Influence of Source-Receiver Distance in Reverberant Room on Front-Back Confusion

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Summary
Previous studies have shown a positive impact of sound reveberation of a room on front-back localisation performance of sound stimuli based on non-individualized head-related tranfer function (HRTF) within reverberation radius. This paper focuses on a comparison of front-back sound localisation performance for cases where a virtual loudspeaker was placed at 5 different distances from the binaural receiver (inside and outside the reverberation radius). Listening tests were based on simulated broad band noise stimuli (500 ms) in a reverberant room at one receiver position and 30 positions of sound sources with two different directivity patterns (omnidirectional and directional). Results show statistically significant differences in source localisation performance for near and far sources.

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1. Introduction

The three dimensional sound source localisation by people belongs to rather complex processes in which the spectral and temporal cues play a very important role. For the ability to localise the direction of the sound source in the horizontal plane, two cues are responsible: Interaural Level Difference (ILD) and Interaural Time Difference (ITD) [1]. When distinguishing the sounds arriving from the front or from the back, highly individual spectral (and monaural) cues are used. The acoustic filtering effects of the pinnae are therefore essential [2].

Front–back discrimination has been therefore reported as very difficult, if not impossible, when sound is based on a non-individualized head related transfer function (HRTF), such as when listening through headphones to sounds recorded or simulated with another person's HRTF or hearing aids. Front-back localisation issues are therefore relevant not only in case of healthy persons but also in case of people wearing hearing aids. Effective sound localisation can improve the quality of life in terms of better spatial orientation, speech understanding in crowded situations etc. Some previous studies [3] have indicated that room reflections do not disturb sound localisation thanks to the precedence effect. In our previous studies we have even found that the presence of the diffused sound field (in rooms), in addition to the direct sound, might even enhance sound localisation with non-individualized HRTF, thanks to more robust cues based on the perception of direct-to-reverberant sound ratios. Experiments presented in this article follow our previous works [4-5] and show the performance of 5 subjects on front-back localisation with simulated sound samples in a reverberant room at different distances from the sound source and for two source directivity characteristics.

The whole preliminary study is based on stimuli auralized in a virtual reverberant room simulated in ODEON® v9 software.

2. Experiments

1.1. Description of the model

The reverberant room at KU Leuven, with a volume of 200m^3, has been modeled in the room acoustical software ODEON®.

This room has been used as a case study in one of our previous experiments [4]
where the measured and simulated binaural room impulse responses were perceptually validated for sound source localisation experiments.
Simulations in the reverberant room were performed for one position of receiver (always facing towards position No.1 at 0 degrees in the front) and 30 positions of sound source as shown in the Figure 1, always aiming at the receiver. Two sets of simulations were done, one for an omnidirectional and one for a directional sound source, with the directivity of a human talker.

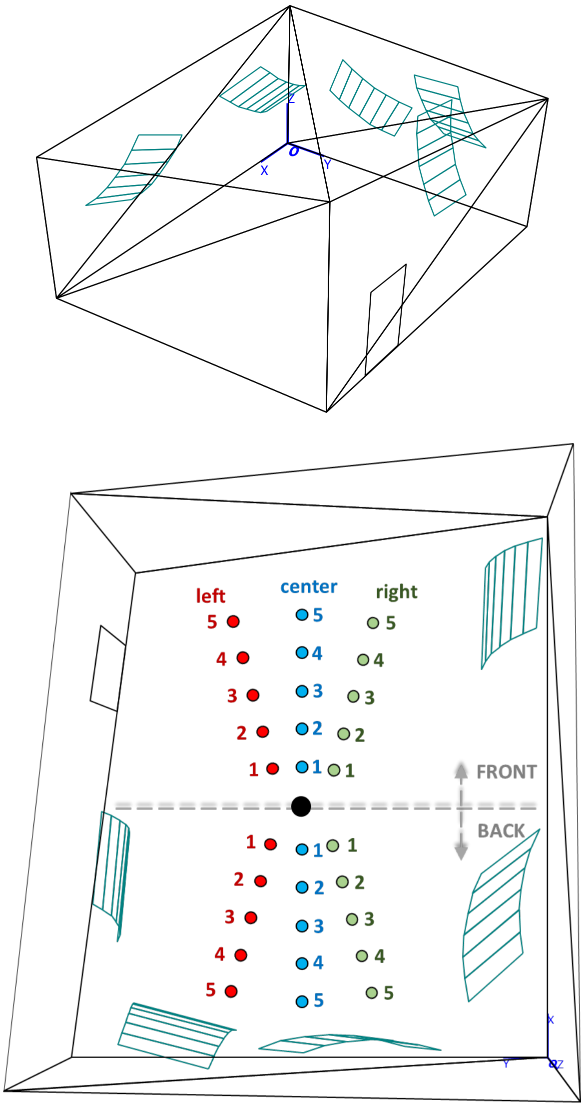

Figure 1. Acoustic model in Odeon (upper picture) with receiver (black circle) and loudspeaker (red, blue and green dots) positions

1.2. Stimuli

Listening tests were based on simulated broad band noise stimuli (500 ms) with the spectrum of average human speech. For the sake of optimal comparison with previous works, binaural simulations were done with HRTF of the known artificial head CORTEX® MK2 manikin, used in the previous experiments [4-5].

1.3. Subjects

Five (5) human subjects participated in the preliminary study. All of them had a normal hearing and had not reported any hearing problems in the past

1.4. Listening test protocol

Listening tests were performed in the anechoic room at KU Leuven by means of the listening unit Head Acoustics®. The task of the subject in the listening tests was to identify if the sound (presented via headphones) was coming from front or from the back, disregarding the directions left-right-central. The virtual sound sources were distributed in an angle span of ±15 degrees in the horizontal direction, so it was presumed that subjects would not make errors in azimuthal angles. Note that the errors that humans typically do in localisation of frontal horizontal angles is typically less than 15 degrees [6].
Each source position was presented three times (3x) in random order, with roving level up to 6 dB, so that people wouldn't be able to use loudness as an indicator.

3. Results and discussion

To understand the localisation mechanism in more detail, the "Front-Back" (i.e. trials with source in the front) and the "Back-Front" (i.e. trials with source at the back) answers were analysed individually as shown in Figures 2 and 3 respectively. In both cases some trends are visible.
The percentage of correct answers is given in the "y" axes" and the case (source-receiver) in the "x" axes. Results indicated by a black colour are based on tests with omnidirectional source and gray colour is used for directional source.
The positions from 1 to 5 on the "x" axes correspond to the distance between the source and receiver in 0,5m step (see also Figure 1). In both Figures (2 and 3), the first 5 results are expressing the positions on the left side of the listener (in red), next 5 positions are central positions at 0 or 180 degrees (blue) thus exactly in front (in Figure 2) and exactly behind (in Figure 3) the listener and last 5 positions in the figure (green) are on the right side of the listener. In Figure 2, that shows the Front-Back results, one can see an effect of distance between the source and receiver on the %

of correct answers for both, omnidirectional and directional sources.
People do more mistakes (i.e. they hear the sound coming from front as if it was coming from back) for source positions placed at larger distances. This can be explained by changes in the direct-to-reverberant sound level in comparison with near source positions (0,5 and 1m). (Note that the reverberant radius in the reverberant room is very short, around 0,3-0,5m depending on frequency in the range 125-4000Hz). When sound source is at the maximal distance (Position 5 at 2,5m from the source), the localisation accuracy is only 50%, whereas at position close to the source (within the reverberation radius), 80-100% answers are correct.

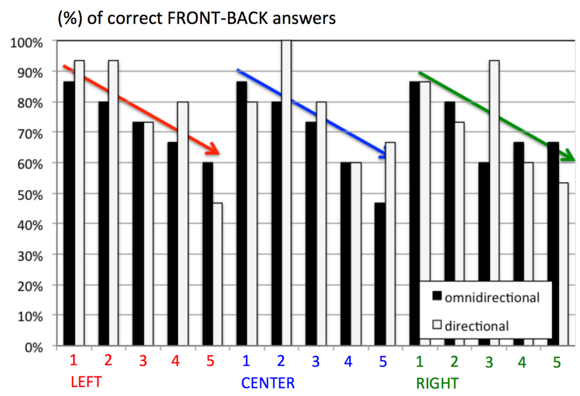

Figure 2. Percentage of correct answers when localising sources in front of the listener.

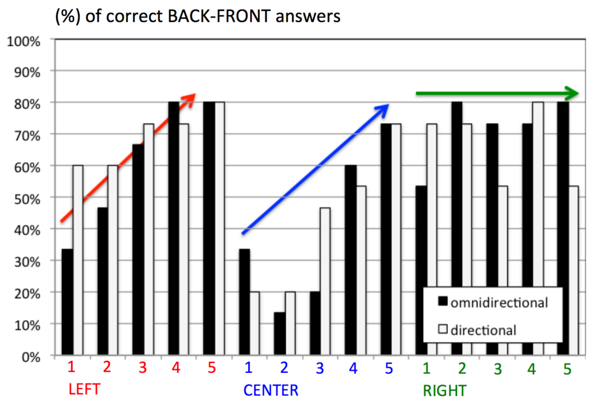

Figure 3. Percentage of correct answers when localising sources behind the listener.

In the situations when sounds were positioned behind the listener (i.e. Back-Front situation in Figure 3), inverse trends were observed. In this analysis, most of the subjects were surer that sound was coming from the back when sources were at distances larger than 2 m behind them (accuracy of around 70-80%).

We can see that the positions at 0,5-1m behind the receiver were more often associated with frontal angles. However, this is valid only in case of localisation of left and central angles. Interestingly, a different trend in localisation performance is observed for sources on the right side of the listener, where results were too much scattered to be able to draw a trend line.

4. Conclusions

The presented preliminary study shows some trends in front-back and back-front localisation performance of sound sources placed at different distances from the receiver. Different trends are found for front-back and back-front localisation.
When frontal angles were presented, subjects did gradually more errors with increasing of the distance between the source and receiver.
In case of back-front localisation, the trend was exactly the opposite, which is the first indication that the direct-to-reverberant level might play a significant role in the experiment.
A rather small sample of people (5 subjects) was used in this study. Next experiments will enlarge the sample size to confirm or reject the observed trends with statistically significant results.

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