JASA EXPRESS LETTERS | ARTICLE | asa.scitation.org/journal/jel

Static and moving minimum audible angle: Independent contributions of reverberation and position

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Abstract: Two measures of auditory spatial resolution, the minimum audible angle and the minimum audible movement angle, have been obtained in a simulated acoustic environment using Ambisonics sound field reproduction. Trajectories were designed to provide no reliable cues for the spatial discrimination task. Larger threshold angles were found in reverberant compared to anechoic conditions, for stimuli on the side compared to the front, and for moving compared to static stimuli. The effect of reverberation appeared to be independent of the position of the sound source (same relative threshold increase) and was independently present for static and moving sound sources.

[Editor: Qian-Jie Fu] https://doi.org/10.1121/10.0025992

Received: 16 January 2024 **Accepted:** 26 April 2024 **Published Online:** 14 May 2024

1. Introduction

Localizing sound sources is an important task when navigating the world and interacting with persons and objects. For example, we need to know where a speaker is in order to face them and need to locate cars in traffic.

The minimum audible angle (MAA) depicts the smallest angular change between two successive sounds that is just perceivable as a location change. It is a quantitative measure of the spatial resolution of the auditory system for static sounds. This just noticeable difference in spatial location has been shown to be as small as 1° in the horizontal plane (Mills, 1958). This classic MAA study revealed strong dependencies of the threshold angle on stimulus frequency and sound source position. The smallest MAAs were found for tonal stimuli between 250 Hz and 1000 Hz with the sound source in front of the listener (0° azimuth), degrading when moving off the midline. The decline of sensitivity with increasing lateral angle can be explained by the angular derivative of interaural time differences (ITDs) and interaural level differences (ILDs), the main cues for the azimuthal sound localization azimuth (Blauert, 1997). In the front, ITDs and ILDs change more rapidly with respect to small azimuthal changes of the sound source than at the side, causing higher spatial resolution in front of the listener compared to the side. MAAs for wideband stimuli are even smaller than those reported for pure tones (Blauert, 1997). The MAA is smaller than the precision of the absolute localization response, since it is a relative discrimination measure with the first stimulus serving as an anchor (Carlile and Leung, 2016).

However, we are usually not located in environments with static sound sources, and even if they were static, we tend to turn our heads, thereby introducing relative motion between us and the sound source. Therefore, the ability to localize a moving sound source and determine its motion is important. The minimum audible movement angle (MAMA) describes the angular distance a sound source has to move in order for the direction of movement to be recognized. The ability to judge where a sound source is moving to or from is crucial for focusing attention on the source and predicting its future position. Relative to static sounds, the binaural system is rather insensitive to moving sounds, which led to the idea of independent processing of static and moving sounds (Perrott and Musicant, 1977). With slowly moving tonal sound sources (2.8°/s), a discrimination of the movement direction is possible for angles as small as 2° to 4° in front of the listener, whereas much larger movement angles are necessary at a 60° azimuth (Harris and Sergeant, 1971). As with MAAs, smaller MAMA thresholds were found when the stimulus bandwidth increases (Chandler and Grantham, 1992). When the moving portions of the trajectory were confined to the first and last 10 ms of the stimulus, higher thresholds were observed than when the source moved during the entire stimulus, indicating that MAMAs are not only derived from a comparison of cues at onset and offset (Perrott *et al.*, 1989). Perrott *et al.* argued that a motion-sensitive mechanism (some kind of continuous evaluation) has to be involved. The MAMA is also sensitive to movement velocity, leading to

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more than a doubling of threshold angle when the velocity is increased from 90°/s to 360°/s (Perrott and Musicant, 1977) or even a fourfold increase for velocities increasing from 15°/s to 90°/s (Grantham, 1986), with best performance at velocities of 20°/s or lower (for review, see Carlile and Leung, 2016). When changing stimulus velocity over a fixed angular displacement, stimulus duration is altered as well. Chandler and Grantham (1992) postulated that a minimum integration time is required for the system to perform optimally, as evidenced by a sharp decrease in performance below a certain stimulus duration. This integration times are, on average, 336 ms for stimuli in front and 512 ms for those at the side of the listener (Chandler and Grantham, 1992).

Although the absolute thresholds vary, the same dependencies on frequency, bandwidth, and azimuth were observed for MAA and MAMA (Chandler and Grantham, 1992). With extensive training, MAMA thresholds seem to approach those of the MAA, but are never smaller (Chandler and Grantham, 1992).

To date, most of the studies on MAAs and MAMAs have been conducted under acoustically dry conditions. An anechoic environment makes it possible to use the direct sound only to obtain the pure ability of differentiating sounds from different locations without any alteration by sound reflections. On the downside, this is not the challenge our auditory system encounters in real listening situations. Instead, we are usually surrounded by objects that reflect some of the sound energy. These reflections are temporally overlapping and lead to a decorrelation of the binaural ear signals, affecting the ability of the auditory system to extract ITDs and ILDs, especially from the ongoing portion of the sound. Due to the mechanisms of the precedence effect (Blauert, 1997; Litovsky *et al.*, 1999), localization ability of static sources is not much affected by moderate reverberation (Hartmann, 1983), but localization accuracy degrades in stronger reverberation, being similarly affected in the front and at the side (Giguère and Abel, 1993). Hartmann (1983) postulated that the localization bias induced by reverberation is invisible in MAA experiments. This is in agreement with results from precedence effect experiments where the discrimination of a leading sound (the lead's MAA) is largely unaffected by the presence of a lagging sound (Litovsky and Macmillan, 1994). In another study, reverberation was not found to affect the MAA (Perrott *et al.*, 1989). Regarding moving sound sources, decorrelation of binaural cues leads to reduced motion detection (Saberi and Petrosyan, 2006), giving rise to the assumption that continuous cue evaluation is impaired. Sankaran *et al.* (2014) observed no significant influence of reverberation on the MAMA for normal hearing and hearing-impaired listeners.

Typical listening situations often take place in reverberant environments and include stationary as well as moving sound sources. The aim of this study is to investigate the effect of reverberation on threshold angles (MAA and MAMA) while controlling for several parameters. For this purpose, we conducted experiments on static (experiment I: MAA) and moving (experiment II: MAMA) sound sources under anechoic conditions and in a simulated reverberant room in different acoustical configurations.

We investigated the following hypotheses: (1) threshold angles are larger at the side than at the front, (2) larger threshold angles are observed for moving sound sources as compared to stationary ones, (3) reverberation not only increases thresholds, but affects moving stimuli (MAMAs) more than static stimuli (MAAs), thereby indicating that the decorrelation by reverberation impairs continuous cue evaluation more than when onsets can be used with static stimuli, and (4) interaural decorrelation due to asymmetric lateral reflections leads to larger thresholds under the asymmetric condition than under the symmetric condition.

2. Methods

2.1 Participants

In total, 16 participants participated in the study. Eight subjects participated in experiment I (21–30 years, mean = 25 years, four female, four male); the remaining eight participated in experiment II (21–27 years, mean = 24 years, four female, four male). All subjects had normal hearing thresholds as confirmed by audiometric testing. Written informed consent was provided, and experiments were approved by the Ethics Committee of the Technical University of Munich, Study No. 97/15. None of the participants had prior experience in MAA or MAMA experiments.

2.2 Room simulation and auralization

The experiments were conducted with stimuli created and auralized in the real-time Simulated Open Field Environment (SOFE v4; Seeber *et al.*, 2010). All sounds were reproduced in an anechoic chamber by 36 loudspeakers mounted in a square array in the horizontal plane at ear height. The array was 4.8 m on each side, and adjacent speakers had an angular separation of 10°. Reverberation was simulated with the RTSOFE software (Seeber and Wang, 2021) as specular reflections based on the image source method (Borish, 1984) to order 10 and rendering them considering frequency-dependent wall attenuation and distance-dependent spectral attenuation and delay. Reflections from order 5 were randomly jittered by up to 5% in time to reduce excessive comb filter effects in the numerically exact rectangular room. The anechoic stimuli and the direct sound and reflections of the reverberant stimuli were reproduced using horizontal Ambisonics of the 17th order (Zotter and Frank, 2019). Floor and ceiling reflections were also mapped to the horizontal loudspeakers with their respective azimuth, delay, and attenuation, because high-order two-dimensional (2D) Ambisonics reproduces moving stimuli almost artifact-free, unlike lower-order three-dimensional (3D) Ambisonics. Floor and ceiling reflections' energy was correctly reproduced, and reflections in the line-of-sight supported source localization as they carried the ITDs and ILDs of the source, while lateral reflections decorrelated the ear signals.

A simple rectangular room was modeled with a floor area of 5 m × 8 m and a height of 3.5 m as a simplified office environment without furniture. The frequency-dependent reflection factors for 125, 250, 500, 1000, 2000, and 4000 Hz of the different surfaces were chosen as those of gypsum board (0.84, 0.95, 0.97, 0.98, 0.96, and 0.95) for the walls and the ceiling and linoleum (0.99, 0.98, 0.98, 0.98, 0.98, and 0.99) for the floor. Despite these fairly hard surfaces, the reverberation time, T20, was only 0.3 s and clarity, C80, was 12.1 dB, because only specular reflections to the 10th order were considered. Nevertheless, the direct-to-reverberant ratio was −4.1 dB for the stimulus used: i.e., reflections dominated energetically. (All values are means across all test positions.)

The listener was located 2.66 m away from the shorter wall, in the middle of the two longer walls, facing into the room (see Fig. 1) at a height of 1 m. This position was not changed in any of the experimental conditions. The sound source was simulated on a circular trajectory with a distance of 2 m from the listener's head at a height of 1 m and using the directivity of a mouth facing the listener.

2.3 Stimuli

White noise (100 Hz to 16 kHz) was ramped with a Gaussian ramp with a rise and fall time of 40 ms. The total level of the stimuli at the head center was normalized for each stimulus to 50 dB sound pressure level (SPL). All stimuli were pregenerated and stored on a computer disk.

2.3.1 Experiment I: MAAs

Noise stimuli of 300 ms duration (direct sound) were played in two successive intervals, separated by an interstimulus interval (ISI) of 500 ms. The ISI started at the end of the direct sound of the first noise signal and not after the reverberation was gone, ensuring the same duration between the onset of the first interval and the onset of the second interval

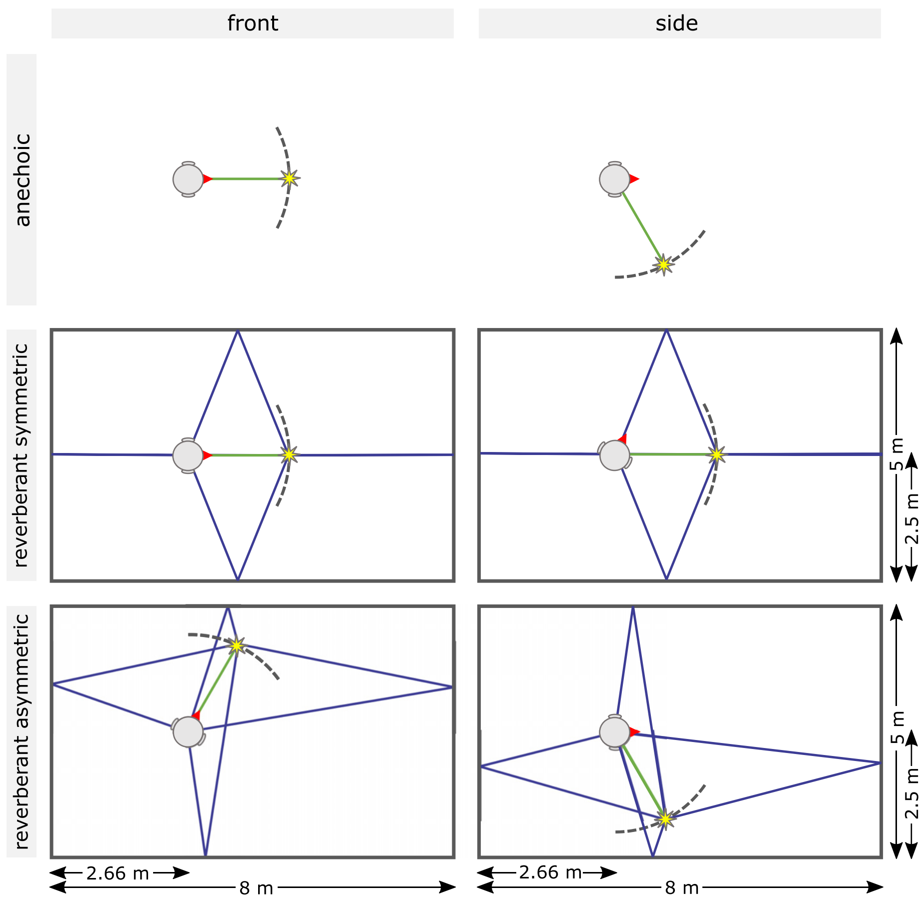

Fig. 1. Schematic top-down view of the simulated room for the sound source in front (left column) and the side (right column) of the listener, showing the pattern of the direct sound in the anechoic (upper panels) and direct sound plus first order sound reflections of the reverberant conditions (middle panels, symmetric condition; bottom panels, asymmetric condition). A thick solid rectangle shows the outline of the room, and a dashed line shows the trajectory of the sound source.

under the anechoic and reverberant conditions. Note that reverberation had ceased by the start of the second interval. Noise signals were frozen for each starting location and test MAA in 1° resolution steps.

2.3.2 Experiment II: MAMAs

To simulate a circular trajectory for the source, impulse responses were created for sources at 0.5° intervals and convolved with rectangularly windowed noise frames to form the trajectory, whereby filter ringing including the reverberation tail was properly added. This assumes the source to be stationary at each of the 0.5° positions sampled over the time span of the signal block.

We used a velocity of 20°/s for the sound source, because this lies within the range of velocities assumed to be optimal for movement detection (Carlile and Leung, 2016). The two moving noise stimuli were separated by an ISI of 1 s. As in experiment I, the ISI started right after the first noise signal finished playing.

2.4 Experimental conditions

To test the effect of reverberation on MAA and MAMA thresholds, we created an anechoic condition with only the direct sound present and two reverberant conditions with reflections up to the 10th order. Two different positions of the sound source were investigated: a 0° azimuth (in front of the listener, front condition) and a 60° azimuth (to the right of the listener, side condition), as depicted in Fig. 1. A jitter of ±30° was applied to the position of the stimulus starting point to reduce the possibility of start or end locations or the spatial center of the stimulus serving as a cue.

Due to the room geometry, the arrangement of the sound reflections under the front condition is more symmetric than for the trajectories under the side condition (see Fig. 1). This causes more asynchronous timing and differing intensity of reflections and thus a higher degree of decorrelation of the binaural ear signals for the side position. The special symmetry of the reflections from a source directly in front of the listener might lead to improved localization performance. For this reason, we included the symmetry as an experimental factor in addition to reverberation and position. This factor is realized by a rotation of the simulated room by 60°, constructing symmetric and asymmetric conditions for the presentation in the front and at the side. An overview of the design and an example of the differences in symmetry of the sound reflections for a sound source can be seen in Fig. 1.

2.5 Procedure

The participants were asked to sit still on a chair in the center of the loudspeaker array during the experiment. They were monitored via a video link during the experiment, ensuring that they did not move. A light spot was projected via video projectors at 0° azimuth to help subjects orient the head to the front. The light and the light spot were turned off when the experiment started, but the black-projecting video projectors provided residual ambient light in the otherwise dark anechoic chamber.

Both experiments were separated into two blocks. One block contained only trajectories in front, whereas the other block contained only trajectories at the side of the listener. The participants were assigned to two equal-sized groups starting with each block.

After the participants did 18 familiarization runs (six trials for each condition) without feedback, the main experiment started. It was designed as a two-alternative forced-choice procedure with two intervals asking whether the second stimulus was left or right of the first stimulus in the MAA experiment or whether the direction of stimulus motion was the same or opposite in the two intervals in the MAMA experiment. An adaptive staircase procedure (1 up-2 down) was used to track the thresholds. Each track started with an angle of 20° that was then adaptively changed. For the MAA experiment, this means that the static sound sources were separated by 20°, whereas in the MAMA experiment, 20° was the angular distance traveled by the moving sound sources. The tracks ended after 15 reversals. Step sizes of 5° were applied for all trials until the third reversal (second reversal in experiment II) and 2° until the sixth reversal (fourth reversal in experiment II). Step sizes of 1° were applied for the remaining trials. For the anechoic and reverberant conditions, independent tracking runs were done in interleaved fashion. The threshold was computed from the mean of the last eight reversal points and corresponds to the 70.7% correct point on the psychometric function.

2.5.1 Experiment I: MAAs

The subjects were presented with two intervals containing white noise of 300 ms duration separated by an ISI of 500 ms. The second stimulus was presented, at random, left or right of the first stimulus and separated by a certain angle. The subjects reported if the second stimulus was left or right of the stimulus via pressing "1" or "2" on the number pad of a computer keyboard on their lap. At 500 ms after the response, the next stimulus was played. No feedback was given.

2.5.2 Experiment II: MAMAs

The subjects listened to two intervals containing a moving sound source playing white noise separated by an ISI of 1 s. In random order, the two intervals included either sound source movements in the same or in opposite directions. The subjects reported if the intervals contained two sound sources moving in the same or in different directions via pressing "1" or "2," respectively, on the keyboard. The next stimulus was played 500 ms after the response. No feedback was given.

In order to limit participants from using the start or end location as a cue (both trajectories travelled the same angular distance), trajectories were presented within ±30° of the main location (front 0°/side 60°) following specific rules. Ideally, start and end positions of the second stimulus would be randomly presented left or right of those of the first stimulus irrespective of movement direction. However, this is constrained by the aim to study around a main location (front 0°/side 60°) and by the wish to evaluate binaural mechanisms in the frontal hemifield rather than front-back cue evaluation. For example, in Fig. 2, if the first stimulus randomly starts on the right and moves further into the right-side zone (which is as wide as the test angle φ), the second stimulus should still be presented with equal probability left or right of it and could move even further to the side. This collides with the aim to study around the front, limiting it to a possible inward movement. The participants might realize that the stimuli cannot be outside the possible range, here in the front. We hence divided the possible range for the trajectories into a middle zone and two flanking side zones as broad as the angle currently tested (see Fig. 2). The following rules were developed to limit participants' learning. First, the onset point of the 1st stimulus is always within the middle zone. Second, if the offset point of the 1st stimulus lies in one of the side zones, the offset point of the 2nd stimulus must not lie in one of the side zones. Otherwise, the 2nd stimulus can start and end in any place within the range.

With these rules, a comparison of onset or offset points serves as a useful strategy only if all onset and offset points can be distinguished and remembered by the participant.

3. Results

Figure 3(A) shows results of experiment I, and Fig. 3(B) shows those of experiment II.

3.1 Experiment I: MAA

Threshold angles for the static MAA are much smaller for sound source positions at the front (median, 3.38°) compared to those on the side (median, 7.56°). Reverberation increases thresholds in the front and at the side, but only a small difference can be observed between the two reverberant conditions (median increase in 1.06° and 1.56° from the anechoic threshold of 3.44° to the symmetric and asymmetric reverberant conditions, respectively). The lowest thresholds observed for anechoic space for sources on the side are in the range of the highest thresholds for frontal sources in reverberation.

3.2 Experiment II: MAMA

Threshold angles for the moving minimum audible angle are far smaller for sound source positions at the front (median, 11.31°) than the side (median, 19.81°), similar to MAAs (see Fig. 3). The presence of reverberation also increases thresholds compared to the anechoic condition, while the symmetry of the reverberation seems to have little impact (median increases in 5.19° and 4.34° from the anechoic to the symmetric and asymmetric reverberant conditions, respectively).

3.3 Comparison of MAA and MAMA

The box plots in Fig. 3 show data for all conditions summarized across participants *via* medians and quartiles. Three main results are apparent: (1) MAMAs are generally much higher than MAAs, (2) threshold angles are smaller for source

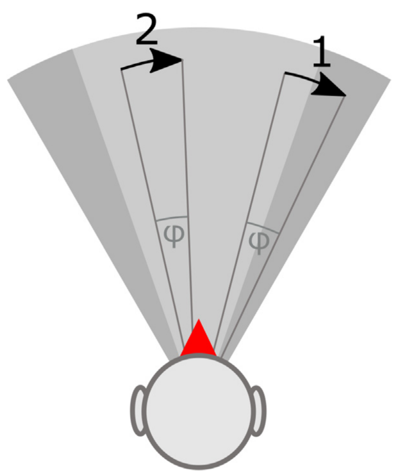

Fig. 2. Possible range of the trajectories divided into a middle zone (light gray) and two adjacent side zones (dark gray) for an exemplary stimulus pair (trajectories 1 and 2) testing the angle φ.

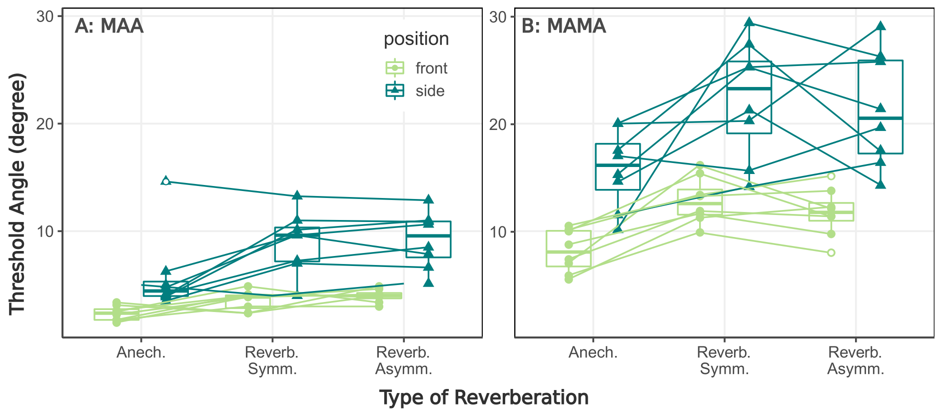

Fig. 3. Threshold angles for white noise bursts in anechoic and reverberant space with symmetric and asymmetric spatial reverberation. Results of individual participants are presented with dots (front) and triangles (side) and connected with lines. Box plots present medians and quartile ranges. Outliers are indicated with white dots above the markers. (A) Experiment I, MAA with noise bursts of 300 ms. (B) Experiment II, MAMA with a stimulus velocity of 20°/s.

positions in the front than at the side, and (3) reverberation increases both MAA and MAMA thresholds compared to the anechoic condition.

To test the statistical significance of the obtained data, we conducted a three-factorial repeated-measures analysis of variance (ANOVA) on the thresholds. The ANOVA with the between-subject factor measurement (MAA, MAMA) and the within-subject factors position (front, side) and reverberation (anechoic, reverberant symmetric, reverberant asymmetric) reveals that the main effects of measurement [$F(1, 14) = 126.120$, $P < 0.001$, $\eta g^2 = 0.739$] and position [$F(1, 14) = 75.252$, $P < 0.001$, $\eta g^2 = 0.580$], but also the interaction term of measurement × position, are significant [$F(1, 14) = 7.221$, $P = 0.018$, $\eta g^2 = 0.117$]. The increase in threshold angle from front to side is larger in the MAMA experiment. Also, the effect of reverberation is significant [$F(2, 28) = 20.871$, $P < 0.001$, $\eta g^2 = 0.272$]. The interactions of reverberation × measurement [$F(2, 28) = 3.306$, $P = 0.051$, $\eta g^2 = 0.056$] and reverberation × position [$F(2,28) = 1.893$, $P = 0.169$, $\eta g^2 = 0.024$] are not significant, and neither is the interaction of reverberation × position × measurement. These results suggest that the effect of reverberation acts independently of the other factors on the threshold angle.

Post hoc testing of the combined MAA and MAMA data with paired t tests with Bonferroni correction on the different levels of reverberation reveals significant differences between anechoic and reverberant asymmetric [$t(15) = -4.875$, $P < 0.001$] and between the anechoic condition and reverberant symmetric [$t(15) = -4.880$, $P < 0.001$], but not between the two reverberant conditions [$t(15) = 0.630$, $P = 0.538$], suggesting that the interaural symmetry of reflections did not affect results.

4. Discussion

The present study found larger angular difference detection thresholds for a broadband noise stimulus in the free field when it was moving (MAMA) than when it was static (classic MAA). For MAA and MAMA, the position of the stimuli (front, 0° azimuth; side, 60° azimuth) had a larger effect on thresholds than reverberation (position, $\eta g^2 = 0.580$; reverberation, $\eta g^2 = 0.272$), with sources on the side yielding higher thresholds.

The thresholds we obtained are higher than the values reported by previous studies. For the MAA at front in the anechoic condition, a mean of 2.36° is more than two times the lowest threshold of 1° reported before (Mills, 1958). Our test used random base locations and thus prevented the learning of absolute locations, which could lead to lower MAA values (Hartmann and Rakerd, 1989). Also, for the MAMA under very similar conditions (20°/s, wideband noise), the threshold of 5.7° reported by Chandler and Grantham (1992) or even 0.9° to 1.6° obtained by Perrott *et al.* (1989) is much smaller than the mean of 8.14° found in our experiment. For both measurements, this might be caused by the jitter of the starting points around the midline by 30°. A jitter of ±15° led to increased values in a study by Grantham (1986), which was associated with lower performance for stimulus positions diverging from a 0° azimuth. Note also that our definition of the MAMA required the discrimination of movement direction across two moving stimuli, whereas others have defined the MAMA as detecting a single moving stimulus from a static stimulus, which likely yields lower thresholds. Furthermore, there might have been an effect of attention: while conditions with positions in the front and at the side were presented in a blocked fashion, the starting position nevertheless varied on a trial-by-trial basis such that focused spatial attention to one particular direction might have been affected. Moreover, in the MAMA experiment trajectories of the first and second stimuli in one trial started at different locations in order to prevent participants from simply comparing stimulus onset locations. While this enforces the comparison of perceived movement across both stimulus intervals, the trajectory locations vary across the two stimuli to be compared. Third, the Ambisonics sound synthesis technique is prone to spatial aliasing effects above a frequency of a few kilohertz. While this has only a small effect on the critical band levels of our broadband stimuli due to averaging effects, ILDs show some increased variance at high frequencies and interaural coherence is slightly reduced (Kuntz and Seeber, 2021). This variance might lead to increased thresholds. Given the methodological differences discussed above, the observation of MAAs of 2.4° appears well in line with the literature and within the expected range, thereby demonstrating that sound field synthesis techniques in the free field can be used to obtain high-quality results in psychoacoustic experiments.

We expected larger angles for the side compared to the front, which is confirmed by data in both experiments. Under the anechoic condition, we obtained for the MAA an increase from 2.36° to 5.77° and for the MAMA an increase from 8.14° to 15.75° when presenting the sounds at the side instead of in front of the listener. This two- to threefold increase has been reported in other studies for the MAA (Mills, 1958) and the MAMA (Harris and Sergeant, 1971; Grantham, 1986). Interestingly, in our experiments, the same factorial increase in thresholds from front to side is present for the reverberant conditions as well. The factorial increase in thresholds from front to side for the reverberant MAA conditions is again in the range of two- to threefold (from 3.78° to 9.09°) and a slightly smaller increase for the MAMA (from 12.28° to 21.8°). It thus appears that the increase due to location is independent of the increase due to reverberation, in agreement with the absence of significant interaction terms between both factors in the ANOVA.

The threshold angle is about 2.5–3.5 times higher with moving stimuli compared to static stimuli. This is in line with the increase by a factor of about 2.4 for moving compared to static stimuli presented in the front of the listener (Harris, 1972). The same increase from static to dynamic stimuli can be observed at both positions and in all levels of reverberation. The threshold increase from front to side is larger in absolute terms with moving sound sources, but the relative change is similar. The results demonstrate that the location estimates from static stimuli are affected to the same degree by reverberation as the continuous evaluation of movement from temporally changing interaural cues. This is remarkable because location could be estimated in the MAA experiment through precedence effect mechanisms from onsets before reverberation has built up—despite the slow onset slope emphasizing the ongoing part—and hence be little affected by reverberation. This is not equally the case for moving stimuli, because reverberation will add to later stimulus parts (Stecker and Hafter, 2002).

In previous literature, the influence of reverberation on MAA and MAMA was disputed. We found impairing effects of reverberation on the MAA, with smaller thresholds for the anechoic compared to the reverberant conditions, contrary to the assumptions of Hartmann (1983), but in line with the effects of decorrelation reported by Saberi and Petrosyan (2006). The adverse effects of reverberation on speaker localization have been shown to be independent of speaker position by Giguère and Abel (1993). This was similarly found in our discrimination tasks.

Contrary to our hypothesis, no significant difference under the symmetric and asymmetric conditions is present. It seems like the differences in timing and level of the lateral reflections do not influence the thresholds systematically under the two reverberant conditions. This might be due to trajectory positions being randomly offset from the midline even for stimuli nominally presented from the front. Thus, frontal stimuli also exhibited some reflection differences in both ears, which were only larger for stimuli presented from the side. The additional decorrelation with lateral stimuli might not have been sufficient to affect thresholds.

5. Conclusion

To conclude, the present experiments are possibly the first to use room acoustics simulation coupled with the Ambisonics sound field reproduction technique to measure psychoacoustic thresholds of azimuthal position changes of static and moving stimuli. MAA thresholds were in agreement with the literature, albeit slightly larger. Compared to single loudspeaker presentation, the sound field technique allows positions to vary freely on a per-stimulus basis, and specific care was taken to prevent participants from using stimulus onset locations to perform a movement discrimination task. Auditory movement discrimination thresholds were larger than previously reported—possibly because of the location randomization of the trajectories being discriminated. MAA and MAMA thresholds were larger for sources to the side than in the front. Reverberation increased discrimination thresholds in a similar way for static and moving stimuli, suggesting that it affected the utilized cues and mechanisms similarly and that onset cues were not contributing to the MAA task.

Acknowledgments

S.W.C. and the rtsofe system were funded by the Bernstein Center for Computational Neuroscience Munich, BMBF 01 GQ 1004B. A.D. was funded for the MAA experiment and write-up by the Deutsche Forschungsgemeinschaft [DFG (German Research Foundation)]—Projektnummer 352015383—SFB 1330 C5.

Author Declarations

Conflict of Interest

The authors have no conflicts to disclose.

Ethics Approval

The study was approved by the Ethics Committee of the Technical University of Munich, Study No. 97/15.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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