2aPPb1. NEAR-FIELD LOCALIZATION IN ECHOIC ROOMS

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1. THE PROBLEM

Most previous studies of spatial hearing focus on sources
l relatively far from the head
l varying in direction only (ignoring distance) -or- varying in distance only (ignoring direction)
l in anechoic space -or- under headphones.

Brungart (1998): 3d, anechoic localization for near sources

Goals of current study
l measure 3d localization in reverberant space
l analyze results in perceptually-relevant manner
l begin to identify acoustic cues used in task.

Hypothesis: reverberation will have little effect.

For sources relatively close to the head
l direct energy should be large (re: reverberant energy)
l behavior should be similar to anechoic results

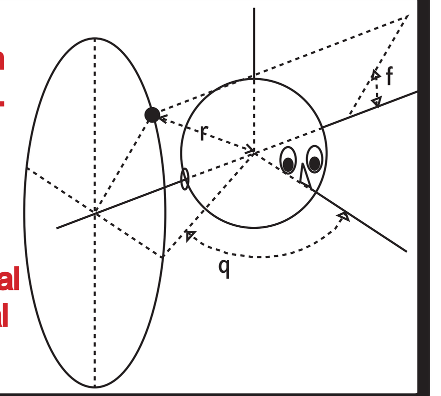
2. BACKGROUND

Many studies use azimuth, elevation, & distance coordinates
l binaurally-consistent responses are hard to identify
l often only up-down and left-right "reversals" are found.

Suggests other coordinates (e.g., Duda, 1997; see right)
l "cone of confusion" errors all fall at same q
l other directional errors seen in f
l distance errors seen in r.

Duda & Martens (1998) & Brungart (1998) argue that large ILDs are a distance cue for near sources. However, ILDs vary with distance and direction (see). Coordinates using radial distance confound ITD and ILD errors.

FIGURE 1: Coordinate system (after Duda, 1997). Coordinates are angle of cone centered on the interaural axis (q), angle from horizontal plane (f), and radial distance (r).



3. PERCEPTUAL COORDINATES

ISO-BINAURAL CONTOURS

Consider point receivers in free space:

l Near-field ILD is constant for sources on a sphere centered on the interaural axis (left side, below).

l ITD is constant for "cones of confusion" that vary primarily with source azimuth (right side, below).

l Gross binaural cues are constant for all sources on a circle perpendicular to and centered on interaural axis.

For near sources, binaural cues are roughly constant on 1d circles of confusion. We introduce the analogue of the far-field "cones of confusion" for sources near the head: doughnuts of confusion!

This analysis ignores head and pinnae effects.

For a spherical head, ILD would vary with frequency, but the ILD function would be constant on any circle of confusion. Thus, iso-binaural contours still would form 1d circles of confusion for a spherical head.

OUR COORDINATES

We propose using spatial coordinates of
l gross interaural time differences (ITDs)
l gross interaural level differences (ILDs) and
l angle along the circle of confusion.

Coordinates are similar to those shown in figure above
l gross ITD is approximately the same as q
l circle of confusion angle equals f
l gross ILD is the iso-ILD surface containg the source.

Gross iso-ILD (left) and iso-ITD (right) surfaces for a point-receiver model (head in white).

4. METHODS

OVERALL PROCEDURE
l multiple 1 - 1.5 hour sessions
l multiple 50-trial blocks in each session
l 200 practice trials (in first session) prior to testing
l 1000 test trials/condition (roughly 10 hrs/condition)

REVERBERANT ROOM
l 14' x 20' rectangule with carpeted floor and hard walls
l reverberation time R_{60} approximately 400 ms

TEST CONDITIONS
l ROOM: subject in center of room (facing short wall)
l BOARD: 8Õx4Õ tiled board 10" from left ear
l all subjects performed ROOM condition first
l some subjects then performed BOARD condition

SUBJECTS
l seven total: two female, five male (22 Ð 44 years of age)
l six with normal hearing; R6 with 15 dB loss @ 2 kHz
l subject A4 from previous ANECHOIC study performed 150 ROOM trials

STIMULI
l five 150-ms long pink noise bursts with 30 ms ISI
l random locations in 1 m hemisphere to right of subject
l level equalized (at head) + additional 15 dB rove

EQUIPMENT
l wooden chair with attached head rest
l PC sound card, Crown D-75A amplifier, point source
l Polhemus Isotraks on point source and response wand

TRIAL PROCEDURE
l random location chosen by computer
l point source positioned by experimenter
l actual location measured by electromagnetic tracker
l one of five possible noise bursts presented randomly
l subject opened eyes and positioned response wand
l computer recorded response location from 2nd tracker

DATA FROM BRUNGART STUDY
l ANECHOIC listening condition
l locations distributed on a log distance scale
l locations slightly biased towards the interaural axis.

5. RESULTS: LEARNING

ANOVA (REVERBERANT CONDITIONS)

Overall, ave abs errors smaller in BOARD than in ROOM.
Hypothesis: changes are due to learning, not acoustics (recall BOARD condition run after ROOM).

Perform 2-way ANOVA on unsigned errors of ITD, ILD, angle for initial and final 200 trials, (p = 0.005).

ROOM condition: errors in initial vs. final 200 trials
l initial significantly larger than final (all 3 cues)
l subject differences significant (all 3 cues)
l interaction significant (all 3 cues)

BOARD condition: errors in initial vs. final 200 trials
l subject differences significant (all 3 cues)
l initial vs. final and all interactions insignificant (any cue)

Errors in final ROOM trials vs. initial BOARD trials
l subject differences significant (all 3 cues)
l initial BOARD ITD error significantly larger than ROOM
l no significant effect for ILD, angle, or any interactions

Taken together, these results indicate that
l subjects continue to learn after 200 practice trials
l wallboard primarily affects ITD judgements
l subjects vary in their abilities in the tested dimensions

A4 ran full ANECHOIC condition and 150 ROOM trials
l A4 more practiced than any other reverberant subject
l initial ROOM errors worse/equal to other subjects'
- when compared to initial 200 test trials
- when compared to first 150 practice trials (not shown)
- significantly worse (relative to others) in ILD judgements

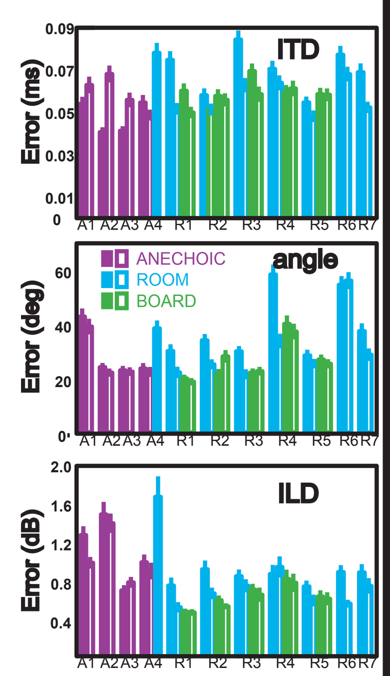
Learning in ROOM condition is not due to the task, but to the acoustics of the reverberant room.

MEAN ABSOLUTE ERRORS

Plots of mean absolute errors confirm ANOVA results: during ROOM, performance improves in all dimensions.

Subjects in ANECHOIC condition do not show a learning effect; however, amount of pre-test practice varied.

Mean absolute errors for initial (filled) and final (open) trials in each condition. There is no learning in ANECHOIC and BOARD. In ROOM, errors decrease with time. Much of this learning carries over into BOARD. Note especially poor performance of subject A4 in ROOM: learning appears to depend on the room reverberation, and not the task.



6. RESULTS: ITDS

COMMON ANALYSIS

Data binned according to ITD (or ILD, angle) of source

For each source bin, responses were binned

(% responses in each response bin plotted)

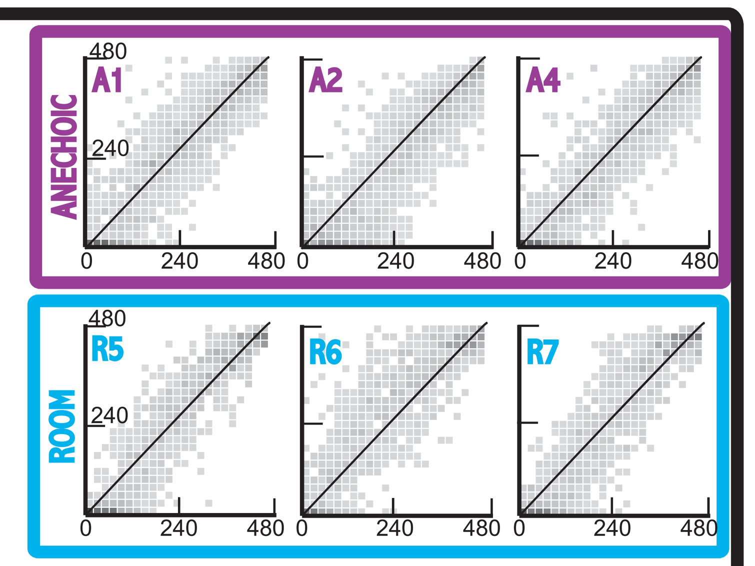
Plots are organized as 24 x 24 grids:
l columns represent source position
l rows represent response position
l gray-scale represents % responses in the row

Subset of subjects shown

Each plot corresponds to one subject (identified by letter/number combination).

Unless noted, data shown is typical of all subjects.

For brevity, BOARD results are not included.

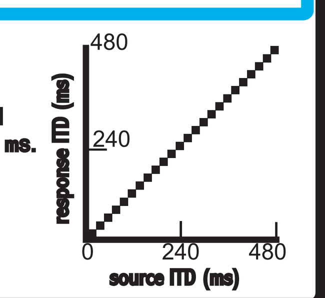


Response vs. Source ITD. Responses fall at or near source ITD in all conditions. Response variability depends on subject, but not on condition. These results indicate that subjects attend to and use ITD as a localization cue in all conditions.

LEGEND

Abcissa and ordinate in 24 equal bins, 20 ms wide, from 0 to 480+ ms.

Black: perfect performance.



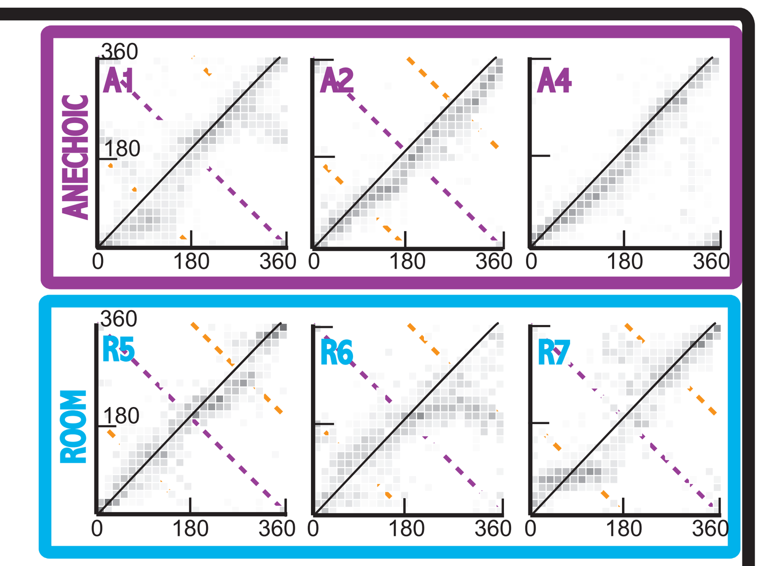
7. RESULTS: CONFUSION ANGLE

ANECHOIC subjects show consistent responses near, but slightly below, the diagonal.

Best ROOM/BOARD subjects are worse than best ANECHOIC subjects.

Subject R6 is not typical in his angle responses. In particular, he is the "worst" subject (has largest response bias and error); however, he suffers from marginal high-frequency hearing loss (10 - 15 dB at 2 kHz).

Subject (R4) showed idiosyncratic changes in the BOARD condition (not shown). Whereas in the ROOM condition, he made many front-to-back reversals, in the BOARD condition, he made many back-to-front reversals. No other significant effects of the BOARD were evident.

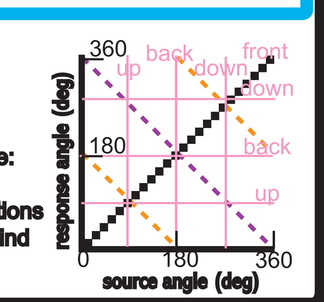


Response vs. Source angle along circle of confusion. ANECHOIC generally has fewer reversals and less spread than ROOM. Individuals differ in their pattern of reversals and (to a lesser extent), in their variability. Results indicate that non-binaural performance varies greatly from subject to subject, and is affected by reverberation.

LEGEND

Abcissa and ordinate in 24 equal bins, 15 deg wide.

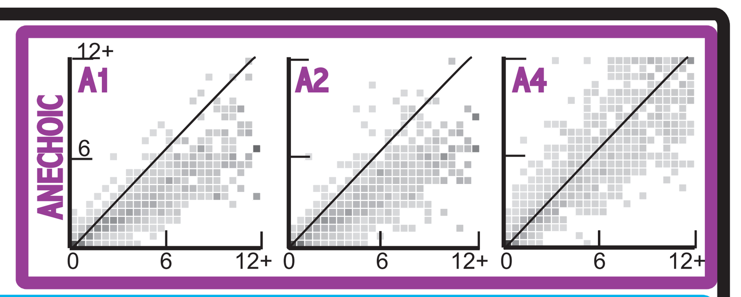
Black: ideal performance. Orange: front-back reversals. Purple: up-down reversals. Pink: angle locations (straight ahead = 0, up = 90, behind = 180, down = 270 deg).



8. RESULTS: ILDs

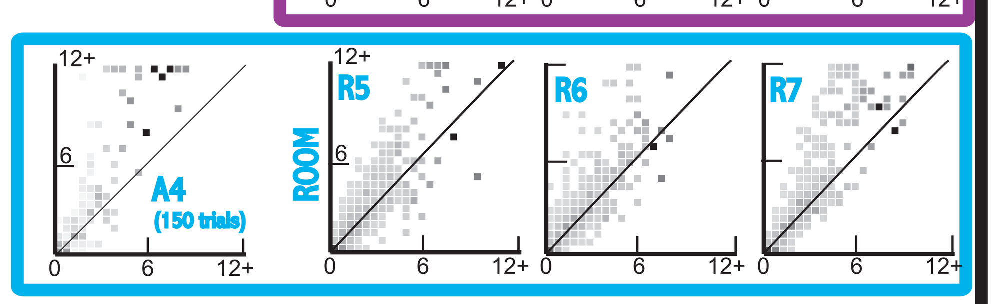
In ANECHOIC, ILD responses tend to be too small (responses too far from the head and/or too close to the median plane), but are highly correlated with ILD of source.

ROOM responses are more accurate than ANECHOIC responses for small ILDs, but for ILDs > 3-4 dB, responses are too close to the head and/or too near the interaural axis.



Subject A4 shows the same stereotypical pattern for his 150 trials in the ROOM (at right).

This experienced subject performed best of all the ANECHOIC subjects, yet showed large bias in the ROOM condition, like our other subjects.

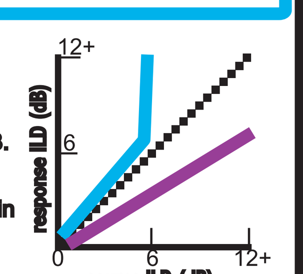


Response vs. Source ILD. ILD is underestimated in ANECHOIC. In ROOM, error is large for near sources (large ILD), but accurate for far sources (small ILD). Subject A4 also shows this pattern. Results suggest that different cues underly perception in anechoic and reverberant conditions.

LEGEND

Abcissa and ordinate in 24 equal bins (0.5 dB wide) from 0 to 12+ dB.

Black: perfect performance. Red, blue, and green: cartoon of results in 3 conditions.



9. RESULTS: DISTANCE

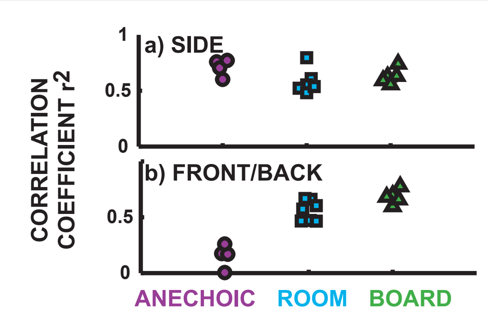
Brungart (1998) ANECHOIC results
l ILD does not change with distance in median plane
l distance judgements poor near median plane

Conclusion: ANECHOIC subjects attend ILD cues

Current ROOM and BOARD results
l judgements not consistent with ILD as a cue
l for near sources, subjects judge sources even nearer

Hypothesis:
l ROOM and BOARD subjects attend ratio of direct to reverberant energy (Mershon et al., 1989; Butler et al., 1980) and ignore ILD
l because little power presented from near sources, reverberant energy near threshold; cue inaccurate
l can explain underestimation of near source ILD
l predicts distance accuracy independent of azimuth.

Correlational analysis supports this hypothesis:
For sources to the side (where ILD is a useful cue) all subjects good at judging distance (high correlations)
For sources near median plane (where ILD absent)
l ANECHOIC near chance performance
l ROOM/BOARD equal to when sources at side



Correlation between source and response distance for sources within 7.5 deg of a) interaural axis and b) median plane. ANECHOIC distance judgements poor in median plane. ROOM and BOARD judgements good at sides or in median plane. Results suggest that subjects in reverberant conditions do not rely on ILD (which should be a robust binaural cue), but ignore it in favor of some other cue, like the direct-to-reverberant energy ratio.

10. SUMMARY

CONCLUSIONS

l Perceptually-based spatial coordinates give insight into auditory localization performance.

l In reverberant conditions, learning continues even after hours of practice.

l In anechoic conditions, learning may be less important.

l Subject abilities vary greatly in all dimensions.

l Subjects in all conditions use ITD cues consistently.

l Individual performance in circle of confusion angle is very idiosyncratic, in all conditions.

l Reverberation affects what acoustic cues are attended
- in anechoic condition, ILD is used to judge location
- in reverberant conditions, ILD is ignored in favor of some other cue (direct-to-reverberant energy ratio?)
- this is especially surprising since ILD should provide reliable binaural information about source position.

l The addition of a nearby, strong reflective surface in an already reverberant room has little effect on localization
- slight decrease in ITD performance
- idiosyncratic changes in circle of confusion errors
- negligible effect on ILD judgements.

FUTURE WORK

l Detailed examination of available acoustic cues in the reverberant room.

l Careful assessment of effect of reverberation on auditory localization for sources near the head.

l Investigation of how learning depends on reverberation.

11. REFERENCES

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