EFFECT OF SPECTRAL CONTENT ON DISTANCE PERCEPTION IN REVERBERANT SPACE

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1. ABSTRACT

In an anechoic environment, distance perception for nearby sources degrades if there is no low-frequency spectral content in a stimulus, presumably because of the importance of low-frequency interaural level difference cues (Brungart, 1999). However, distance perception is essentially the same for monaural and binaural stimuli simulated at nearby distances in reverberant space (Shinn-Cunningham, Santarelli, and Kopčo, 2000 ARO Abstract #103). These results suggest that low-frequency stimulus content may be less critical for distance perception of nearby sources in reverberant space than in anechoic space. The current study examines the effect of spectral content on distance perception in reverberant space.

Sources were simulated using individually measured head-related-transfer functions taken in a classroom. Sources were simulated at distances from 0.15 to 1.7 m, either directly in front or to the right of the listener. Stimuli were 300-ms-long noise bursts generated by filtering and time windowing white noise. Three broadband (wideband, low-pass, and highpass) and three narrowband (200-Hz wide stimuli centered at 400, 3000, and 5600 Hz) conditions were tested.

Although inter-subject differences in overall ability were large, the effects of stimulus spectral content were consistent. In general, accuracy was better for broadband than for narrowband stimuli, and better for lateral than for medial sources. In addition, judgments were least accurate for highpass stimuli.

These results suggest that low-frequency content provides important cues for source distance in reverberant environments, as it does in free-field conditions. However, distance information may be encoded by different stimulus attributes in reverberant and anechoic space.

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2. INTRODUCTION

BACKGROUND

In anechoic environment humans can judge sound source distance only if sounds
- are nearby and laterally displaced
- contain low-frequency energy (Brungart, 1999)

In reverberant space, direct to reverberant energy ratio (D/R) is an important distance cue (Hartmann, 1983)

D/R cue is
- available at all source azimuths
- independent of stimulus frequency or bandwidth

CURRENT STUDY

Measure accuracy of distance perception in simulated reverberant environment as a function of
- **source azimuth:** lateral vs. medial
- **stimulus frequency content:** low vs. high
- **stimulus bandwidth:** narrow vs. broad

Compare data to results of acoustic analysis of the D/R in the stimuli

HYPOTHESES

Effect of laterality:
- small because D/R cue available everywhere

Effect of frequency content:
- small because D/R approximately frequency independent; however
- constant bandwidth means that fewer peripheral filters are activated at higher frequencies --> high-frequency performance worse

Effect of bandwidth:

How is distance perception influenced when
- multiple peripheral filters are excited - across-channel integration
- single peripheral filter is excited

Possible importance of temporal fluctuations in stimulus due to reverberation for distance perception

3. METHODS

EXPERIMENTAL PROCEDURES

Six normal hearing subjects (4F, 2M)

Source Stimuli
- one 300-ms-long white noise burst
- five stimulus types (see Table 1)
- overall RMS energy normalized
- presentation level roved by +/-5 dB from trial to trial
- headphone presentations, simulating different source locations

Source Locations (see Figure 1)
- Nine distances (15 to 170 cm, log spaced)
- Two directions (medial and lateral)

Each trial
- subject informed about room condition
- simulated source presented
- subject indicated heard position on screen (Figure 1)

Experiment
- four sessions
- each session consisted of twelve runs (random order)
- runs (45 trials) held direction and stimulus type fixed
- nine distances presented randomly within run

Simulation Method
- individually measured Head-Related Impulse Responses for listeners in a small classroom (3x3 meters)

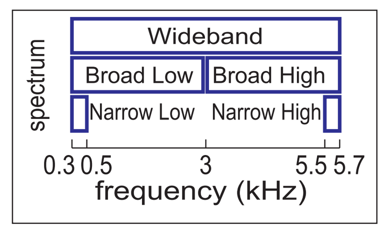
DATA ANALYSIS

Computed correlation coefficient r between log(response distance) & log(simulated distance)

Chance performance defined by p=0.0001

TABLE 1 Bandwidth (in Hz and in ERBs) of experimental stimuli

Stimulus type	Bandwidth (kHz)	Number of ERBs
Wideband	0.3 - 5.7	22.5
Low-freq broadband	0.3 - 3.0	16.8
Low-freq narrowband	0.3 - 0.5	3
High-freq broadband	3.0 - 5.7	5.6
High-freq narrowband	5.5 - 5.7	0.3



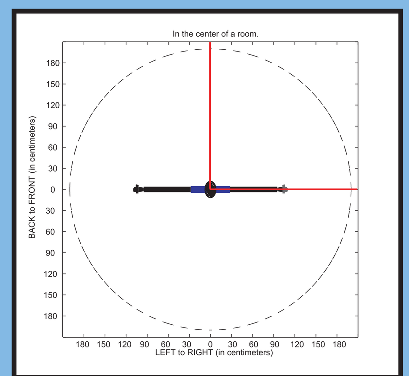
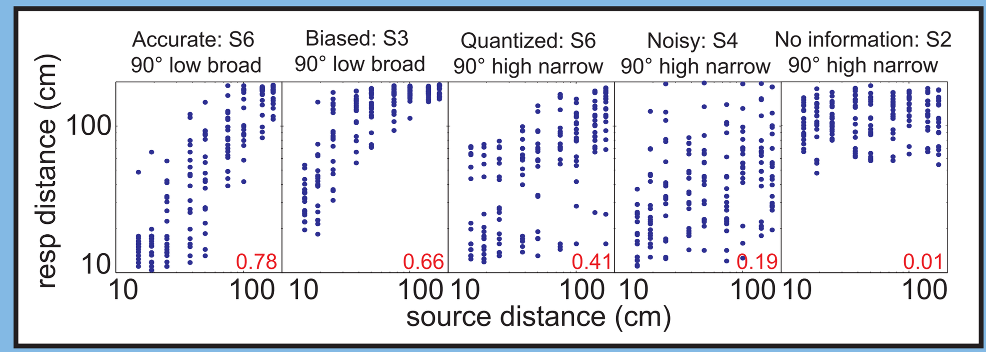


Figure 1 Screen shot from the experiment. Subject used a mouse to click perceived location.

4. RESULTS

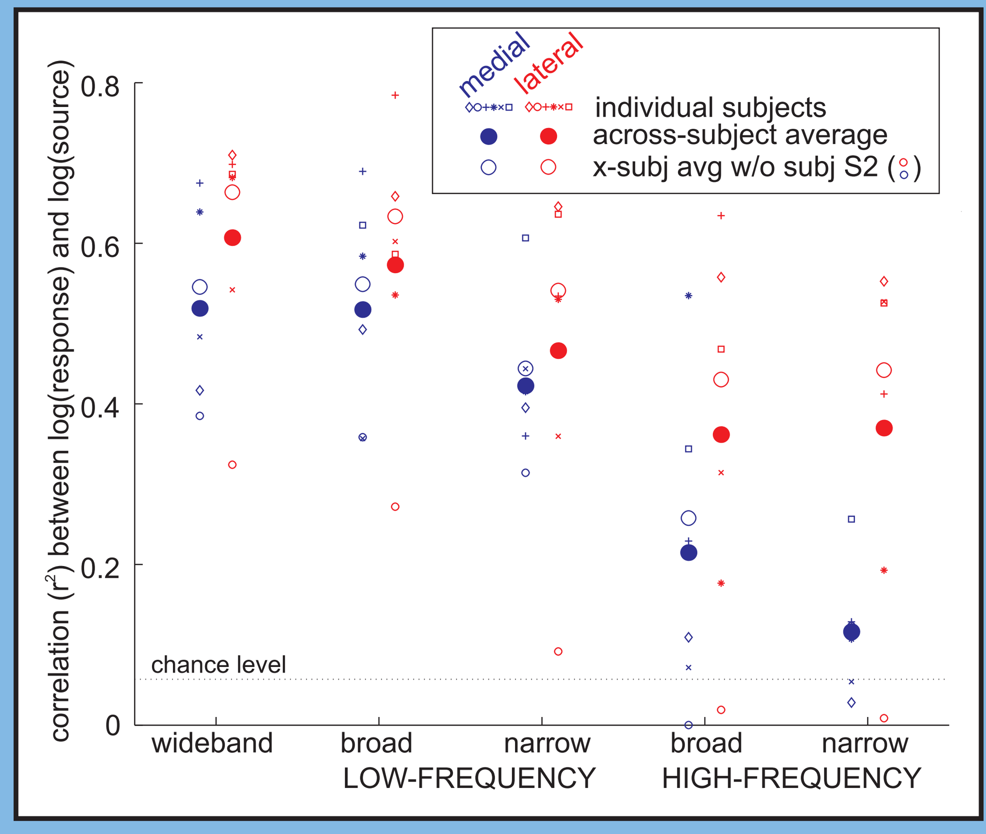
Figure 2. Example of raw results: Typical patterns of responses. Bottom right in each panel: values of correlation (r^2) between source and response distance in plotted data.



Performance deteriorates in various ways, e.g.:
- biased and saturated (non-linear) responses
- quantized responses
- noisy linear responses

Correlation coef (r^2) is a way to summarize results

Figure 3. Overall results: Square of correlation coefficient (r^2) between log of source and log of response distance as a function of stimulus type and azimuth

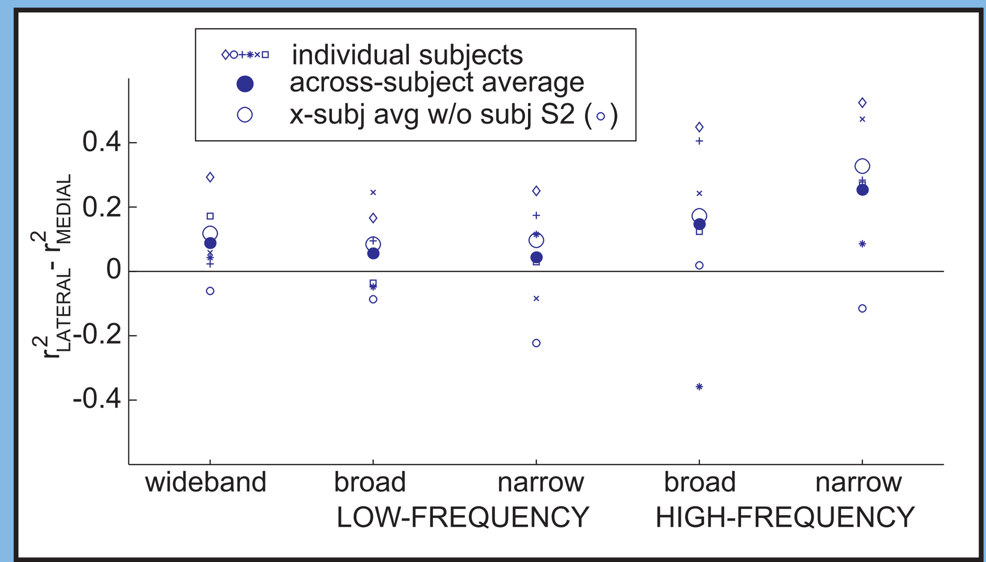


Wideband performance best
Broadband lowpass performance almost as good as wideband
Performance deteriorates with:
- decreasing source laterality
- increasing frequency
- decreasing stimulus bandwidth

Order in which performance deteriorates does not correspond to stimulus bandwidth in ERBs (Table 1)

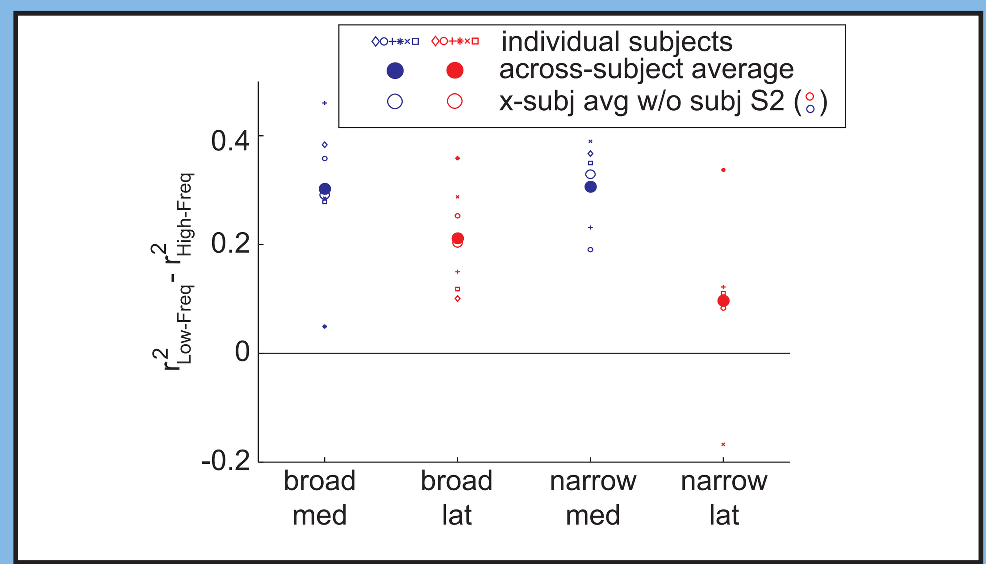
Subject S2 (o)
- had great difficulty performing task
- performance significantly correlated with overall stimulus presentation level

Figure 4. Effect of source direction: difference in correlation (r^2) between lateral and medial data



Small positive difference for stimuli with low-frequency content
Large positive difference for high-frequency stimuli, in particular, for narrowband stimuli

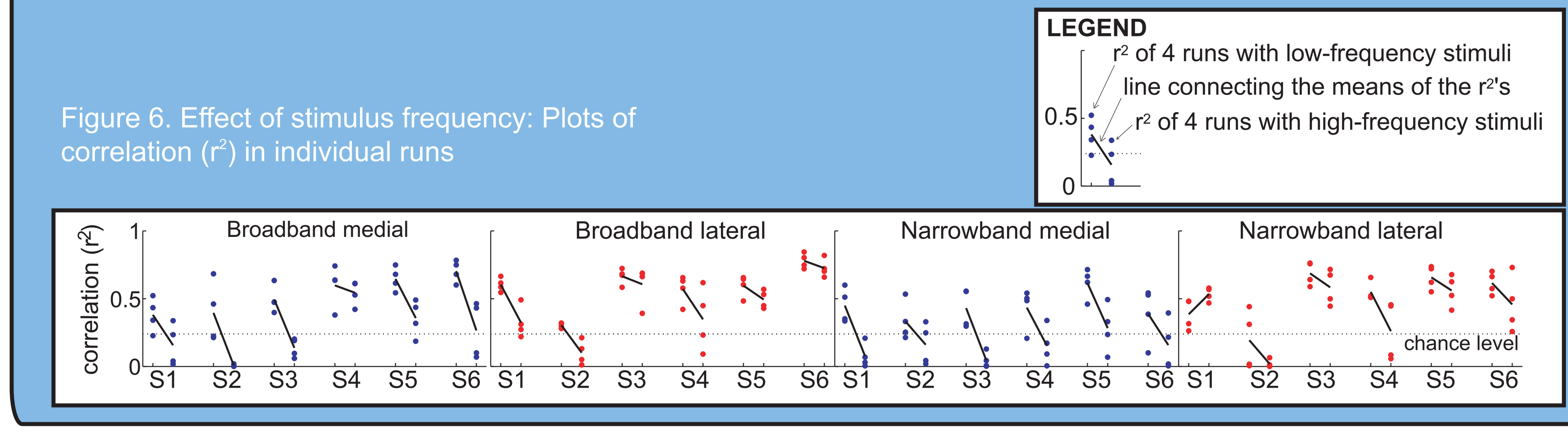
Figure 5. Effect of stimulus frequency: difference in correlation (r^2) between low- and high-frequency data



Large positive difference for medial sources
Small positive difference for lateral sources

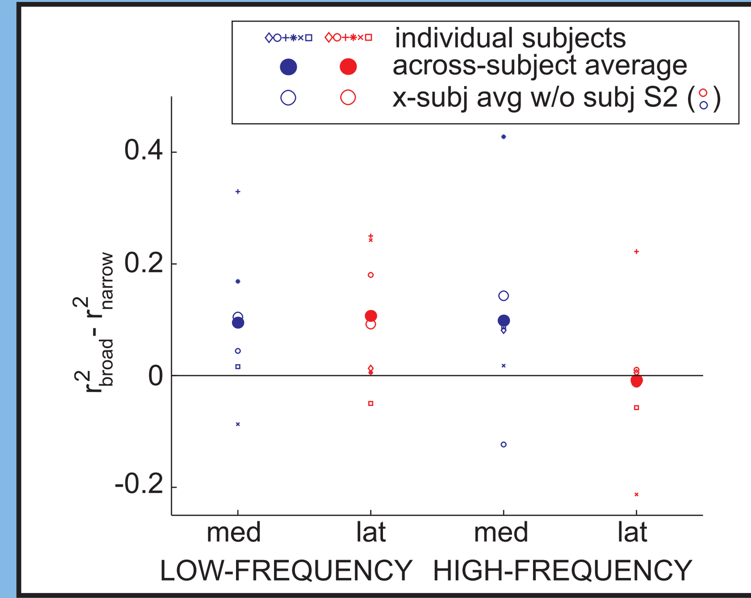
In individual runs, difference in r^2 for lateral sources small relative to across-run variance in r^2 (Figure 6)

Figure 6. Effect of stimulus frequency: Plots of correlation (r^2) in individual runs



4. RESULTS (cont.)

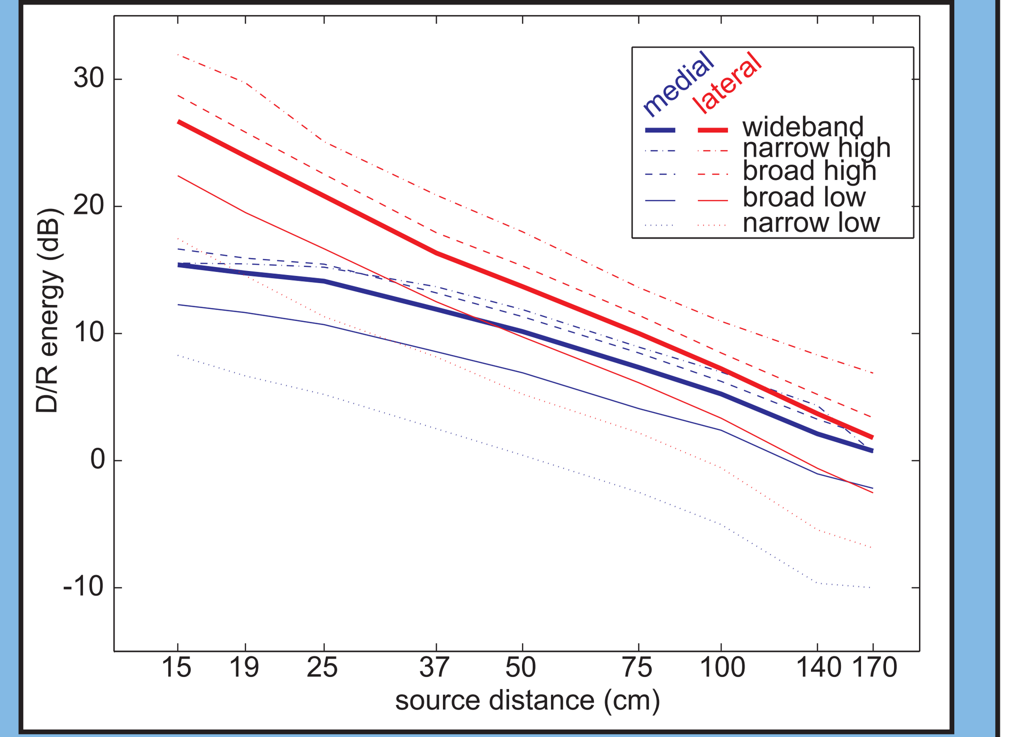
Figure 7. Effect of stimulus bandwidth: difference in correlation (r^2) between narrowband and broadband data



Overall, difference between broadband and narrowband performance is
- small positive for medial and/or low-frequency sources
- none for lateral high-frequency sources

5. ACOUSTIC ANALYSIS OF D/R

Figure 8. D/R energy in the right ear as a function of source distance for different stimulus types (D/R in the right ear always changes at least as much as D/R in the left ear). Across-subject average.



Consistent with behavior (Fig 3):
- D/R difference between nearest and farthest location larger for lateral data
- assuming large absolute D/R is bad, stimuli with largest absolute D/R (dashed and dash-dotted lines) lead to worst performance (high-frequency data in Fig 3)

Inconsistent with behavior (Fig 3):

All red lines and all blue lines are almost parallel --> there should be no effect of stimulus type

6. SUMMARY

BEHAVIORAL DATA

Interaction between azimuth, frequency, and bandwidth:

Wideband performance best

Performance with low-freq stimuli very good across bandwidths

For stimuli containing low frequencies, lateral and medial performance comparable, for the rest, lateral better

Lateral performance
- small influence of stimulus frequency or bandwidth

Medial performance
- worse at high frequencies and for narrowband stimuli

Number of activated peripheral channels is not crucial

ACOUSTIC ANALYSIS OF D/R

D/R changes are
- larger laterally than medially
- almost identical for both bandwidths and frequencies

DISCUSSION

Trends in D/R changes match behavioral data partially:
- medial performance better than lateral only at high frequencies
- lateral performance independent of bandwidth or freq

However:
- effect of laterality is small for low-freq stimuli
- medial performance is influenced by bandwidth and spectrum

CONCLUSIONS

Low-frequency content is important for distance perception, similar to anechoic data (however, the effect is primarily on medial distance perception)

There is interaction among effects of azimuth, frequency and bandwidth on distance perception

Effectiveness of D/R as a distance cue changes with azimuth, spectrum, and bandwidth of the stimulus

Absolute values of D/R appear to be important (however, see Zahorik, 2003)

7. REFERENCES

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