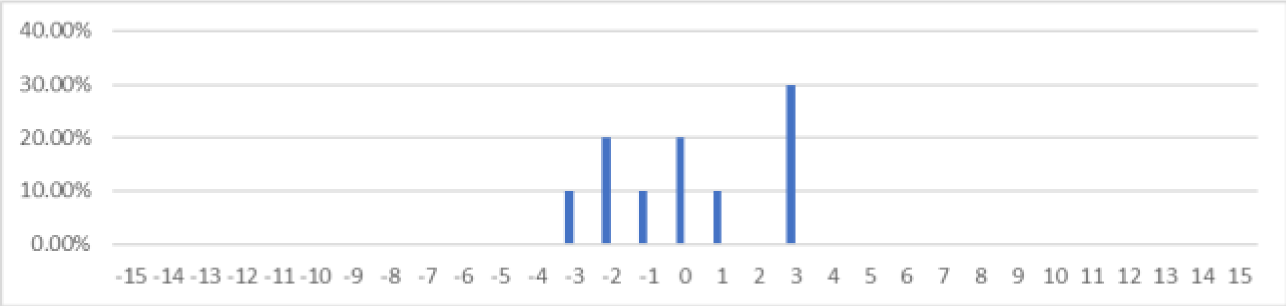

Figure 5 – CON1-CON1; mono signal on uncalibrated headphones

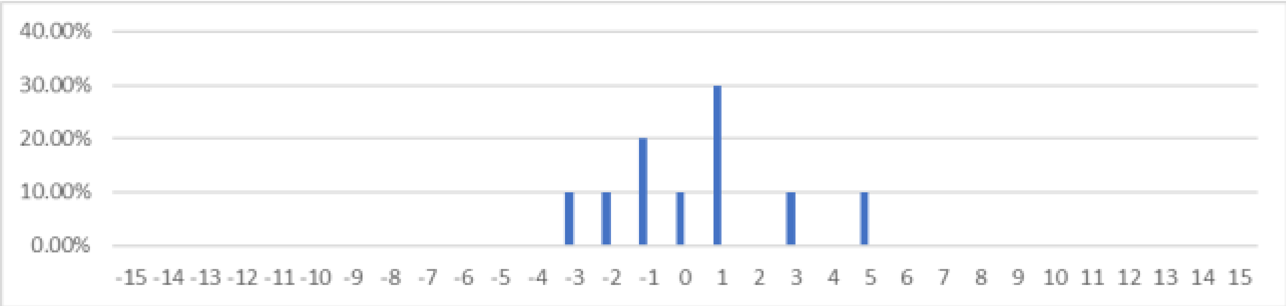

Figure 6 – CON1-CON1; mono signal on calibrated headphones with a flat frequency response.

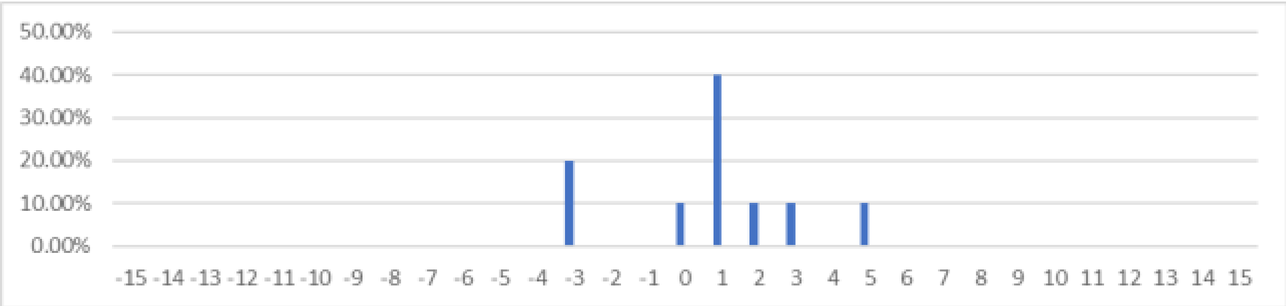

Figure 7 – CON1-CON1; mono signal on a hybrid system using headphones and a subwoofer.

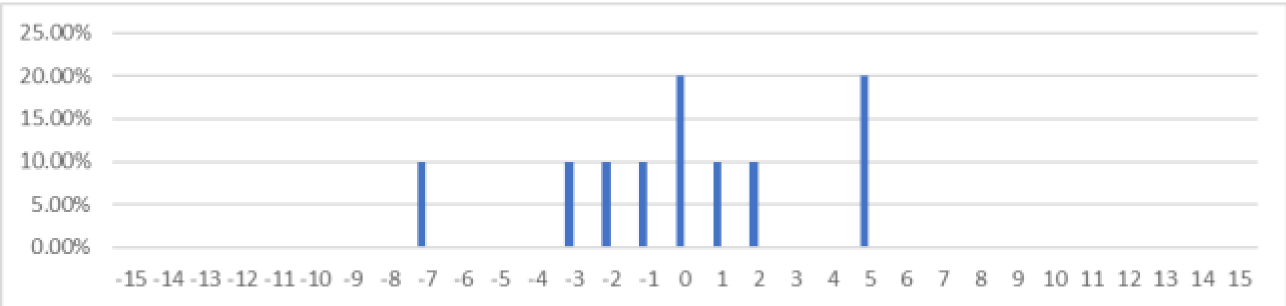

Figure 8 – CON1-CON1; a binaural Ambisonics system.

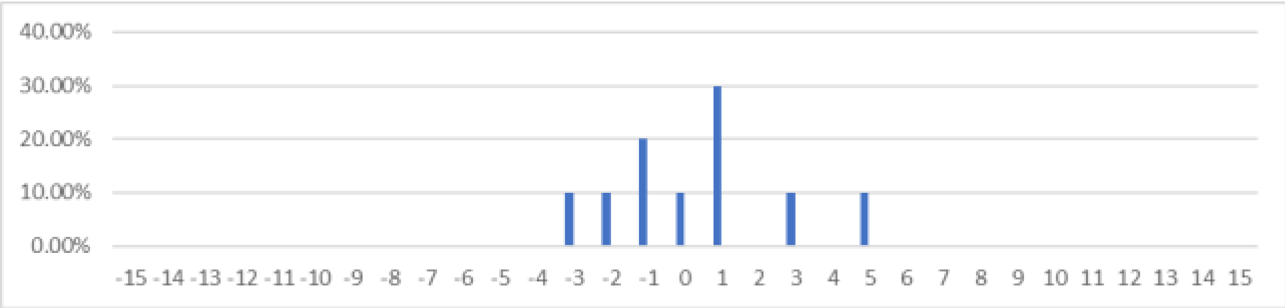

Figure 9 – CON1-CON1; mono signal on calibrated headphones with a flat frequency response.

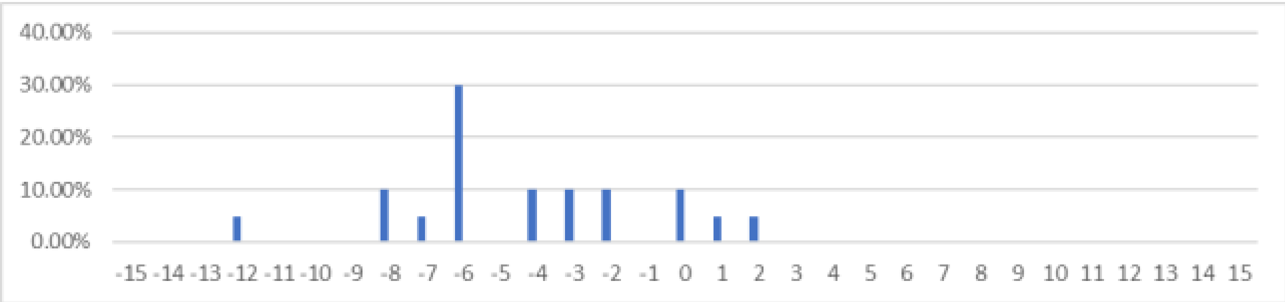

Figure 10 – BSP4-HBDS; mono signal on calibrated headphones with a flat frequency response.

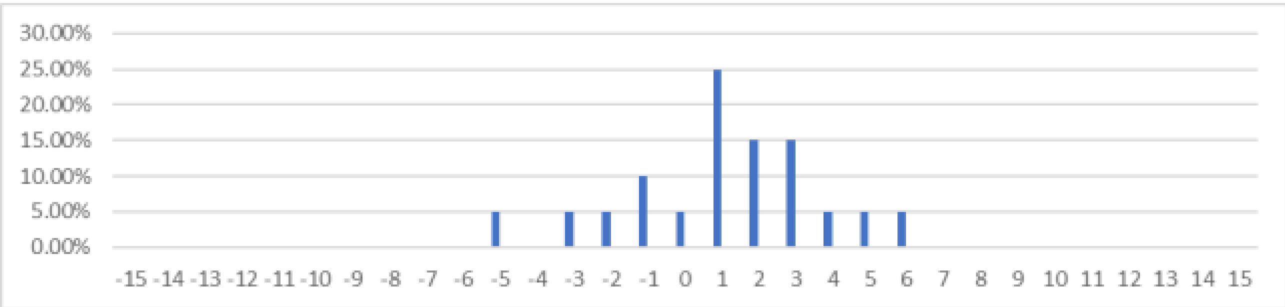

Figure 11 – CON1-HBD7; mono signal on calibrated headphones with a flat frequency response.

Table 1 – Overview of the results of the preliminary test.

Listening pair	BSP4-HBDS		CON1-CON1		CON1-HBD7	
Sound Reproduction System	Avg	StDev	Avg	StDev	Avg	StDev
mono signal from four overhead speakers and a subwoofer	-0.8	3.82	0.7	2.21	2.2	3.35
2nd order Ambisonics system	-1.9	4.15	1.0	2.67	2.8	4.02
mono signal on uncalibrated headphones	-1.4	2.06	0.2	2.25	1.0	3.00
mono signal on calibrated headphones with a flat frequency response	-4.3	3.48	0.4	2.37	1.2	2.66
mono signal on a hybrid system using headphones and a subwoofer	-0.7	4.34	0.8	2.44	1.8	2.75
a binaural Ambisonics system	-2.3	3.05	0.0	3.62	2.3	3.06

5 Discussion

Presented results show an interesting spread of uncertainty in a listening test for impact sound insulation. The standard deviation of each of the different parts of the test is smallest when comparing two identical signals (CON1-CON1), between 2dB and 4dB and is ~1dB greater for tests that compare two different sound samples (BSP4-HBDS, CON1-HBD7). The value of the standard deviation coincides with the human barely noticeable difference which is considered to be between 1dB and 3dB.
The overall average result for the comparison of the same signal (CON1-CON1) is +0.5dB, which means that listeners set the loudness of the controlled sample a bit louder than it should be to match their actual level.
Calibrated headphones should be considered as a reference to all the other measurements because the response of that system has a completely flat frequency response. However, the preliminary results show an unexpected tendency. The average result of this test is sticking out in some cases and the standard deviation does not have the lowest value compared to other listening test systems. The system with the smallest standard deviation should be considered as the most reliable sound reproduction source. Since the sample size is fairly small, only ten participants, these tests should be taken with the grain of salt as they could be within the possible error of the test.
The continuation of the work in this field will include a bigger sample pool of participants, with an expansion of the test to the perception of localization as well. The bigger sample size could produce the information about what would be the threshold for the number of participants in the listening test considering impact sound insulation to get the reliable and stable result.

Acknowledgments

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