Pavol Jozef Šafárik University in Košice
Faculty of Science, Institute of Computer Science

Distance localization of nearby sound sources in reverberant rooms

Gabriela Andrejková and Norbert Kopčo

Sound localization in distance

The main questions:

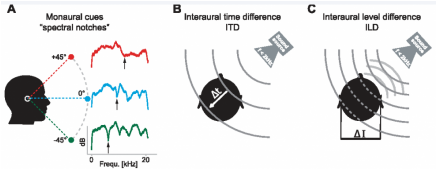
Q1 How accurately can humans estimate the distances of stationary sound sources?

Q2 What determines perceived sound source distance?

Q3 What are the neural correlates to perceived sound source distance?

Ability to localize sounds in space depends on

- anatomical and physiological properties of the auditory system
- monaural cues
- behavioral cues - ITD, ILD



https://binauralhdtracks.com/what-is-binaural-audio/

Zahorik et al. [1]

Summary showed:

- Q1 listeners systematically underestimate distances to faraway sound sources – approximation by a compressive power function
- Q2 examined various acoustical and non-acoustical factors which can contribute to source distance perceptions – intensity, direct-to-reverberant energy ratio, changes in the at-the-ear spectrum as a function of distance, binaural cues.
- Q3 the role of areas within right temporal cortex in auditory distance perception

Most studies are oriented to faraway sound localization analysis.

---

[1] P. Zahorik et al.: Auditory distance perception in humans: A summary of past and present research. Acta Acustica united with Acustica, 2005

Brungard et al. [2]

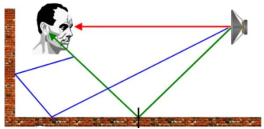
Proximal distance (<1m), in anechoic room:

- angular error - 20° behind subject, 14.5° on the side
- distance performance better than in distal region; dependent on azimuth
- **distance errors (DEr)** are greater near the median plane than at more lateral locations
- **DEr** are greater at high elevations ($> 20^\circ$) than at middle and low elevations
- biases not analyzed

[2] D. Brungard et al.: Auditory localization of nearby sources. II. Localization of a broadband source. J. Acoust. Soc. Am. 106 (4) , 1999

Hypotheses

Main goal: Compare distance location in anechoic and reverberant room.
Influence of reverbaration.



https://songnhac.com.vn/blogs/news/reverb-la-gi

We divide the proximal space by border in 50 cm - **near and far half-space**

- **H1.** In the near space, the responses of subjects will be more consistent than in the far space.
- **H2.** There will be significant differences in biases for polar angles.

- 7 subjects, subject:
  - listen with closed eyes
  - sit in the middle of a 14' x 20' rectangular classroom
  - pointed to the perceived sound source location using a handheld wand
- stimulus:
  - five 150-ms long pink noise bursts separated by 30 ms silence
  - random location in 1-m diameter hemisphere to right of subject

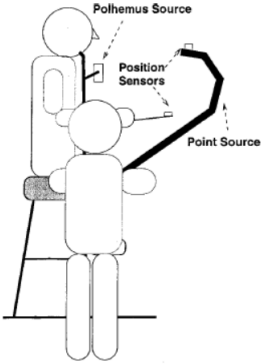


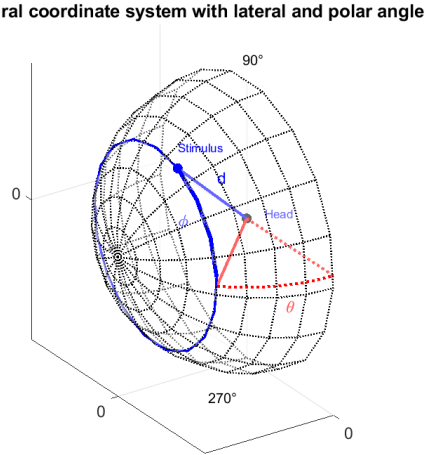
Figure from [2]

[3] Santarelli, S., Kopco, N., Shinn-Cunningham, B. G., & Brungart, D. S. (1999). Near-field localization in echoic rooms. J. Acoust. Soc. Am., 105(2), 1024.

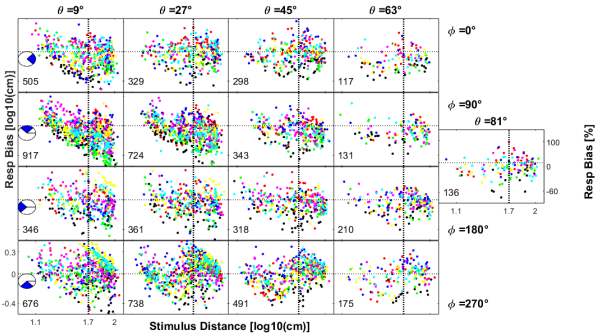
The data were binned into 17 bins (17 directions) in each distance

- **2 distances** – near, far; border 50 cm
- **lateral angle** – 5 regular intervals centered at θ=[9, 27, 45, 63, 81]°
- **polar angle** – one bin for $\theta > 72°$, 4 bins centered at ϕ=[0, 90, 180, 270]°

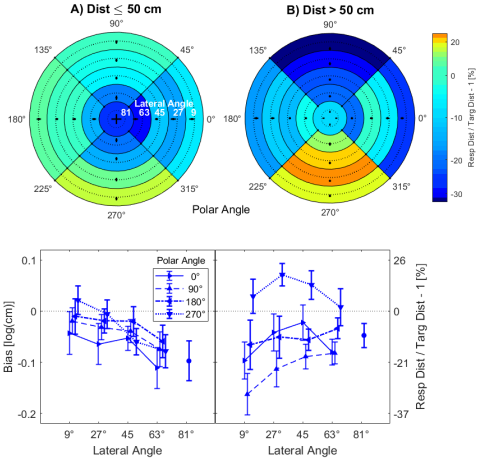
- coordinate system – to follow ISO ITD and ISO ILD



Distribution of data in bins

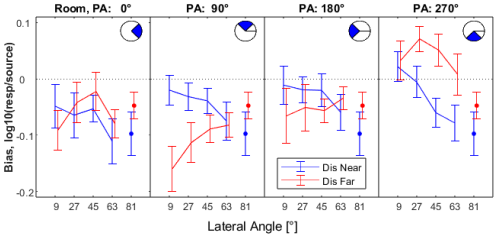


- both spaces – near and far
- approximately 1000 trials/per subject, performed over several sessions
- evaluated biases using a log-log scale (log10(resp distance) - log10(stim distance)),
- ANOVA



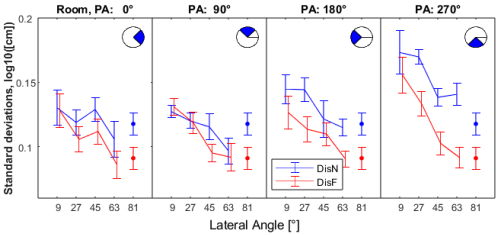
- **near and far space** - differences, higher biases in far space
- **4 polar spaces** - upper, down, front, back
- **evaluation** -green color and dotted line corresponds to no bias
- **lateral angle** - greater near the median plane in far space
- **polar angle** - overestimations in down bins, underestimations in upper bins

Biases Analysis



- Bias – to measure prediction accuracy
- **a lower biases** - the predicted values are closer to the actual values – the model is more accurate
- **a higher biases** – greater error in predictions
- **3-way ANOVA** (distance - D, polar angle - P, lateral angle - L) - **main effect of P** ($F(3,18)=16.48$, $p<0.001$) and **interactions DxP** ($F(3,18)=17.99$, $p<0.001$) and **DxL** ($F(3,18)=10.18$, $p<0.001$)

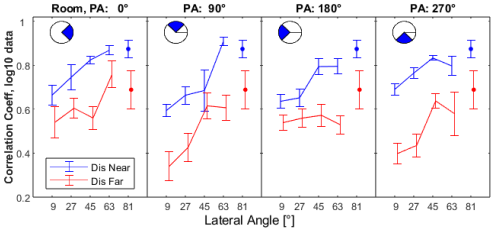
Standard Deviation (STD) Analysis



- STD – to describe the variability in bins

- **a higher STD** in near distance in the most bins - the values are spread out over a wider range
- **a lower STD** indicates that the values are closer to the mean
- **3-way ANOVA** (D, P, L) – all main effects, all interactions, for **DxPxL** before correction $F(9,54)=2.22$, $p=0.0348$

Correlation Coefficient (CorCoef) Analysis



a relation between stimuli and responses data in each bin

- higher values in near distance in all bins
- increasing CorCoef in lateral angles
- in PA 90° the bigest increasing CorCoef with lateral angle
- **3-way ANOVA** (D, P, L) - all main effects, all interaction, for **DxLxP** $F(9,54)=3.39$, $p=0.0023$

Conclusion

Biases, STD and CorCoef in distance perception for stimuli in proximal distance, reverberant room, 3 dimensions

- biases of stimuli in the horizontal plane – an overall underestimation (approx. -10%) that tends to increase for near lateral stimuli (-20% for $\theta = 81°$)
- biases appears to be stronger in front than behind the listeners

These results – auditory distance perception of sources in proximal distance is highly non-isomorphic, with the largest distortions in the vertical dimension.
Support of both hypotheses.

Acknowledgement
Work supported by EU HORIZON-MSCA-2022-SE-01 101129903, APVV-23-0054, SK-AT-23-0002

Thank you very much for your attention