Sensitivity to binaural cues beyond threshold revealed by eye movements

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SPEECH AND HEARING SCIENCES

Association for Research in Otolaryngology 2016

INTRODUCTION

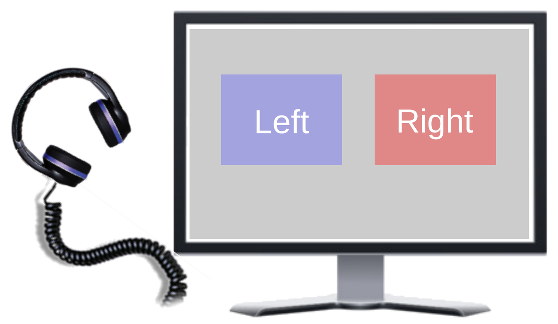
Binaural Hearing
(comparing inputs from both ears)
helps us navigate the auditory environment

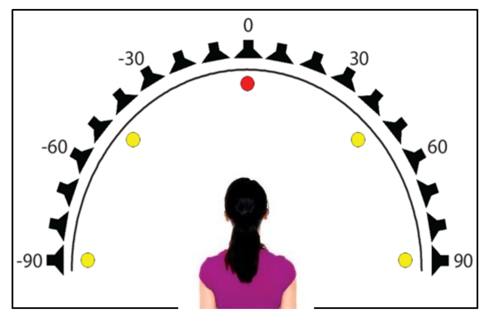
We typically study binaural hearing by measuring sensitivity to differences in sound *level* and *timing* across the ears

Common behavioral methods to test binaural hearing:

Binaural cue threshold testing
(over headphones)
Absolute threshold ("JND") [1, 2]
Intra-cranial perception/lateralization

Supra-threshold sound localization
(in sound field)
Perceptual acuity at different sound locations (e.g. RMS error)
Minimum audible angle [3]





Conventional behavioral methods leave some issues unexplored

Threshold testing doesn't probe certainty / the decision-making process

We operate at supra-threshold levels in everyday life,
(but supra-threshold tests like localization don't isolate specific ITD or ILD cues)

Localization RMS error doesn't capture different response patterns [4]

Audition guides other behavioral actions, like visual fixation

These are the motivations for the current study

We aim to test perception of binaural cues in a way that is:

1) Sensitive to abilities **beyond threshold**
2) Sensitive to **speed** of perception
3) Sensitive to **certainty** of perception
4) Sensitive to **reliability** of perception
5) Suitable for **all ages**

i.e. we want to reveal subtleties in the process of binaural perception and the timeline of actions that proceed from perception, to add to existing measures of perceptual acuity

REFERENCES

[1] Yost (1974) Discrimination of interaural phase differences. *JASA*
[2] Yost & Dye (1988) Discrimination of interaural differences of levels as a function of frequency. *JASA*
[3] Mills (1958) On the minimum audible angle. *JASA*
[4] Greico-Calub & Litovsky (2010) Sound localization skills in children who use bilateral cochlear implants and in children with normal acoustic hearing. *Ear & Hearing*
[5] Fedderson et al. (1957) Localization of high-frequency tones. *JASA*
[6] McMurray & Aslin (2004) Anticipatory eye movements reveal infants' auditory and visual categories. *Infancy*

METHODS

PARTICIPANTS: 13 young listeners with normal hearing (ages 19 – 32 y)

AUDITORY stimuli:
4.8-second 1/3-octave binaurally uncorrelated narrowband noises centered at 500, 1500, or 4000 Hz

ITDs perceptible at low frequencies

ILDs perceptible across the spectrum, but arise naturally mainly above 500 Hz [5]

Binaural cues:
interaural level differences (ILDs) of 0 – 2 – 4 – 8 – 16 – 24 dB
Applied smoothly over a 30-ms window at stimulus midpoint
Randomized for level and direction (left/right)
interaural time difference (ITD) stimuli still in pilot phase for noise and pure tones

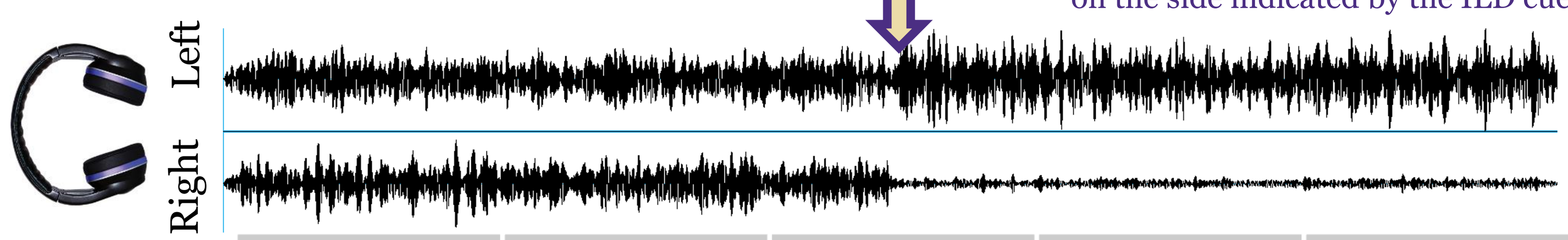
VISUAL stimuli: animated videos of a ball moving left or right, occluded by a Y-shaped tube

0.8 s | 1.6 s | 2.4 s | 3.2 s | 4.0 s

Practice video
(transparent tube)

Stimulus lateralization changes at midpoint (2.4 s)

Ball emerges 1 second later (3.4s) on the side indicated by the ILD cue



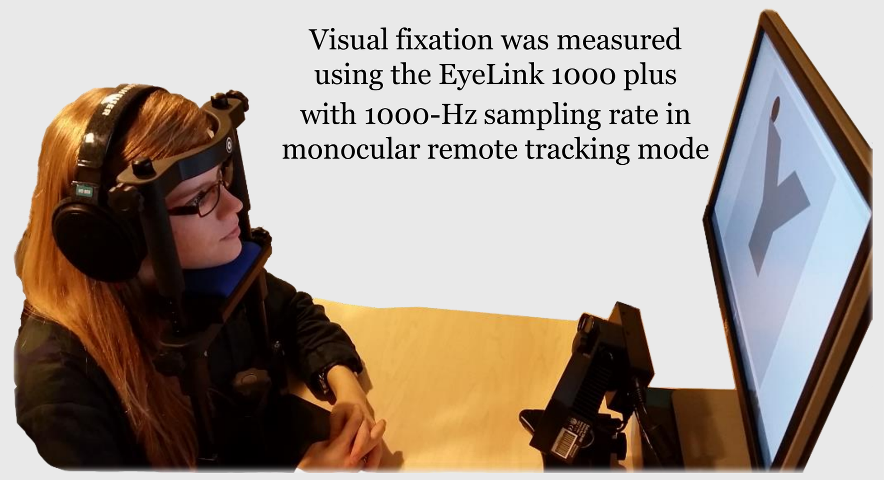
Test video
(opaque tube)

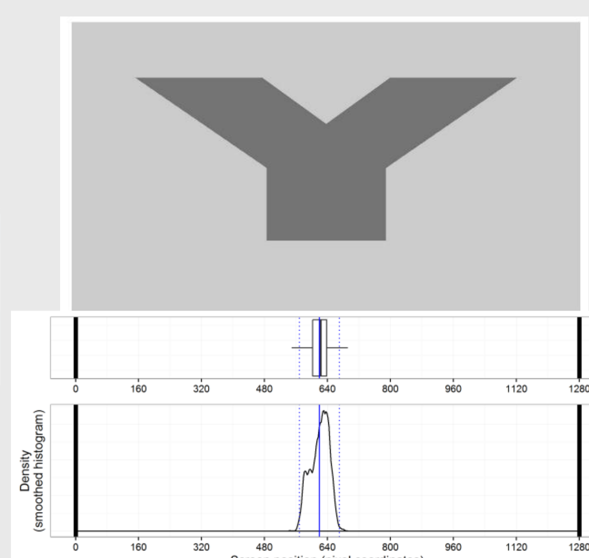
When sound change happens, observers *anticipate* the emergence of the ball before it appears.

This paradigm has been used to test sound and shape categorization in toddlers [6] and adults, and is used here to test left/right cue categorization

MEASUREMENT OF EYE GAZE

Visual fixation was measured using the EyeLink 1000 plus with 1000-Hz sampling rate in monocular remote tracking mode





Data samples were binned into visual fixation areas (center, left, right)

Defined as +/- 2 SDs (blue dotted lines) from tracked gaze position when ball was in center

Group data were aggregated and then low-pass filtered at 10 Hz.

Ashley Moore assisted with data collection.
Financial Support provided by NIH-NIDCD 1R03DC014309 (M. Winn) and DC003083 (R. Litovsky) and the NIH Loan Repayment Program

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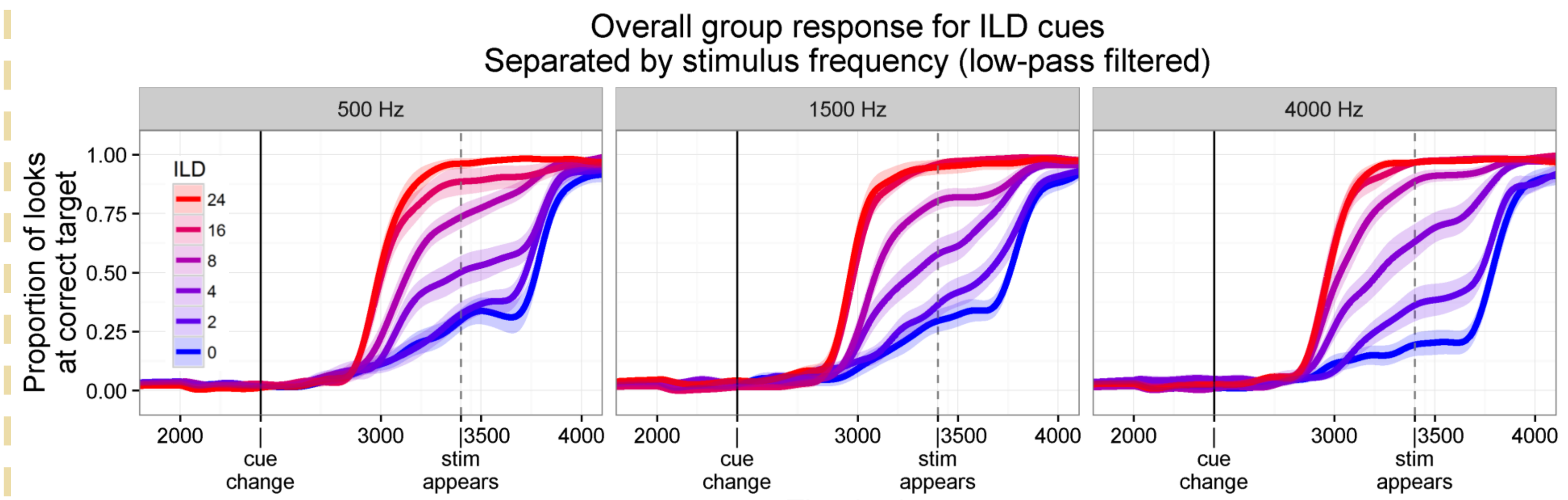
Scan for demo movie stimuli

Scan to download poster

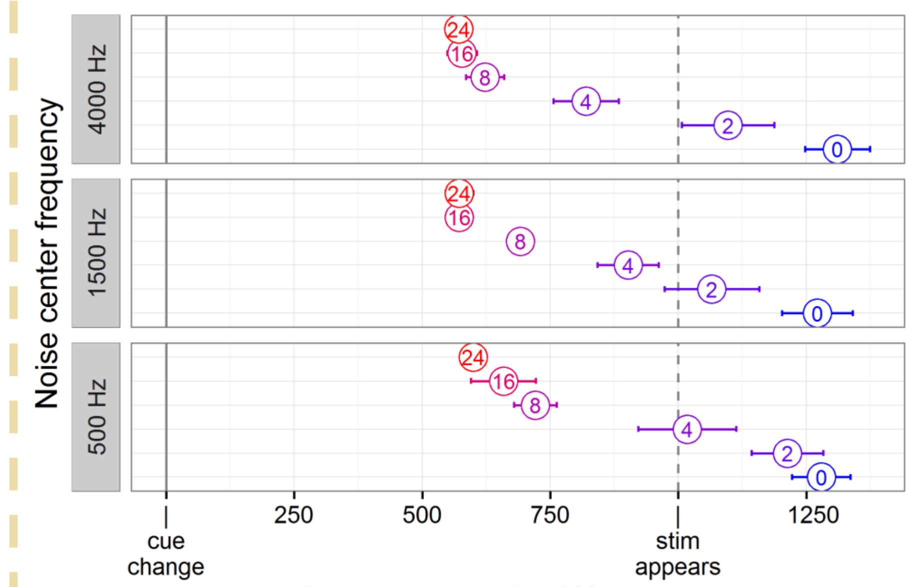
RESULTS



"Correct" means looking toward the side consistent with the ILD cue / direction of where the ball goes
"0" on y-axis means looking at the wrong side or still looking at the center
ribbon width = +/- 1 standard error

Larger interaural level differences elicit correct anticipatory eye movements that are:
* quicker (earlier onset of saccades)
* more reliable (higher proportion correct at any given time)

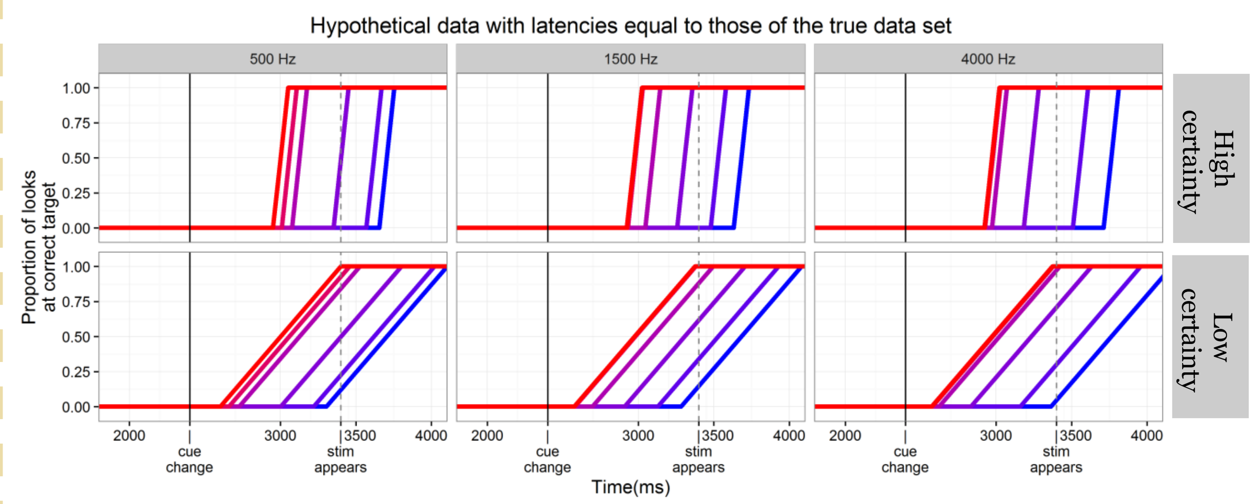
More accurate, slightly faster responses for HIGH-frequency stimuli



Latency: How much time does the listener need after the binaural cue onset before eye movements are correct at least 50% of the time?

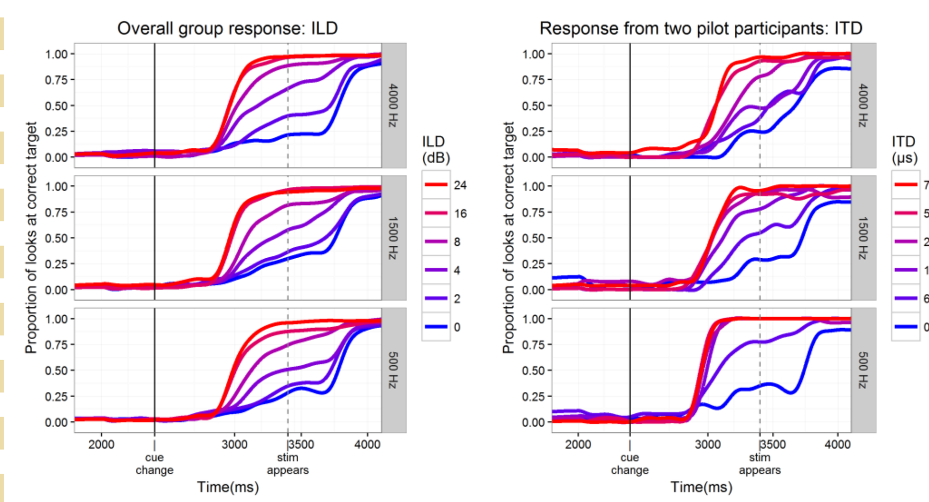
Frequency-dependent shifts in latency are easier to see at intermediate cue levels

"Is this just an expensive measure of reaction time?"



Measures of *reaction time* could yield results consistent with either row of plots; time-series latency measurements provide richer data that demonstrate the growth of certainty/reliability over time.

"What about interaural TIME differences?"



Two participants have completed this study using ITD cues implemented with whole-waveform shifts on 1/3-octave noise bands.

Noises contained inherent amplitude fluctuations; ITDs were available in the stimulus envelopes.

We are also piloting ITDs using sinewave stimuli, which have no envelope cues

Faster and more accurate responses for noises with *fine-structure* ITDs (500 Hz) compared to noises where ITDs are perceptible in the *envelope* (4000 Hz).
Best fine-structure ITD responses are slightly quicker than best responses to ILDs (by ~ 100 ms)

CONCLUSIONS

- Binaural sensitivity is not "all-or-none"; there are gradient levels of response ***latency*** and ***certainty*** over time
- Eye movements guided by binaural cues can be at least as fast as 550 ms in latency; longer latency for smaller cue levels
  (saccades take roughly 200ms to generate, yielding an ILD "processing time" of about 350 ms for these stimuli)
- Perception of ILDs is quicker and more reliable for high-frequency noise stimuli compared to low-frequency noise
- Perception of envelope ITDs *might be* slower than perception of fine-structure ITDs (so far n= 2)
- Binaural sensitivity can be measured with anticipatory eye movements…
  - …requiring no overt behavioral response (i.e. is not affected by differences in motor capacity), with a toddler-friendly paradigm [6]
  - …relatively quickly (~ 50 minutes for 14 reps of 6 cue levels going two directions at 3 stimulus frequencies)