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DISTANCE PERCEPTION OF NEARBY SOURCES LOCATED AROUND THE LISTENER IN ECHOIC ROOMS

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Distance perception

- is typically examined for sources **varying only** in **distance**,
- sometimes for sources varying **simultaneously azimuth and distance** [1],
- almost **no studies** considered **also varying elevation**,
- often for far sources (distance $>$ 1 m from head), under headphones, or in anechoic space.
- distance percepts are based on the received level, Interaural level diffrence (ILD) and Direct-to-reverberant energy ratio (DRR) [2]

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[1] A. Ihlefeld and B. Shinn-Cunningham (2011): Effect of source spectrum on sound localization in an everyday reverberant room. JASA 130 (1)

[2] N. Kopco, K. K. Doreswamy, S. Huang, S. Rossi and J. Ahveninen (2020): Cortical auditory distance representation based on direct-to--reverberant energy ratio. NeuroImage, 208

Introduction

Very few studies considered distance perception when location varies in all 3 dimensions:

- Brungart et al. (1999) [3]: 3D localization of real anechoic sources near the head (distance < 1 m),
- Santarelli et al. (1999) [4]: nearly identical study in a reverberant room,
- both studies only provided rudimentary analysis of distance perception, focusing on azimuth-dependence

[3] D. S. Brungart and N. I. Durlach: Auditory localization of nearby sources. II. Localization of a broadband source. JASA 106 (4), 1999

[4] S. Santarelli, N. Kopco, B. G. Shinn-Cunningham, & D. S. Brungart (1999): Near-field localization in echoic rooms. JASA 105(2), 1024.

Introduction

Current study:

– Reanalyze the Santarelli et al. (1999) [4] data to characterize how level-independent **distance perception** varies with source location simultaneously in all three dimensions.

Hypotheses:

H1. Overall, performance will be accurate because two level-independent distance cues (ILD and DRR) are available for nearby sources in reverberation.

H2. Performance will vary with all three dimensions, especially with elevation, as listeners have limited everyday experience with judging the distance of sources above/below them.

Methods (Santarelli et al., 1999) [4]

Setup

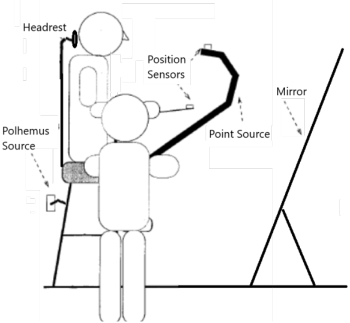
- 7 subjects (22-44 years of age)
- classroom 5 x 4 m, $T_{60} \sim 500$ ms
- freely positionable point source stimulus
- Polhemus Isotraks on point source and response wand
- mirror on plastic easel (for subject to view responses)

Stimuli

- five 15 ms pink noise bursts separated by 30 ms silence –>150 ms
- random 3D location in 1-m diameter in right hemisphere
- level equalized (to overcome distance effects) +15 dB rove

Procedure

- subject's eyes closed, source placed to random location, stimulus presented, source removed, subject responds with eyes open
- 1000 trials in 50-trial blocks, performed over 10 1-hr sessions



Methods: Analysis

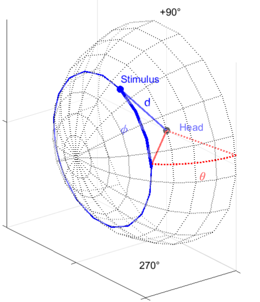
Data target/response pairs

- binned by target location into 2 distance (near / far; cut-off 50 cm) x 25 directional bins by
  - **lateral angle** *theta* – 5 regular intervals centered at θ=[9, 27, 45, 63, 81]°
  - **polar angle** ϕ – one bin for $\theta > 72^\circ$, 4 bins for $\theta = 45, 63^\circ$, 8 bins for $\theta = 9, 27^\circ$,

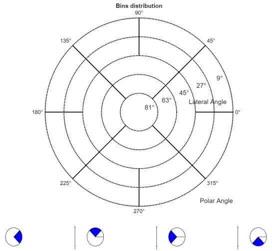
- log-transformed
- in each bin, we examined:
  - response bias,
  - response st. dev.,
  - Pearson corr. coef.

Hemisphere containing targets –>

Interaural coordinate system with lateral angle and polar angle



Bins on a Flattened Surface of Hemisphere



Results: Raw Data

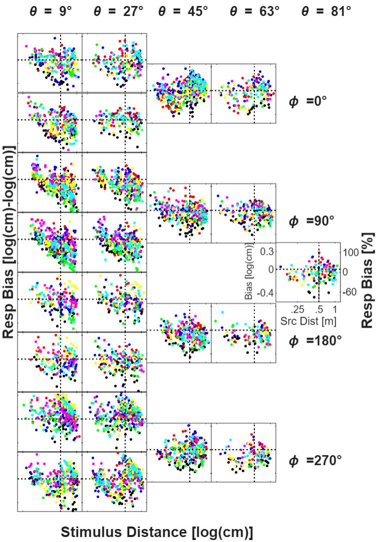
Distance responses bias

- logarithmically or in %
- as a function of actual target distance
- in directional bins (distance bins indicated by dotted line)
- on individual trials (dots),
- for individual subjects (color)

Considerable range

- from underestimation (-60%) to overestimation (+100%),
- varying by ϕ, θ and d, e.g.:

  - underestimation - far sources at $\phi = 90°$
  - overestimation - near sources at $\phi = 225°$ and $\theta = 9°$



Results: Bias

Visualization

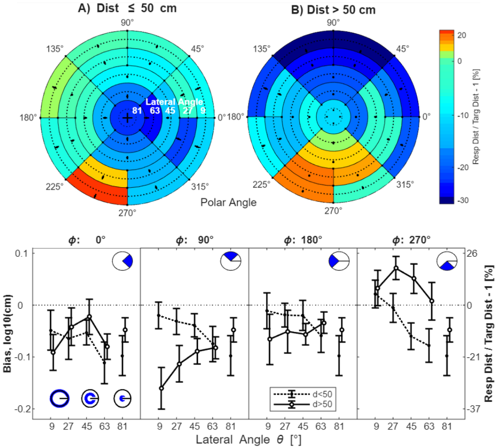
– data plotted in two formats

Upper panels

- polar plot of color-coded distance bias in 25 directional bins

Lower panels

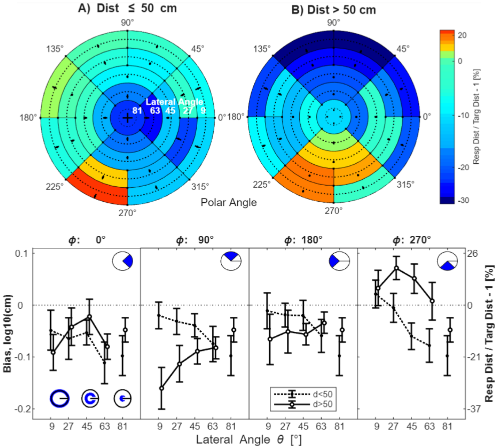
- distance bias as a function of lateral angle θ,
- one panel per ϕ (using only 4 polar angle bins)
- separately for the two distance bins



Results: Bias

Upper panels

- slight underestimation in front and behind the listener near horizontal plane, as well as for lateral sources (0 to -20%),
- underestimation above subject up to -30% for far sources (dark blue patch),
- overestimation below subject up to 40%, especially behind the subject (red and orange patches).



Results: Distance Bias

Lower panels

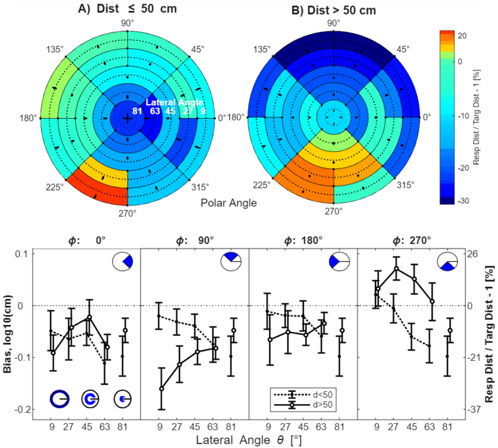
Nearby sources: – underestimation

- growing with lateral angle for all polar angles,
- strongest for frontal sources,
- weakest for stimuli under subject, switching to overestimation for $\theta = 9°$.

Far sources:

– stronger effect of ϕ, especially for $\theta < 36°$,

- targets above listener are dramatically underestimated, especially for $\theta = 9°$,
- targets below the listener are overestimated, especially for $\theta \leq 45°$.

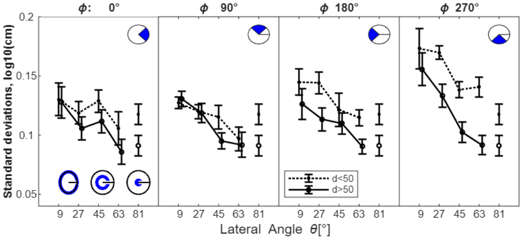


Significant $d \times \theta$, $d \times \phi$ interactions ($p < 0.001$).

Results: Standard Deviation

Response variability

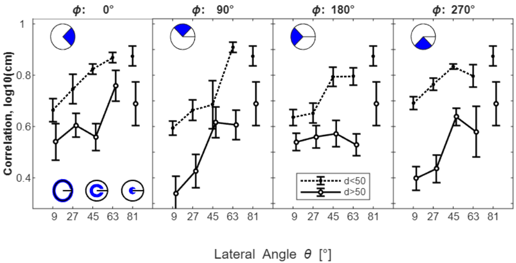
- always decreases with θ,
- in front and above subject, similar for near and far sources,
- behind and below subject, larger for nearby sources and dramatically increases with decreasing θ (worst directly below)
- significant interaction $d \times \phi \times \theta \ < 0.05$



Results: Correlation

- Target-response correlation
- ranges from .35 to .9,
- mostly increases with θ, best for lateral nearby sources,
- always larger for nearby than distant sources,
- for near sources, pattern similar across ϕ,
- for far sources, correlation especially low directly above ($\phi = 90°$) and below ($\phi = 270°$) subject ($\theta = 9°$)
- Significant $d \times \theta \times \phi$ interaction (p < 0.005)

Correlation varies dramatically across examined area.



Summary and Discussion

We examined distance perception of nearby sources in 3D in real reverberation.

Biases:

- general underestimation (10%), not consistent with previous distance-only studies (reporting overestimation for d<1 m [5])
- strong underestimation (30%) for sources above listener and overestimation (more than 20%) for sources below. Space might be perceptually warped / distorted in the vertical dimension as sources rarely come from these locations.

SDs:

- grow with decreasing target laterality, and for nearby sources behind and below listener,

Some of the effects might be due to response method. But most point to distortions in auditory space representation [6].

[5] P. Zahorik, A. V. Bronkhorst & D. Brungart (2005): Auditory distance perception in humans: A summary of past and present research. Acta Acustica/Acustica

[6] O. W. Brimijoin (2018): Angle-Dependent Distortions in the Perceptual Topology of Acoustic Space. Trends Hear., vol. 22, pp. 1-11

Summary and Discussion

Correlation:

- mostly follows the effects shown by bias and SD (e.g., worst above and below subject),
- main exception: correlation is always larger for nearby than distant sources, even though SD is larger for nearby sources behind and below listener, implying that correlation should be lower.

Next steps:

- compare to anechoic data of Brungart et al. (1999) [3]
- analyze temporal profile of learning

Summary and Discussion

Take-home messages:

- This study provides normative characterization of how good (bad) localization performance is in the "best-case" real reverberant room scenario.
- Auditory distance perception of sources in proximal region is highly non-isomorphic, with the largest distortions in the vertical dimension.
- The results might be useful as a reference for development of VR/XR applications in which near field is simulated.

Thanks to our collaborators Virginia Best and Barbara Shin-Cunningham

Thank you very much for your attention