Distance localization of nearby sound sources in reverberant rooms

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Abstract

The three spatial dimensions - azimuth, elevation, and distance - are typically examined separately in sound localization studies. Santarelli et al. (1999) performed an experiment in a reverberant classroom in which subjects were asked to point to the perceived position of sound sources presented from a random location in the right hemifield within 1 m of the listener's head. Here, a new analysis examines how distance localization response biases depend on source location simultaneously varying in all three dimensions on the same data. On average, a 10-% underestimation in distance judgments was observed. However, underestimation was as large as 30% for locations above listener, and it changed to overestimation of sources below. These results show that errors can be larger than observed previously, especially when vertical locations of stimuli are considered.

1 Introduction

Most experiments examining sound localization have been done at distances greater than 1 meter. At distances less than 1 m (proximal region), however, there are important distance-dependent changes in the binaural and spectral characteristics of the sound reaching the ears. Duda & Martens (1998) and Brungart & Durlach, (1999) argue that large interaural level differences (ILDs) are a distance cue for near sources. However, ILDs vary with distance and direction. Shinn-Cunningham et al. (2000) showed that when stimuli are close to one ear, ILDs vary dramatically with source position and frequency so that using only binaural cues, broadband sound stimuli can be located to somewhere on a ‘‘torus of confusion’’. Here, distance performance is examined for nearby sources in reverberation, using previously collected data.

2 Santarelli et al. experiment

Full description of the experiment is provided in (Santarelli et al., 1999). Seven subjects (2 female, age range 22 – 44 years) participated in the study. Six had normal hearing, one had marginal high-frequency loss. Subjects were seated in the middle of a 14' x 20' rectangular classroom with a carpeted floor and hard walls. Stimulus consisted of five 150-ms long pink noise bursts separated by 30 ms silence, with level equalized at the head (to overcome distance effects) and additionally rowed by ±7.5 dB. On each trial, stimulus was presented from a random location within 1-m diameter hemisphere to the right of subject (see Fig. 1). Subjects' task was to listen to the target, positioned by experimenter, with eyes closed and respond by pointing a hand-held wand to the perceived target location with eyes open.

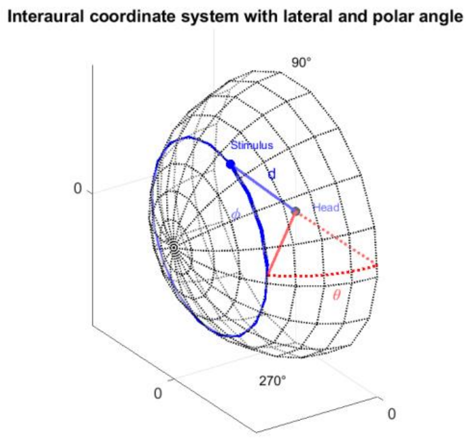

Fig. 1: Hemisphere centered at a subject's head (black point) in which stimuli were presented. Stimulus (blue point) has lateral angle θ (0° – 90°; red), polar angle Φ (0° - 360°; blue) and distance d (d ≤ 100 cm) from the center of the head. Subject facing θ = 0° and Φ= 0°.

We evaluated the results using the interaural polar coordinate system (Fig. 1) which allowed us to track the dependence of the distance responses simultaneously on the lateral and polar angles, as well as on source distance. The data were binned into 34 bins by dividing them into 2 distances (near, far; border 50 cm) and direction (17 bins). The directional bins were combinations of lateral angle (5 regular intervals centered at θ = [9, 27, 45, 63, 81°]) and polar angle (one bin for θ > 72°, 4 bins centered at Φ = [0, 90, 180, 270°] for θ in range of 0 to 72° (see upper panels of Fig. 2). We evaluated biases using a log-log scale (log10(response distance) – log10(stimulus distance)), also showing the relative underestimation or overestimation in percent. Repeated measures ANOVA was used to analyze the data with Box-Geissler-Greenhouse epsilon used to correct for potential violations of the sphericity assumption.

3 Results

We evaluated averaged data within each directional and distance bin for each subject and then collapsed across subjects, separately for the nearby (d < 50 cm) and far (d > 50 cm) sources. The top row in Fig. 2 shows spherical plots in which the lateral and polar angles correspond to the side view of the hemisphere, as shown in Fig. 1, and the distance biases in each bin are shown by color, as well as by a radial position of a point shown within each bin cyan color and dotted line corresponds to no bias). The bottom row shows the same data as a function of lateral angle and parameterized by the polar angle.

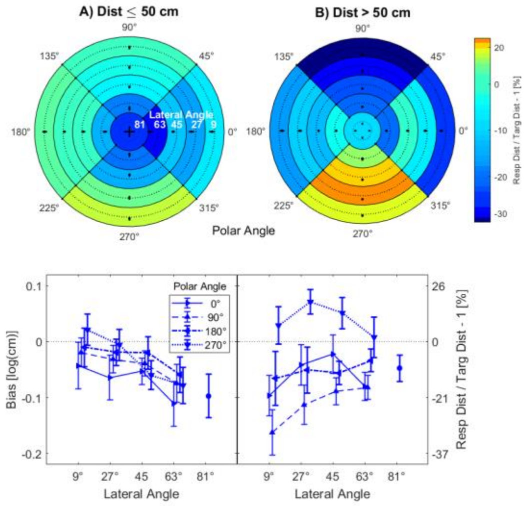

Fig. 2: Across-subject mean (±SEM) bias in distance responses analyzed logarithmically in 2 distance bins (columns A vs. B) and 17 directional bins. The upper panels use a spherical plot corresponding to the surface of the hemisphere shown in Fig. 1, with 5 lateral angle and 1 or 4 polar angle bins. The response bias is indicated by color of each patch, or by radial offset of the point shown in each bin (range matching the -40 to +30 % range of the color bar). In the lower panels, the data are rearranged and plotted as a function of lateral angle and parametrized by the polar angle (with 4 polar bins considered for $\theta > 72°$).

A 3-way repeated-measures ANOVA with factors of Distance (2 levels), Lateral Angle (4 levels) and Polar Angle (4 levels) found a main effect of Polar Angle ($F(3,18)=16.48$, $p<0.001$) and interactions Distance x Polar Angle ($F(3,18)=17.99$, $p<0.001$) and Distance x Lateral Angle ($F(3,18)=10.18$, $p<0.001$). For the nearby sources the dependence of biases on lateral angles was similar across the polar angles, with more underestimation at more lateral angles (downward trend in all lines of panel A). Considering the polar angles, the underestimation was the strongest for the frontal stimuli (solid line), while for the stimuli below the subject the trend switched to slight overestimation (dotted line at $\theta = 9°$ in panel A). In contrast to the nearby sources, for the far sources the effects were much stronger (vertical spread of data is larger), indicating a large dependence of distance biases on the polar angle (also see the dark blue patches and red patches in the top panels of Fig. 2).

4 Conclusion

The current study examined biases in distance perception for nearby stimuli varying in location in all three dimensions in reverberation. For stimuli in the horizontal plane the results don't vary dramatically, with an overall underestimation (approximately -10%) that tends to increase for nearby lateral stimuli (-20% for $\theta = 81°$ in panel A) and appears to be stronger in front than behind the listeners (dash-dotted vs. solid line in panel A). In summary, these results illustrate that auditory distance perception of nearby sources is highly non-isomorphic, with the largest distortions in the vertical dimension.

Acknowledgement

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