DISTANCE PERCEPTION OF NEARBY SOURCES IN REVERBERANT AND ANECHOIC LISTENING CONDITIONS: BINAURAL VS. MONAURAL CUES

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0. ABSTRACT

When sources are within reach of a listener, interaural differences vary with both the direction and distance of the source (e.g., see Brungart & Rabinowitz, 1999, Shinn-Cunningham et al., 1999). Previous results of localization experiments performed in anechoic space support the idea that listeners use these binaural cues to judge source location (Brungart & Durlach, 1999). However, results from similar experiments in a reverberant space suggest that reverberation aids localization performance, even for sources within a meter of the listener (Santarelli et al., 1999).

In order to test whether these reverberant cues are used in addition to, or instead of, binaural cues for source distance and direction, subjects were asked to indicate the apparent location of stimuli presented over headphones. The stimuli were created using individualized HRTFs measured in a reverberant space, and were processed either to include or exclude reverberant energy.

Results suggest that naive subjects base their perception of the distance of nearby sources almost exclusively on reverberant cues and cannot use interaural level differences when reverberant and anechoic trial blocks are interspersed. In addition, distance perception in a reverberant simulation is roughly equally good under monaural and binaural listening conditions for lateral sources, suggesting that there is little binaural contribution to distance perception of nearby sources in a reverberant environment.

In a follow-up experiment, subjects identified the distance of a lateral anechoic source under binaural listening conditions and were provided feedback. Although performance of all subjects improved, a few subjects could not learn to use the large interaural level differences in the stimuli as a distance cue even with feedback.

Results show that reverberation is a more salient and robust distance cue than are interaural level differences for nearby sources simulated under headphones. This result may also hold for real-world listening conditions.

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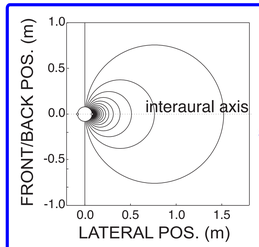
1. BACKGROUND

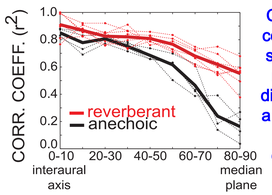
For near sources, ILDs (interaural level differences) provide *distance* as well as direction information.

Distance information is maximal along the interaural axis, decreasing to zero on the median plane.



Iso-ILD contours for source locations around a spherical head (Shinn-Cunningham et al., 2000)

Distance perception for nearby sources is better with reverberation than in anechoic space.



Correlation coefficent of source and response distances as a function of cone-of-confusion angle. Anechoic results degrade as source nears median plane. In reverberant space, distance perception remains good for medial sources (Santarelli et al., 1999).

2. STIMULUS GENERATION

Head-related transfer functions (HRTFs) were measured in a reverberant room for

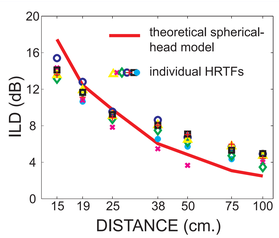
- 7 subjects
- 7 distances (see right)
- lateral and medial sources

"Anechoic" HRTFs were generated by windowing

Pink noise sources were simulated from "anechoic" and "reverberant" HRTFs

Noise level was roved from trial to trial (15 dB)

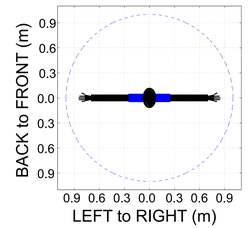
Foiur additional subjects used non-individualized HRTF simulations



ILD in direct sound of individualized HRTFs as a function of source distance along interaural axis. Measured lateral HRTFs contain robust ILD (as do simulations).

3. EXPERIMENT 1 (E1)

Are reverberant distance cues used in addition to, or instead of, ILD cues?



Computer screen display. Subjects indicated with a mouse where the simulated source was heard. The indicated location was used to compute perceived source position.

APPROACH:

Compare binaural and monaural performance.

METHODS:

Simulate lateral and medial positions:
anechoic and reverberant (A/R)
binaural and monaural (B/M)

Block by condition (i.e., AB, AM, RB, RM)
70 trials/block
4 blocks/condition in random order

HYPOTHESES

- lateral better than medial
  reverberation and ILD larger to side
- reverberant better than anechoic
  reverbation adds information
- binaural better than monaural
  binaural adds ILD for lateral sources
  reverberation cue may be binaural

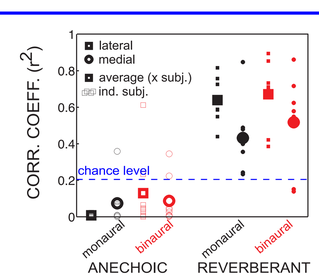
4. E1: DIST. CORRELATION

Compute the correlation between source and response distance to measure distance perception

Distance perception is generally below chance for all anechoic conditions, including binaural lateral
(the subject above chance in anechoic conditions reported using timbre, not distance, cues)

In reverberant conditions, performance for
- medial is worse than lateral
- medial binaural is better than monaural (even though medial binaural differences ~ 0)
- lateral binaural is slightly better than monaural

Reverberant distance cues are mainly monaural. Binaural and anechoic distance cues are weak.



Correlation between source and response distance for each condition. Anechoic results are generally at chance levels. Monaural and binaural reverberant results are comparable.

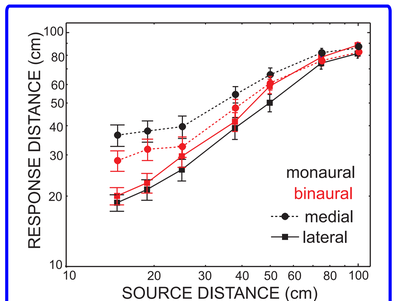
5. E1: MEAN DIST. RESPONSE

Compute mean response (x subs) in reverberant conditions.

Lateral responses are
- generally accurate
- similar for binaural and monaural presentation

Medial responses are
- generally too large (overestimate distance)
- less accurate for monaural than binaural (even though there is no binaural distance cue)

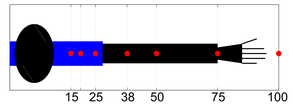
Perceived distance affects perceived direction
(i.e., monaural medial stimuli contain no binaural distance information, but are heard at different directions AND distances than binaural stimuli).



Mean response vs. source distance in reverberant conditions. Medial results show overestimation bias that is larger for monaural presentations.

6. EXPERIMENT 2 (E2)

Can subjects learn to use ILD as a distance cue under headphones?



Computer screen display. Subjects indicated with a mouse which of the seven distances was heard. Correct distance flashed three times after response was recorded.

APPROACH:

Test lateral anechoic binaural with feedback.

METHODS:

Seven alt. forced-choice experiment

Provide feedback on each trial

Repeat 70 trial blocks until performance stable

Six of same subjects as in EXPERIMENT 1

HYPOTHESIS:

I with training, subjects will perform well
ILD distance cues may depend on context

7. E2: DIST. CORRELATION

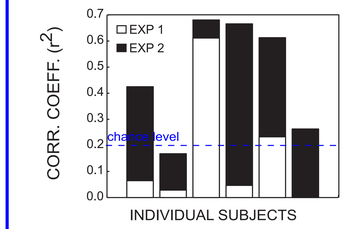
Compute the correlation between source and response distance to measure distance perception

Feedback improved performance of **all** subjects (only one subject still below chance)

Performance still below that seen in Brungart study

Anechoic distance cues in lateral sources can be perceived.

However, with feedback, lateral anechoic performance only reaches the levels achieved for reverberant stimuli without training.



Correlation between source and response distance for anechoic lateral. All subjects improve with feedback; however, final performance levels only approach untrained reverb. conditions.

8. CONCLUSIONS

- Reverberation provides a robust cue for distance in a spatial auditory headphone display.
  - without feedback, reverberant results are good
- Binaural cues add little to reverberant distance perception.
  - distance performance is similar for monaural and binaural lateral reverberant headphone stimuli
- Perceived direction influences perceived distance.
  - medial reberberant monaural stimuli are heard at different directions and distance judgements are more biased than for binaural stimuli
- Anechoic distance cues can be learned, but don't yield robust distance percepts under headphones
  - naive subs do poorly with anechoic binaural cues
  - with training, all subjects improve (2/3 above chance performance levels)

9. REFERENCES

Brungart, DS & NI Durlach (1999). "Auditory localization of nearby sources II: Localization of a broadband source in the near field," J Acoust Soc Am, 106, 1956-1968.

Brungart, DS & WM Rabinowitz (1999). "Auditory localization of nearby sources I: Head-related transfer functions," J Acoust Soc Am, 106, 1465-1479.

Santarelli, SG , N Kopčo, and BG Shinn-Cunningham (1999). "Localizaion of near-field sources in a reverberant room," in Proceedings of the 22nd mid-Winter meeting of the Association for Research in Otolaryngology, (St. Petersburg Beach, FL), 26.

Shinn-Cunningham, BG, SG Santarelli, and N Kopčo (2000). "Tori of confusion: Binaural cues for sources within reach of a listener," J Acoust Soc Am., in press.