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# LOCALIZING THE END POSITION OF A CIRCULAR MOVING SOUND SOURCE NEAR MASKED THRESHOLD

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## ABSTRACT

This preliminary study investigates the influence of motion, and therefore time varying interaural cues, of a sound source on localization performance in the presence of a binaurally correlated noise masker in the free field. Three subjects localized the most lateral sound source position of a moving or static 500 Hz sine tone, both with a constant duration of 300 ms, in the presence of an octave-band noise from the front. All tones were presented 5 dB above the masked threshold obtained at the end position of the moving trajectory. The simulated angular velocities ranged from 0°/s to 200°/s. Static stimuli were positioned at azimuthal angles from 0° to 60°. Both types of stimuli were simulated with 17<sup>th</sup>-order Ambisonics and played on 36 horizontally arranged loudspeakers in an anechoic chamber.

Without the noise masker, the localized direction for positions up to 10° is close to 0°, directly in the front, for both, static and moving sine tones. If a noise masker at 0° is presented with the target sine tone 5 dB above masked threshold, the overall localization bias increases for static and moving stimuli. The results show an increasing underestimation of the laterality of the tone's end position for increasing angular velocities and positions. The underestimation seems to be almost the same for moving and static sound sources. The results indicate that localizing the most lateral end position of a moving sound source seems not to be affected by a sluggish integration of source location in presence of a noise masker.

## 1. INTRODUCTION

Sound localization is one of the earliest investigated human auditory skills and various research has been conducted to understand the underlying auditory mechanisms. It is well known that the main cues used by the auditory system to localize sound sources in the horizontal plane are interaural level and time differences (ILDs & ITDs) [1]. For frequencies below 1500 Hz, ITDs are dominantly used over ILDs by humans to evaluate the location of a sound source [1, 2]. The ITD is directly related to an interaural phase difference (IPD). This IPD in a target signal causes an unmasking of the target signal compared to an in-phase target when presented in a binaurally correlated noise masker, an effect known as the binaural masking level difference [3]. While both sound localization and binaural unmasking rely on interaural time or phase differences, the auditory mechanisms might differ substantially.

Past studies observed less unmasking of signals with time varying interaural cues, as induced by, e.g., a moving sound source in the free field, in the presence of noise, which is referred to as a sluggish behavior of the auditory system [4]. The aim of this study is to investigate the interaction of these two auditory mechanisms for moving sound source in the free field in the presence of a noise masker. In a monaural situation, without binaural unmasking, the sine tone would be masked and not audible and therefore not localizable for the participants. Free field localization of a sound source in the presence of a masker involves therefore two different mechanisms in the auditory system at the same time. On the one hand, a mechanism causing unmasking of the tone which makes it audible, probably based on interaural correlation, on the other hand the localization of the moving tone based on the interaural time difference. Both mechanisms are risen by the same physical cue, the ITD, and should interact in this situation. Both mechanisms are mentioned in the literature to be sluggish. The minimum audible movement angle is shown to increase with increasing sound source velocity [5, 6] which suggests an integrative and sluggish process of localization cues. Other studies showed less binaural unmasking for fast changing interaural phase differences [4] which also indicates a sluggish behavior of the underlying auditory mechanism. The present experiment relies on both mechanisms when investigating if motion has an influence on localizing the end position of a trajectory in the presence of a noise masker. In order to learn about the overall integration process, free field localization performance was measured for static and moving 500 Hz sine tones near masked threshold in the presence of an octave-band noise from the front. Some previous studies investigated localization ability near threshold [7-10], but all of them tested only static sound sources. To the best of the authors' knowledge, no study has yet measured localization of a moving sound in the presence of a noise masker, and thus investigated the dynamic interaction of the auditory mechanism for binaural unmasking and localization.

## 2. METHODS

### 2.1 Stimuli

In this study, a 500 Hz sine tone, which was either moving or static, was used as target sound to be localized by the participants in the presence of a static octave-band noise with a center frequency of 500 Hz and a fixed level of 60 dB SPL at the listeners' position. The target as well

as the noise stimuli were similar to a previous experiment [11]. The target probe tone had an effective duration of 300 ms, defined at 90% of the signal's amplitude, and 10 ms Gaussian shaped rise and fall times.

Seven constant sound source angular velocities were tested: 0°/s, 10°/s, 30°/s, 50°/s, 100°/s, 150°/s and 200°/s. The starting position, coinciding with the beginning of the effective duration of the probe tone, was always 0° in front of the listener and the signal moved clockwise at constant distance to the listener. Additionally and for comparison, static stimuli were generated in 10° steps from 0° to 60° to cover the whole range of possible lateral end positions of the signal, reached with a given velocity at the end of the overall effective probe tone duration. The level of the moving sine tones were set to 5 dB sensation level above the average threshold across participants obtained at the most lateral end position of the movement trajectory, previously measured in [11]. The levels of the static sine tones were determined by spline-interpolation of the measured thresholds [11] at the currently used static positions, and were increased by 5 dB. All sine tone stimuli were samplewise precalculated with two-dimensional 17<sup>th</sup> order Ambisonics with mode-matching decoding. The Ambisonics coefficients were manually derived from the spherical harmonics, the decoder was implemented according to [12].

The noise signal, with a duration of 600 ms, was played from a single loudspeaker at 0° in front of the listener, leading approximately to an interaurally correlated noise. The sine tone is temporally centered in the noise masker. The effective duration of the sine tone started 200 ms after the noise onset.

The stimuli were presented in the Simulated Open Field Environment (SOFE v4) [13] in an anechoic chamber with 36 horizontally arranged loudspeakers (Dynaudio BM6A mkII, Dynaudio, Skanderborg, Denmark) with a 10° spacing. The loudspeakers are mounted on a custom made 4.8 m x 4.8 m squared holding frame in a height of 1.4 m. The loudspeaker at 0°, in front of the listener, has a distance of 2.4 m to the listener's position. Equalization filters were used for the playback to compensate for the loudspeakers' frequency response and the time-of-arrival difference.

## 2.2 Participants

Three male voluntary participants finished this preliminary experiment. Participant's age ranged from 26 to 29 (mean: 27.7, std.: 1.5). All participants had normal hearing thresholds with a hearing loss less than 15 dB up to 8 kHz as assessed with a clinical audiometer (Madsen Astera2, GN Otometrics A/S, Taastrup, Denmark). All subjects gave written consent and no one was payed for participating in the experiment. The study was approved by the ethics committee of the TUM, 65/18S.

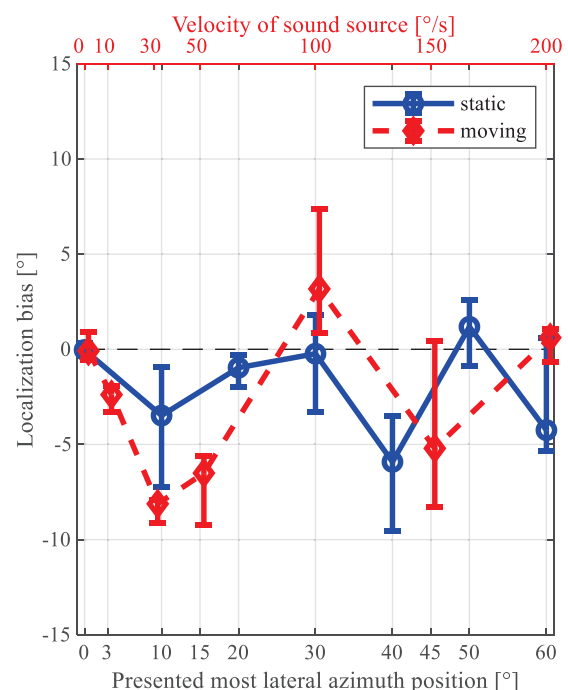
## 2.3 Experimental Procedure

All participants sat in the completely darkened anechoic chamber in the center of the loudspeaker array. They were instructed to not move their head during stimulus presentation. After the stimulus finished, participants had to indicate the most lateral perceived direction of the sine tone. For a static stimulus participants had to indicate the

perceived sound source direction, whereas for a moving sound source they had to point to the end position of the motion trajectory, which is the most lateral position of the sound source reached during the duration of the sine tone with a given angular velocity. Participants indicated the localized direction using the *ProDePo*-method [14]. For the *ProDePo*-method, a red dot was displayed randomly in a range of  $\pm 30^\circ$  around the target position on acoustically transparent screens in front of the loudspeakers. The subjects moved this red dot to the perceived direction of the sound using a track ball device on their knee. With a click on the left button on the track ball, the indicated angle was confirmed. The participants were instructed to focus on the most lateral position during the whole stimulus, which should correspond to the most unmasked position for moving stimuli (e.g. end position of the trajectory). All angular conditions for static and moving sound sources were repeated 10 times for each participant. The order of all stimuli presentations was completely randomized. As a baseline the sine stimuli were also tested without the noise masker.

## 3. RESULTS

The localization bias for both conditions without the noise masker is shown in Figure 1. Bias is defined here as a deviation from the target sound position and calculated as the difference of the localized position and the stimulus position for each subject separately.

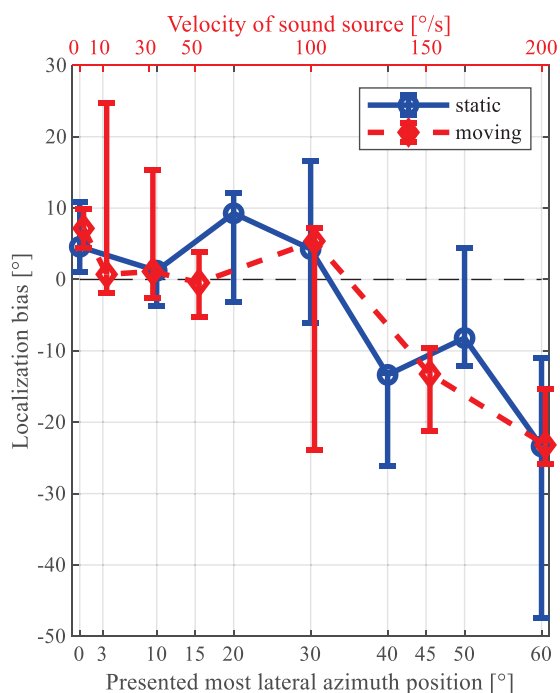


**Figure 1.** Localization bias relative to the stimulus position for static and moving 500 Hz sine tones without a noise masker. The blue circles show the median localization errors with upper and lower quartiles for static sine stimuli, the red diamonds show the median of the localization bias with their upper and lower quartiles. The medians are connected with lines for better readability. The upper red x-axis shows the corresponding velocities of the moving sound sources.

The overall absolute mean localization error for static stimuli is  $2.3^\circ$  and for moving stimuli  $3.7^\circ$ .

Localization performance seems to be similar for both, static and moving sine tone presentation. However, the error bars are fairly large for both conditions without noise. This could stem from the used stimuli, as a low-frequency sine tone is more difficult to localize than broadband signals. For moving stimuli with slow velocities and therefore lower lateral end positions, there is a larger tendency to underestimate the sound source position, i.e. to localize the stimulus closer to the front.

The localization bias increases for both static and moving stimuli in the presence of a noise masker. Figure 2 shows the median localization bias for static and moving sine stimuli in the presence of the noise masker. For both static and moving stimuli the localization bias for stimuli directly in the front of the listener (e.g. at  $0^\circ$ ) increases and sound source laterality is overestimated somewhat by up to  $10^\circ$ . For static stimuli at more lateral positions, the localized sound direction is highly underestimated. The localization bias here ranges from  $-8^\circ$  to  $-18^\circ$  for positions larger than  $40^\circ$ . An underestimation can also be observed for moving stimuli with velocities higher than  $100^\circ/\text{s}$ . Localization bias ranges from  $-10^\circ$  to  $-18^\circ$  for higher velocities. Since the level was kept constant for moving and static stimuli, the tone was temporally masked during part of the movement trajectory.



**Figure 2.** Localization bias relative to the stimulus (end) position for static (blue circles) and moving (red diamonds) 500-Hz sine-tones in the presence of an octave-band noise masker, centered at 500 Hz, are shown. Negative localization bias indicates an underestimation of laterality. Median localization bias is presented with upper and lower quartiles. Medians are connected with lines for better readability. The upper red x-axis shows the corresponding velocities of the moving sound sources.

This is because the level of the moving condition was set to 5 dB above the threshold obtained at the most lateral end position of the movement trajectory and therefore positions in front of the listener during the movement are temporally masked and not audible. Even though part of the trajectory is temporally masked, no large difference between static and moving conditions could be observed.

#### 4. CONCLUSIONS

The aim of this preliminary study was to investigate if the motion of a sound source in the free field can influence the localization performance in the presence of a noise masker when the target sound is presented near masked threshold. For stimuli presented without noise in the free field the localized trajectory-end positions of the moving sources are not different from the localized positions of the static stimuli for all tested velocities. Therefore, a sluggish integration of binaural cues for the location estimate could not be observed. In the presence of a noise masker, the overall localization error increases relatively to the baseline without noise. Especially for higher velocities and for static lateral sound sources the localized positions are highly underestimated. This is more likely because of a localization shift in the presence of a noise masker [8]. Getzman and Lewald [15] found that at the end of a motion trajectory sound position is overestimated. They used bandpass stimuli and presented them without a noise masker. The opposite result was observed in the current preliminary experiment, which might be due to underestimation occurring for sound sources in the presence of noise.

Because the integration of localization cues as well as the mechanism for binaural unmasking shows a sluggish behavior [4-6], it was expected that the localization of the end position of a moving sound in the presence of a noise masker would also show sluggish binaural integration. From the results of this preliminary study, a sluggish behavior for localizing the end-position of moving sources near masked threshold could not be observed.

#### 5. ACKNOWLEDGEMENTS

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