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2aPPa1. Experiments on authenticity and naturalness of binaural reproduction via headphones

Janina Fels*, Josefa Oberem and Bruno Masiero

***Corresponding author's address: Institute of Technical Acoustics, Medical Acoustics Group, RWTH Aachen University, Aachen, 52074, NRW, Germany, Janina.Fels@akustik.rwth-aachen.de**

Binaural stimuli presented via headphones need to be plausible in localization and sound coloration for a successful reproduction of an acoustic scene, especially for experiments on auditory selective attention. The goal is to provide artificially generated acoustic scenes in a way that the difference between a real situation and an artificially generated situation has no influence in psychoacoustic experiments. The quality and reliability of binaural reproduction via headphones comparing two different microphone setups (miniature microphone in open dome and ear plug) used for individualized Head-Related Transfer Functions and headphone transfer function measurements is analyzed. Listening tests are carried out focusing on authenticity, naturalness and distinguishability in a direct comparison of real sources and binaural reproduction via headphones. Results for three different stimuli (speech, music, pink noise) are discussed.

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INTRODUCTION

In virtual environments or psychological experiments like investigations on auditory attention [3, 4, 5, 7] a natural and authentic binaural reproduction is desired. This investigation focuses on the authenticity and naturalness of binaural reproduction via headphones. To analyze the indiscernibility between a binaural reproduction via headphones and real sources, individual HRTFs with blocked and open auditory canals are measured. A listening test to examine the sound quality is performed in an anechoic chamber.

MEASURING METHODS AND EQUIPMENT

Equipment used in this investigation is depicted and described in the following paragraphs. Furthermore, the approach of binaural synthesis is explained.

Microphones

To measure individual HRTFs and Headphone Transfer Functions (HpTFs), miniature microphones (*Sennheiser KE-3*) are fixed to the entrance of the participant's ear. Hammershøi [6] showed that the entrance of the ear canal is a suitable point for binaural recordings, since the further sound propagation towards the eardrum is independent of the direction of incidence. The miniature microphone is either fixed by an earplug or a little silicon carrier called Open-Dome.

Headphone and loudspeakers

On account of findings by Møller et al. [10] as well as further investigations by Völk [13] an open headphone (*Sennheiser HD 600*) is used for binaural reproduction, showing a coupling similar to the coupling to free air.
Coaxial loudspeakers used for the listening setup are built at the *Institute of Technical Acoustics, RWTH Aachen University* and its frequency response has been compensated.

Room setup for listening test and measurements

The listening tests takes place in a fully anechoic chamber. The subject is asked to sit inside a frame of 24 loudspeakers (cf. Figure 1), which are equally distributed over azimuth and three elevation levels. The chair is provided with a backrest, armrests and an adjustable head rest. To control and minimize the movements of the subject's head an electromagnetic tracker (Polhemus Patriot) is used during HRTF measurements and the listening test. Limits for the allowed head movements are set to ± 1 cm in translation and $\pm 2°$ in rotation. To take the focus from the visual sense to the aural, lights are turned off during the listening test [1, 12].

Subjects

A number of 80 unpaid students and doctoral candidates aged between 20 and 36 who indicated normal-hearing, participated voluntarily in the experiment. All listeners, 40 of each sex, can be considered as non-expert listeners, since they are not trained in listening tests.

Binaural measurements, synthesis and equalization method

HRTFs are measured individually for every subject. Since HRTFs are measured statically from the given 24 loudspeakers the position of the subject inside the frame is monitored and

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FIGURE 1: Anechoic room with loudspeaker setup and subject.

saved with the help of the electromagnetic tracking system. To make the direct comparison of real sources and binaural reproduction without moving headphones during the listening test possible, subjects also have to wear headphones during the HRTF measurement.
In a second step HpTFs are measured to calculate an adequate robust equalization. After Masiero and Fels [8], headphones are repositioned on the subjects head after each of in total eight HpTF measurements. The equalization is calculated using the mean of the HpTF measurements. Since phase information is lost at this process, minimum phase is used. Furthermore, notches in the high frequency range are smoothed.

EXPERIMENTAL DESIGN

Stimuli

Three different stimuli were presented:

- Pulsed pink noise [200 Hz – 20 kHz] (0.8 s)
- Music [200 Hz – 10 kHz] (1.8 s)
- Speech [200 Hz – 8 kHz] (0.8 s)

Experimental procedure

Every subject delivers one block including 20 trials of every stimulus. Direction of incidence, level and stimulus are randomized but equally distributed over all participants. An in-between-subject-design is used, which is why half of the subjects belong to the group of open meatus and the other half to the group of blocked meatus. A 3-AFC design is used for the listening test. Therefore, in a trial one stimulus (e.g. pink noise) is played three times in a row. Either one is played by loudspeakers (a), whereas the other two are binaurally reproduced by headphones (b), or the other way around (possible orders: aab, aba, baa, bba, bab, abb). The order of reproduction

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methods is randomly chosen and equally distributed over all subjects and over all directions. Moreover, playing levels are roved in 1 dB steps between 60 dB and 70 dB. Written instructions and buttons for the answer of a trial are given on a tablet computer.

RESULTS AND DISCUSSION

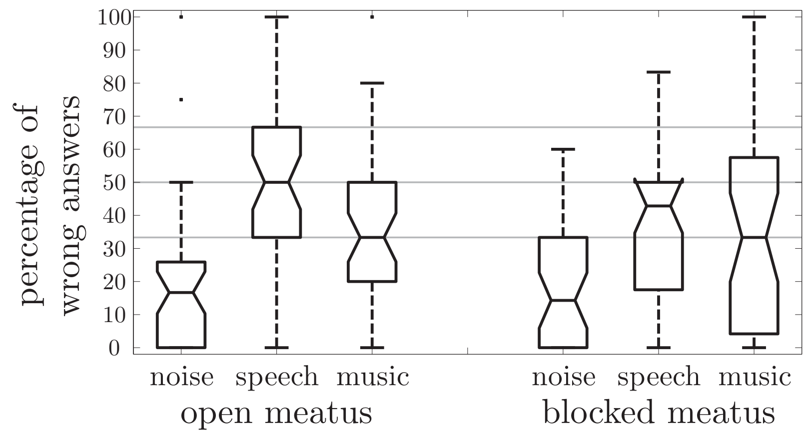

FIGURE 2: Results of a direct comparison of real sources and binaural synthesis in 3-AFC design with three different stimuli.

The results of the experiment are shown in Figure 2 in six box-plots. The percentage of falsely answered trials are used to calculate medians, inter-quartile range and whiskers including the adjacent values, as well as outliers. For both the open meatus (shown on the left in Figure 2) and the blocked meatus (shown on the right in Figure 2) variations are large. Analyses of variance (ANOVAs) of the given data regarding the kind of stimulus are carried out and do not differ for the two measuring methods for pink noise ($F(1,39) < 1$) and for music ($F(1,39) < 1$). The ANOVA regarding speech yields a significant effect of the measuring method ($F(1,39) = 4.17, MSE = 534, p < .05$) indicating a higher rate of errors for participants of the group of open meatus. In general, despite the kind of stimulus no difference between the measuring methods can be found ($F(1,39) = 2.22, MSE = 630, p > .1$).

Within one measuring method further ANOVAs are performed, which show for both measuring methods that subjects do the least number of errors when pink noise is played. The ANOVA for the group of open meatus yields a significant difference between all stimuli, further examined with a post-hoc Bonferroni test ($F(2,78) = 15.33, MSE = 551, p < .001$), indicating a higher error rate for the stimulus of speech than the stimulus of music as well as for the stimulus of pink noise. Very similar results can be seen for an ANOVA within the group of blocked meatus ($F(2,78) = 10.04, MSE = 500, p > .1$). The main difference to the results of the group of open meatus is that error rates for music and speech do not differ significantly.

On account of the 3-AFC design a greater percentage of wrong answers than 33.3% denotes that subjects are not able to hear a difference between the real source and the binaural reproduction in 50% of all played stimuli. This is the case for music and speech for both measuring methods. Moreover it can be stated that for the group of open meatus subjects are not able to hear a difference between the presented stimuli in 75% of all trials. However, for the stimulus of pink noise subjects have less difficulties to distinguish. In subsequent surveys participants also stated how pink noise was easier to distinguish due to coloration in higher frequencies as well as slight changes in location. The latter were also mentioned for the other stimuli presented.

Further analyses show no significant influence by gender, specialization in acoustics, playing level or direction of incidence.

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CONCLUSION

Findings from PDR measurements as stated by Møller [9] showing worse results for an open auditory canal than for a blocked ear canal cannot be confirmed by the outcome of the listening test. Subjects of both groups show the same behavior regarding the ability to distinguish between real source and binaural synthesis in an anechoic environment. The consequence of these results is that the condition of the ear canal is not of major importance when headphone equalization and binaural synthesis are adequate. Additionally, to the findings in previous localization tests [2, 11, 14], where localization with real sources and binaural reproduction via headphones is identical, statically validated findings regarding the naturalness of binaural reproduction and indiscernibility can be made. By reason of the results of this investigation it can be noted that at least 50% of all subjects are not able to distinguish between real sources and binaural reproduction when stimuli like music and speech are directly compared. Stimuli with a greater frequency range up to 20 kHz like pink noise are more easy to distinguish.

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