Minimum Audible Distance (MAD) by the Example of Wave Field Synthesis

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Introduction

The so-called minimum audible angle (MAA) is formed with respect to the listener's head by two sound sources at the same distance just auditory differentiable in position when sounded in succession. Here, a similar concept referred to as the minimum audible distance (MAD) is introduced, denoting the distance of two sound sources in the same direction with regard to the listener just auditory differentiable in position when sounded in succession. For the MAD measurement, an adaptive two-alternative forced choice procedure is proposed and evaluated using a circular Wave Field Synthesis (WFS) array in reverberant listening environment.

Previous Work

Edwards (1955) reports the accuracy of distance judgments to decrease with the source distance, supported by Zahorik et al. (2005) and Völk (2010). Laws (1972) reports the MAD (distance-difference-limen) to increase with the source distance, with relative values of MAD and distance in the range between 0.1 and 0.5 (for distances between 0.25 and 8 m), and relative overall thresholds for distance (including loudness, sound color, and all other cues) in the range of 0.02 to 0.05. Strybel and Perrott (1984) report relative values for broadband noise impulses globally decaying with distance, in the range between 0.2 and 0.03 for sources at distances between 0.5 and 50 m.

Procedure and Stimuli

All experiments described here are conducted in a slightly reverberant laboratory (50 ms average reverberation time, 6.8 m × 3.9 m × 3.3 m) at Lehrstuhl für Mensch-Maschine-Kommunikation, Technische Universität München. The audio playback is realized by primary WFS point sources, with the signal processing and hardware setup described by Völk (2010). The experiments are conducted with the subject seated in a darkened laboratory, aiming at applying the visual stimulus darkness and therefore providing a controlled situation with regard to audio-visual interactions. As sound stimuli, uniform exciting noise (UEN) impulses (Fastl and Zwicker 2007, section 6) are used here, selected for containing equal intensity in all critical bands and thus assumed to provide the listener with all spectral localization cues at the same perceptual weight. According to Blauert and Braasch (2007), pulse durations of more than 200 ms allow for orientating head movements by eliciting so-called dynamic localization cues. To provide dynamic localization cues, 700 ms impulse duration, 20 ms Gaussian gating, and 300 ms pause between the two impulses is used here.

Proposed Method and Verification

According to the MAA measurements of Perrott and Pacheco (1989), a two-alternative forced choice 2-down/1-up method combined with Parameter Estimation by Sequential Testing for the step size adaption is proposed for assessing the MAD. The stimuli to be compared are generated by primary-sources positioned symmetrically around a reference distance. The subjects are asked to indicate where the second hearing sensation occurred in relation to the first (in a specified plane) by pressing one of two buttons, while the presentation sequence is chosen randomly. This procedure is repeated until both, the deviation between the last two minimum and the deviation between the last two maximum values remains smaller than a threshold dependent on the experimental setup and the reference distance. Since this procedure converges towards the 70.7% point of the psychometric function, the MAD is defined here as the distance threshold where about 71% of all judgments of the relative positions of the sound sources are correct.

Figure 1 shows the inter-individual averages of the intra-individually averaged results of eight subjects in age between 21 and 36 years (average 26.1) for the MAD measurement with broadband UEN impulses presented by frontally located WFS point sources at distances to the head distributed symmetrically around 10 m.

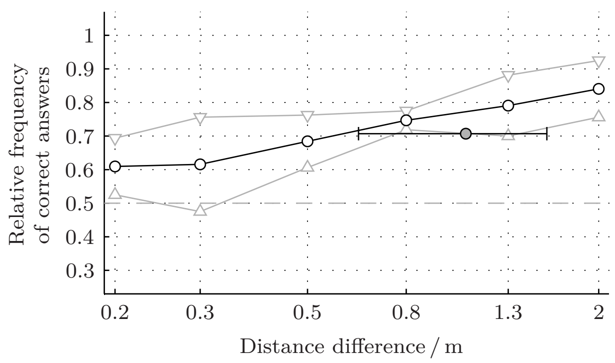

Figure 1: Average results of a static two-alternative forced choice minimum audible distance experiment (open circles) with broadband uniform exciting noise impulses played back by frontal Wave Field Synthesis point sources at 10 m reference distance. Triangles indicate the sequences closer first (downward) and farther first (upward pointing). The filled circle shows the median of the corresponding adaptive procedure.

The experiment is conducted using the procedure proposed here and with a static two-alternative forced choice method implementing the same task. In the static case, each source constellation was evaluated by each subject 40 times in random order (open circles), 20 times presenting the closer sound first (downward pointing triangles) and 20 times the distant sound first (upward pointing triangles, average duration 17.2 minutes). The filled circle with horizontal error-bars indicates the median and inter-quartile range of the intra-individual medians of three repetitions of the adaptive procedure per subject (average duration 6.7 minutes). The data shown in figure 1 indicate that the adaptive procedure employed here tends to overestimate the MAD defined by the 70.7% point of the psychometric function. The results of the static procedure (triangles) indicate that the MAD depends on the presentation sequence. It may be concluded that a change in the source distance away from the listener is more likely to be detected. This effect is possibly accompanied by a tendency for the listeners to prefer the farther button, supported further in that the psychometric function proceeds rather shallow within the distance differences covered here, not reaching 100%. However, the latter two effects can not be separated based on the data shown here. The adaptive procedure on average converges to the static situation where the farther sound is presented first that is the larger MAD. The fact that the transformed up-down procedure is designed to be robust towards response preferences (Levitt 1971) supports the existence of two MADs at a given distance, depending on the presentation sequence.

Results and Discussion

The actual results are shown here as quartiles of the individual medians (open) and inter-quartile ranges (filled symbols) of three repetitions per condition for each of eight normal hearing subjects in age between 21 and 36 years (average 26.1), acquired with the adaptive procedure (average duration 6.7 minutes per condition). Figure 2 represents data for frontally positioned primary point sources at different distances for broadband (circles) and low-pass (2 kHz, triangles) UEN. The data confirm the

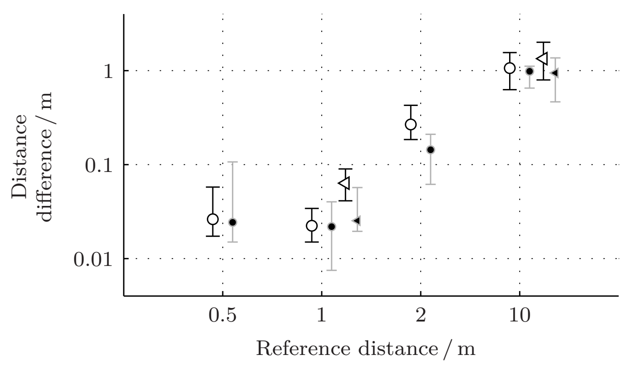

Figure 2: Quartiles of intra-individual medians (open) and inter-quartile ranges (filled symbols) of minimum audible distances in Wave Field Synthesis. Broadband (circles) and low-pass (triangles, 2 kHz) uniform exciting noise impulses and frontally incident spherical waves.

decaying accuracy of distance discrimination with distance reported by Edwards (1955) and Laws (1972). The median intra-individual inter-quartile ranges reach values in the range of the medians of the intra-individual medians, indicating for most conditions comparable inter- and intra-individual variability values. Low-pass filtering results in increased MADs at 1 m reference distance. Separate one factorial analysis of variance indicates for 1 m reference distance a significant main effect of the stimulus [$F(1,7) = 6.41$; $p = 0.0391$], but not at 10 m [$F(1,7) = 1.79$; $p = 0.2231$]. Relating the median broadband MADs to the corresponding reference distances results in the relative values given by table 1. The data of table 1 confirm earlier

distance difference / m	0.02	0.02	0.28	1.06
reference distance / m	0.5	1	2	10
relation	0.05	0.02	0.14	0.11

Table 1: Medians of intra-individual medians of minimum audible distances in Wave Field Synthesis. Broadband uniform exciting noise impulses and frontally incident spherical waves.

data regarding the global magnitude, but not the decay over distance reported by Strybel and Perrott (1984).

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