7 - 12 SEPTEMBER 2014, KRAKÓW
FORUM ACUSTICUM

Perception of room size and ability of self-localisation in a virtual environment: headphone experiment

Vojtech Chmelík
Department of Building Structures, Faculty of Civil Engineering, STU Bratislava, 813 68 Bratislava, Slovakia

Juraj Francetić
Brodarski Institut, Zagreb, Croatia

Kristian Jambrošić, Marko Horvat, Hrvoje Domitrović
University of Zagreb, Faculty of Electrical Engineering and Computing, Zagreb, Croatia

Monika Rychtáriková, Christ Glorieux
Laboratory of Acoustics and Thermal Physics, KU Leuven, B-3001 Leuven, Belgium

Summary
This article reports results of two experiments performed in a collaboration between the University of Zagreb, Croatia, and KU Leuven, Belgium. Four different rectangular rooms are simulated and compared: a small room of 30m^2, a large room of 2016m^2, a medium size room and a corridor with the same volume of 252m^2. The average sound absorption and scattering coefficient in the 4 mentioned rooms are varied. Auralizations were performed for 2 stimuli: a sequence of hand-claps (expressing the sound that a listening person would produce him/herself) and human steps (expressing a person passing by). In the first experiment we investigate how much information about the shape and a size of the room a normally sighted person is able to grasp from purely acoustical stimuli, presented over headphones. This experiment was performed in the medium size room. In the second experiment, the accuracy of a listening person to indicate her/his position was assessed in the 4 virtual rooms. The virtual environments were created in Odeon® software and the results were statistically analyzed.

PACS no. 43.55.-n, 43.55.Ka, 43.55.Hy

1. Introduction

The combination of acoustic and visual information (i.e. audiovisual information) is crucial for people to localize themselves in a surrounding environment. People with visual impairment intensively exploit the availability of auditory and haptic cues to compensate their missing sight. Although they do not receive more or better acoustic information than people with good sight and hearing, they are able to extract more information from perceived audio stimuli. The ability of visually impaired people to explore the surrounding area using just their ears is amazing. In addition to very accurate localization of a sound source, they are also able to reconstruct the geometry of the surroundings and indicate their position therein [1], [2].

Research that focuses on differences in processing of acoustical information by visually impaired people on one hand and normally sighted people on the other hand has been ongoing for a long time. Experiments on how early- and late-onset blind persons differ in perceiving the environment around them has been studied in [3], [4]. The ability of people to localize objects on the basis of sound reflections has been investigated and described by several authors [5].

The experimental work presented in this article is a follow up of our previous research work, which showed via listening experiments that people are able to detect differences between different rooms with various volumes, degrees of absorption and reverberation times [6].

2. Experiments

Two different laboratory listening test experiments were performed. The first test was oriented on the determination of the listening person's position in a simulated room, and the second on finding differences between rooms with various sizes and volumes.

1.1. Acoustical simulation

All of the simulations were performed with acoustical prediction software ODEON®. This software makes use of a hybrid prediction algorithm, which combines an image source method and method of early scattered rays with special ray-tracing and radiosity method that is used for calculation of late reflections. [7]

1.2. Stimuli

Two natural sounds with impulsive character were used in the experiment. The first one was a hand clap as produced by a standing person. The source was simulated always at a distance of 0,7 m from the receiver's ears. The idea was to investigate the sound produced by the listener himself. The second stimulus was the sound of footsteps of a person moving through the room, while the receiver's position and head orientation stayed unchanged.

1.3. Test subjects

Listening tests were performed with fifteen human subjects. The listeners were aged between 19-47 years. All of them were normally hearing people, 11 men and 4 women. Two of the test persons reported that they have at a basic knowledge in acoustics.

1.4. Laboratory listening tests

The listening tests were performed in an anechoic chamber of the Laboratory of Acoustics and Thermal Physics at KU Leuven, to ensure a quiet environment without any disturbing noises from outside or inside. Preliminary to the test, each subject obtained some basic information about the test and short instructions, how to perform it.
The task of a subject in the first experiment was to decide about her/his position the virtual room based on two different stimuli.
In the second experiment, which was conceived to investigate people's ability to assess the size of a room, the test persons were asked to associate sounds with one of the 4 rooms.

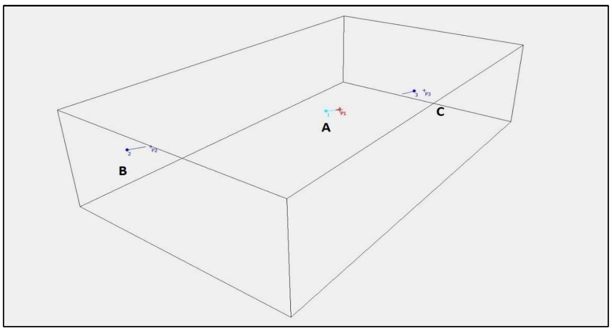

Figure 1. Room 1 - medium size, 12 m x 7 m x 3 m. Three simulated positions - A, B and C

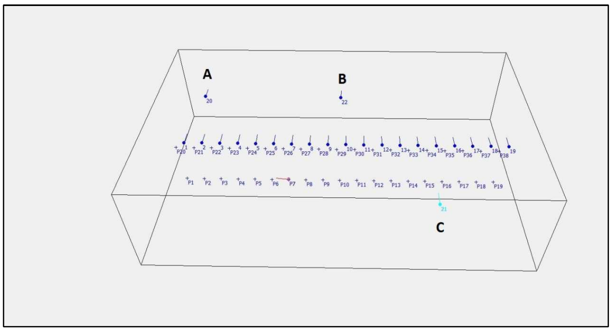

Figure 2. Location of foot steps of a virtual walker used as a source for the simulations.

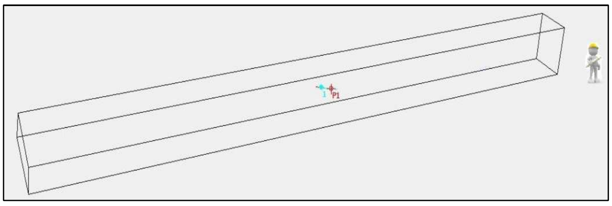

Figure 3. Room 2 - Long corridor with dimensions of 35 m x 2.4 m x 3 m.

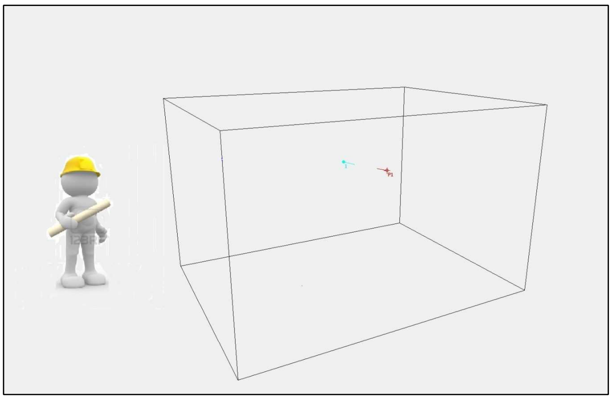

Figure 4. Room 3 - small room with dimensions of 4 m x 3 m x 2.5 m.

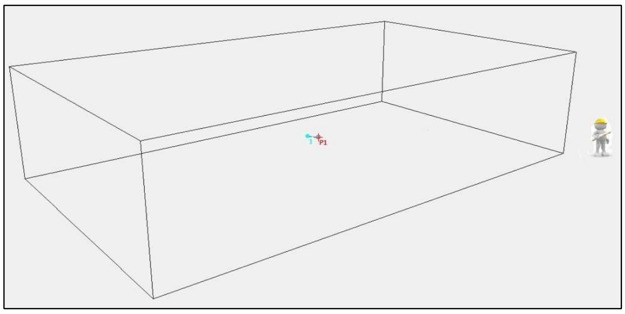

Figure 5. Room 4 - large room with dimensions of 4 m x 3 m x 2.5 m.

1.5. Experiment 1: self-localisation in a medium sized room

The virtual acoustical scenario used for this experiment was a simple shoe-box shaped room with dimensions of 12 m x 7 m x 3m. The volume of the room was 252 m^3. In order to investigate the influence of room acoustical parameters on people's ability to localize themselves in a room, a series of scenarios were simulated. The absorption coefficient of the surfaces in the room was varied between the values 0.1, 0.2 and 0.4, except for the floor, which was kept acoustically reflective. For each case, also the scattering coefficients of surfaces were also varied. In a first scenario, the scattering coefficient was set to 0.05. Also a case with a ceiling having a scattering coefficient of 0.9 was simulated. In another scenario, the scattering coefficient of all surfaces were set to 0.9 for one of the walls and 0.05 for all other surfaces. In total, 9 different configurations were simulated and used in laboratory listening tests.

In the first part of the test the simulated listener was standing in one of three simulated positions (position A - corner of the room, position B - center of the room, position C - random position) (Figure 1). The task for the tested person was associate 3 simulation based auralized sounds with the three positions (A,B,C) at which the sounds appeared to be heard.

In the second part of the first test, the stimuli were based on footsteps of a walkthrough virtual person in virtual environment, who walked along the length of the room, as shown in the Figure 2. The orientation of the receiver in the simulation was towards the center of the room. The task in the second part of the first experiment was the same as in the first part, i.e. to associate the perceived listening positions with one of the 3 positions in the virtual room.

1.6. Experiment 2: room size assessment

In the second experiment, four different rectangular rooms were simulated: Room 1 was the same as in the experiment with self-localisation; Room 2 (Figure 3) was a long corridor with dimensions of 35 m x 2.4 m x 3 m, and the same volume of 252 m3 as Room 1. Room 3 with dimensions of 4 m x 3 m x 2.5 m and a volume of 30 m3 was the smallest one (Figure 4) and Room 4 the largest, with doubled dimensions

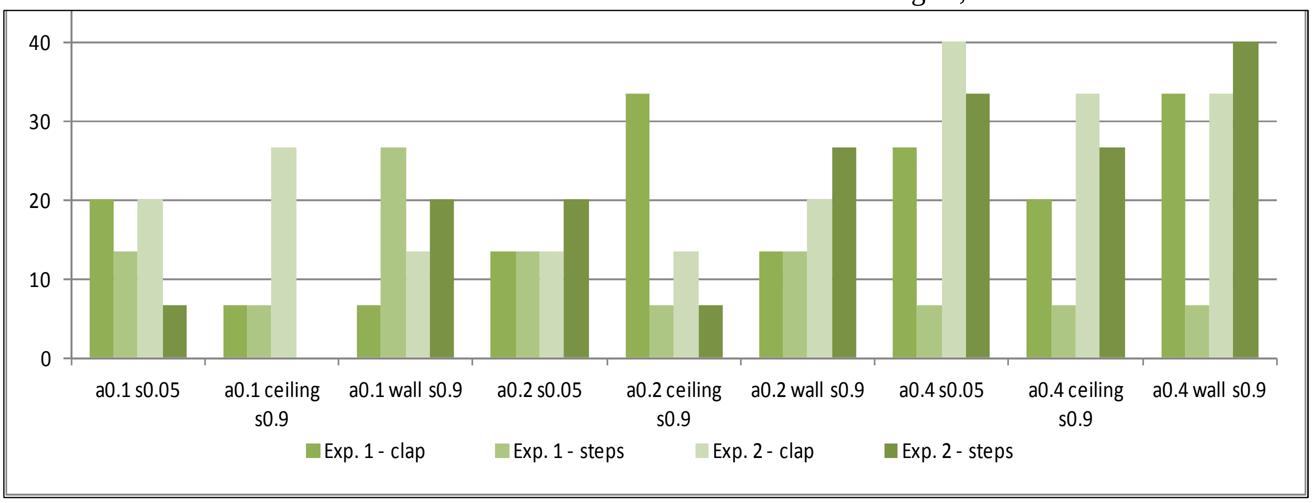

Figure 6. Percentage of correct answers in the listening experiments. Absorption (a) and scattering (s) values are indicated.

in comparison with Room 1, i.e. 24 m x 14 m x 6 m and a volume of 2016 m3 (Figure 5). The same 9 configurations (related to absorption and scattering properties) as in the first experiment.
In the first part of the experiment, the simulated listener was always simulated standing in the middle of the room and listening to series of sound claps produced by him/herself. The task of the subject was to identify the room (Room 1 - 4) in which the sound was produced.
In the second part of the test, the stimuli were based on sound produced by a (simulated) person walking along the room (its central axis), producing the sound of 11 steps. The task was the same as in the first part of the experiment 2, i.e. to identify the room in which the sound was produced.

3. Results and discussion

Figure 6 shows the percentages of correct answers in listening tests performed by test subjects for each of the 9 configurations.
In most cases the percentage of correct answers are hardly above guessing values, indicating that people were hardly able to correctly identify their positions in the room. better though for sound produced by a walking person, compared to hand-clap sounds.
The influence on the accuracy of the estimates on the acoustic conditions of the room (different absorption and scattering) is depicted in Figures 7-10. The performance improved when the absorption was higher, for both hand-clap and steps (Figure 8). In the case of self-localisation, no significant influence of scattering was found for hand-clap stimuli (Figure 9). When footstep sounds were used, then scattering on the side wall, was slightly beneficial (Figure 10).

Acknowledgements

The paper partly originated within the framework of the Scientific Grant Agency VEGA 1/0358/13 project.
We would like to acknowledge Marie Jiříčková for help with the listening test experiments.

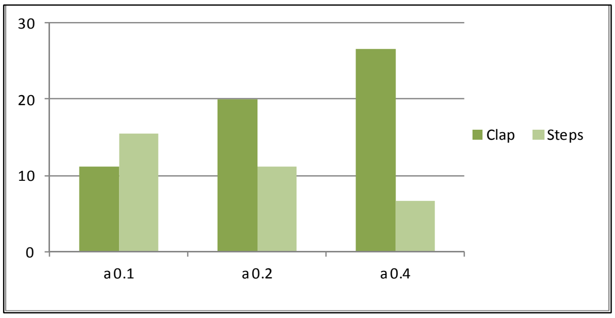

Figure 7. Self-localisation: percentage of correct answers for different values of absorption coefficient and scattering coefficient

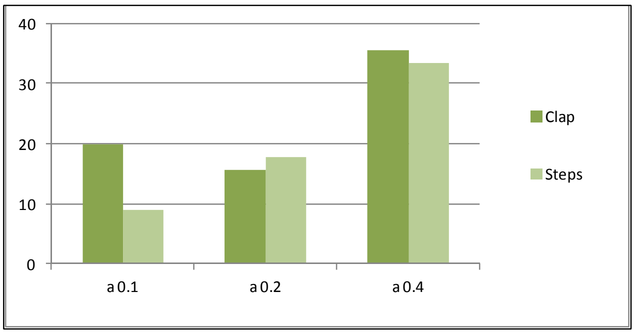

Figure 8. Room size assessment: percentage of correct answers for different values of scattering and scattering coefficient.

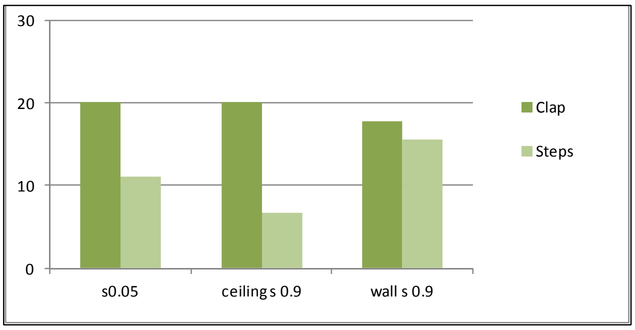

Figure 9. Self-localisation: percentage of correct answers according for different values of scattering and absorption coefficient.

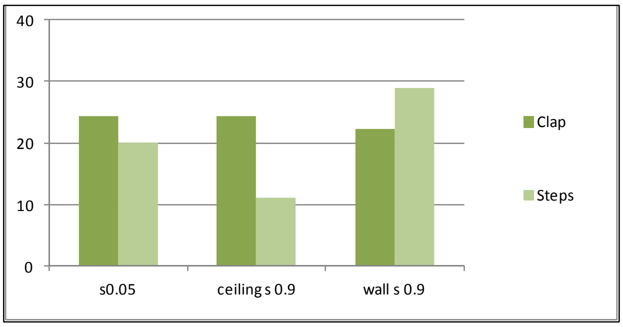

Figure 10. Room size assessment: percentage of correct answers for different values of scattering and absorption coefficient.

References

[1] John M. Hull, "On Sight and Insight. A Journey into the World of Blindness", Oxford, 1990.

[2] David Pelegrin Garcia, Monika Rychtáriková, Christ Glorieux: Interactive auralization of self-generated oral sounds in virtual acoustic environments for research in human echolocation, In Proceedings of Forum Acusticum 2014, Krakow, Poland

[3] N. Lessard, M. Pare, F. Lepore: Early-blind human subjects localize sound sources better than sighted subjects. Nature 395 (1998) 278-280.

[4] P. Voss, F. Gougoux, R. J. Zatorre: Differential occipital responses in early- and late-blind individuals during a sound-source discrimination task. Neuroimage 40 (2008) 746-758

[5] Rosenblum, E.D., et al.: Echolocating distance by moving and stationary listeners. Ecological psychology 12 (2000), nr. 3, 181-260

[6] V. Chmelik: Principles of inclusive design in architecture and room acoustics. doctoral thesis, Slovak university of technology, Bratislava, 2013

[7] J. H. Rindel: The use of computer modeling in rom acoustics. In Journal of Vibroengineering 12 (2000), nr. 3, 181-206