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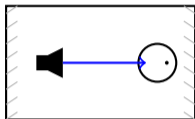


**Distance localization of nearby sound sources
in reverberant rooms**

Gabriela Andrejková and Norbert Kopčo

Anechoic vs. Reverberant Room

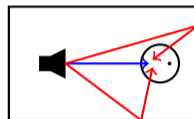
Anechoic Room



Only direct sound reaches listener

- Clear sound
- No reflections
- Walls absorb sound
- Easy to understand speech
- Example: recording studio test room

Reverberant Room



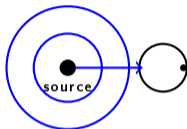
Direct + reflected sound

- Echo-like sound
- Multiple arrivals to ears
- Walls reflect sound
- Speech can be harder to understand
- Example: church, gym, empty hall

Difference: One path vs. many paths to the listener

Hearing in Near vs. Far Space

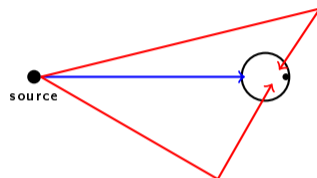
Near (Proximal) Space



Strong, direct sound

- Source is very close
- Direct sound dominates
- High intensity differences
- Strong differences between the ears (timing, loudness)

Far (Distal) Space



Direct + reflections

- Source is far away
- Reflections become important
- Lower intensity differences
- Sound is less precise, more diffuse

Near - dominated by direct sound | **Far** - mixture of direct + reflected sound

Sound localization in distance

Ability to localize sounds in space depends on

- binaural cues - Interaural Time Difference (ITD), Interaural Level Difference (ILD)
- monaural cues - spectral cues from the pinna (outer ear)
- head and body effects
- auditory processing in the brain

The solved questions in the research area:

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

Q2 What determines perceived sound source distance?

We try to answer for parts of proximal space (<1 m). **ITD?**

Showed for **faraway** sound sources:

- 1 listeners systematically **underestimate distances** – approximation by a compressive power function
- 2 various acoustical and non-acoustical factors can **contribute to source distance perceptions** – intensity, direct-to-reverberant energy, changes in the at-the-ear spectrum as a function of distance, binaural cues
- 3 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

Brungart et al. [2] - Anechoic Room

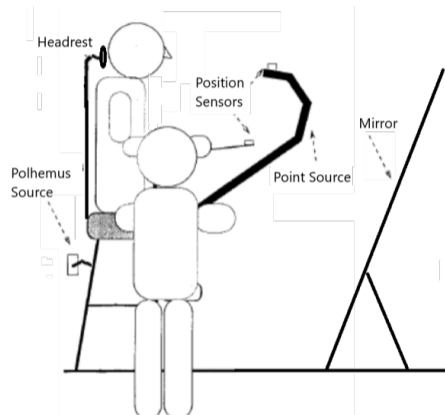
Proximal distance ($<1\text{m}$), in anechoic room:

- 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 higher elevations ($> 20^\circ$) than at middle and low elevations ($\leq -20^\circ$)
- biases not analyzed; special type of error

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

Santarelli et al. exp. in RR followed Brungart's exp. in AR

- **RR**: 7 subjects:
 - listen with closed eyes
 - sit in the middle of a 14' x 20' rectangular classroom at BU
 - pointed to the perceived sound source location; 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



Modified figure from Brungart [2]

Hypotheses

- **H1.** Performance for nearby sources in reverberant room is significantly different for stimuli in subspaces directly above, in front, behind, or below the listener.
- **H2.** The temporal profile during the whole experiment shows a learning effect: distance performance is improved with experience of listener.

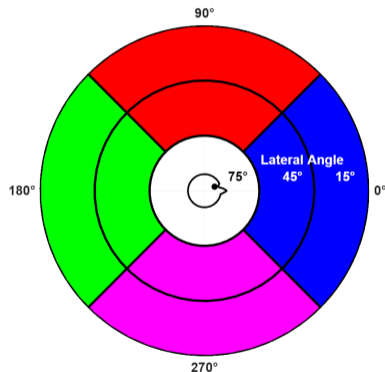
Main goal: a new analysis - the distance localization performance in these data.

Evaluation - the mean absolute error (MAE) and standard deviation (SD) in responses as a function of source location varying simultaneously in all three dimensions.

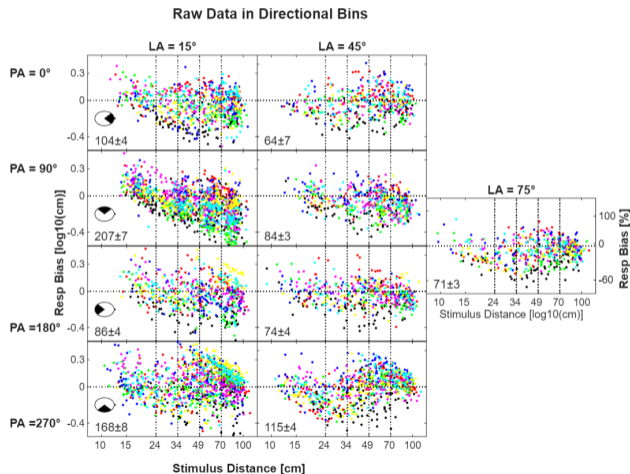
Methods

The data were binned into 9 bins (9 directions) in each distance

- coordinate system – to follow ISO ITD and ISO ILD
- **lateral angle** – 3 regular intervals centered at $LA=[15, 45, 75]^\circ$
- **polar angle** – 4 bins centered at $PA=[0, 90, 180, 270]^\circ$ for LA centered in $15, 45^\circ$ and one bin for LA centered in 75° ,

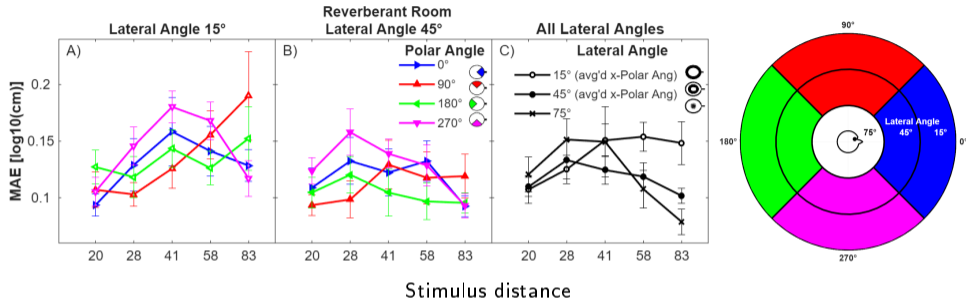


Data distribution



- approximately 1000 trials/per listener, performed over several sessions
- one color for one listener
- Using a log-log scale ($\log_{10}(\text{resp dist}) - \log_{10}(\text{stim dist})$),
- **5 distances** log equidistant intervals with centers: 20, 28, 41, 58, 83 cm

Results - MAE Analysis

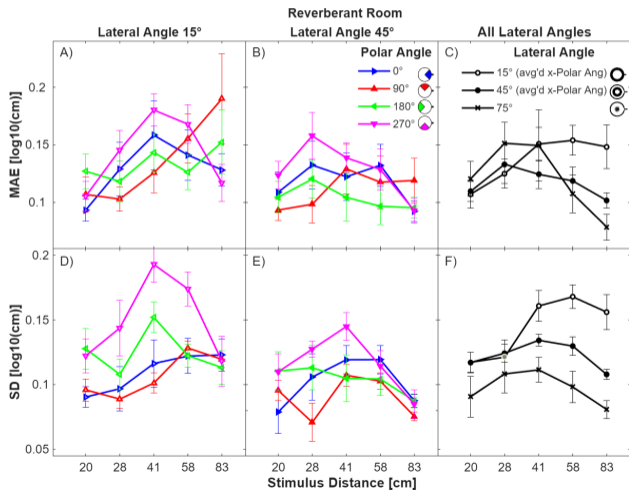


- The largest MAEs – in stimuli in bins below listeners
- For stimuli above the listener (red), near the medial plane – increases with distance
- Larger MAEs in smaller lateral angles,

(LA 15°),

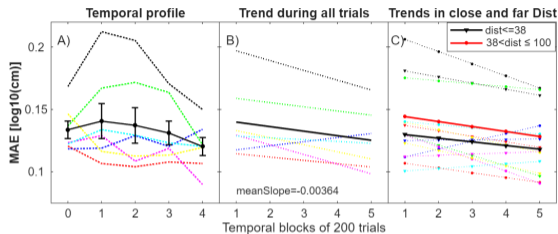
- With increasing from 41 cm distance MAEs don't increase, C)
- 3-way ANOVA: LA(2), PA(4), D(5) – significant main effect **LA**, and interaction **PAx D**

Results - Standard Deviation (SD) Analysis



- a **highest SD** in bins below the listeners
- SD is affected by distance, polar and lateral angle independently of each other
- Partial 3-way ANOVA for PA(4), LA(2), D(5) shows main effect **LA**.
- After averaging across polar angles 2-way ANOVA with factors LA(3), D(5) showed main effect **LA**.

Temporal Profile Analysis



- All data of each listener - divided into 5 temporal blocks per 200 trials in chronological order
- For each listener and each trial - MAE and SD calculated and averaged across stimuli in each temporal block
- The time course of the averaged values also represents the course of adaptation to the stimuli
- Followed decreasing MAE in linear model
- Significant effect in linear model - starting and ending values

Conclusion

Distance perception for stimuli in proximal distance, reverberant room, 3 dimensions

A behavior of **MAE** and **SD** is influenced by

- **MAE**
 - the **lateral angle**, the error is small near the head, it increases with distance, and stabilizes except for LA 75 where decreases
 - both **polar angle** and **distance**, the error is small near the head, the largest error is manifested below the listener
- **SD** - the **lateral angle**, larger errors are for frontal stimuli
- **Temporal profile** - shown adaptation to stimuli in experiment time

These results – auditory distance perception of sources in proximal distance is non-isomorphic, with the largest distortions in the polar angle.

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