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Lateralization of Competing Interaural Envelope Cues Measured with the CCi-Mobile Research Platform

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INTRODUCTION

- Normal hearing (**NH**) listeners use interaural level differences (**ILDs**) and interaural time differences (**ITDs**) in the fine structure and envelope to localize sounds[1]:

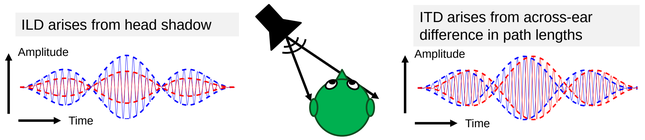


Fig. 1: Illustration of envelope interaural cues. Red: right ear signal, Blue: left ear signal.

- Prior work investigating combinations of ILDs and envelope ITDs (**ENV-ITDs**) in NH listeners found that both cues contribute to **lateralization** (perceived intracranial location) in the presence of the other cue[2]:
  - Vertical axis shows where listener heard a sound in their head (R: Right, C: Center, L: Left)
  - Green curves shows use of both cues together
  - Orange curve shows that ENV-ITD changes lateralization
  - Blue curve shows that ILD changes lateralization

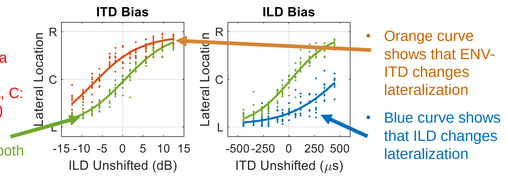


Fig. 2: Lateralization curves for a NH listener. One binaural cue is held constant; the other has been adjusted.

- Bilateral cochlear implant (**BiCI**) listeners only have access to envelope modulations of high-rate pulse trains, but can use ENV-ITDs to lateralize stimuli when using research processors[3,4].
- However, the utility of ENV-ITDs in more realistic situations, when both ILDs and ENV-ITDs are present, is unclear.
- **To investigate the impact of either the ILD or ENV-ITD on lateralization in BiCIs, the current study adapted a *cue competition* paradigm previously used for localization[1]**:
  1. Measuring baseline lateralization: Pairs of ITDs and ILDs from a head model are presented to determine extent of lateralization.
  2. Measuring cue-shifted lateralization: Either the ILD or ENV-ITD receives a systematic cue-shift.

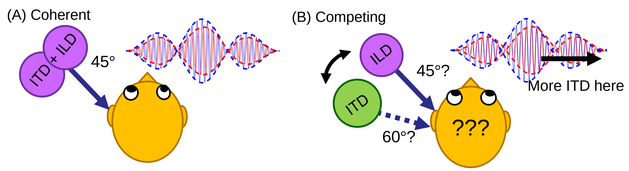


Fig. 3: (A) Depiction of coherent cues, with corresponding ILD and ITD; (B) a coherent cue pair with an additional systematic cue-shift in ITD applied.

Hypothesis: If either cue contributes to lateralization in the presence of the other cue, then a cue-shift will cause a change in BiCI listeners' responses.

OBJECTIVE

Investigate the impact of combinations of ENV-ITDs and ILDs on BiCI listeners' ability to lateralize sounds.

METHODS

Stimulus

- Stimuli (see Fig. 4) were delivered using the CCi-Mobile, a bilaterally synchronized research platform[5]. Stimuli targeted a single-electrode pair yielding the best ITD sensitivity in each listener (based on prior visits to the lab and an ITD matching task):

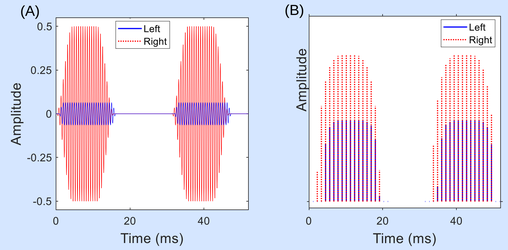
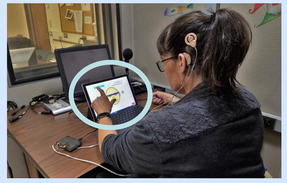


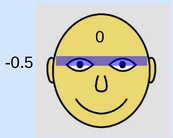
Fig. 4: (A) Acoustic stimulus, carrier frequency of 1688 Hz, ILD of 17 dB and ITD of 655 μs; (B) electrodogram of single channel stimulus processed by the CCi-Mobile.

- Pairs of binaural cues were applied to the stimuli:
  - **Coherent:** Eleven pairs of ITDs and ILDs generated from a head model[6] (see Table 1).
  - **Competing:**
    - ENV-ITD cue-shift (±300 μs, ±600 μs)
    - ILD cue-shift (±10 dB, ±20 dB)

Angle (°)	ITD (μs)	ILD (dB)
0	0	0
5.1	64	1.8
6.8	85	2.4
9.1	113	3.2
12.2	151	4.3
16.3	201	5.7
21.8	265	7.5
29.2	347	9.7
39.1	446	12.4
52.3	556	15.1
70.0	655	17.3

Table 1: Coherent ITD and ILD values generated from a head model[6]





Interface records values from completely left to completely right as -0.5 to 0.5.

Fig. 5: (Left) A participant uses the CCi-Mobile. Listener indicates on the interface where they perceive the location of the auditory event. (Right) Interface screen.

ID	Age	Etiology	Years BI	Pulse Rate (pps)	100 pps JND (μs)	Electrode Pair	Mod. Rate (Hz)
IBF	68	Hereditary	12	900	38	L12, R12	100
IBO	54	Otosclerosis	5	1200	100	L12, R13	64
IBY	56	Progressive	8	900	96	L4, R6	32
ICJ	70	Childhood illness	9	900	160	L12, R12	64
IDA	52	Progressive	5	900	468	L12, R13	32
IDH	20	Unknown	14	1200	165	L12, R14	32

Table 2: Participant information. *(pps = pulses per second).* T and C levels remapped for IBY and ICJ.

Analysis

- Lateralization curves were fit with the following function using nonlinear-least-squares[7]:
  - $f(\phi) = \sigma_y \operatorname{erf}\left(\frac{\phi-\mu_x}{\sqrt{2}\sigma_x}\right) - \mu_y$

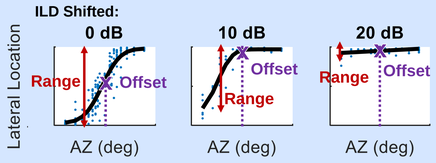
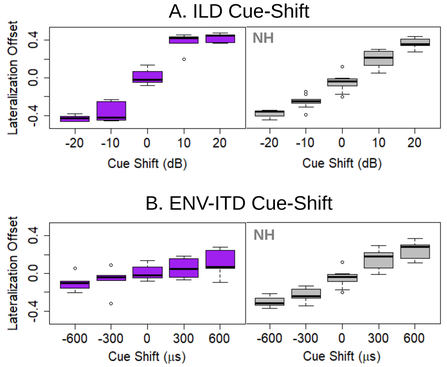


Fig. 6: Five lateralization curves (participant IBF) fit with the above function. Dashed red arrows represent lateralization range. Solid purple x's represent lateralization offset.

- Two parameters of interest were extracted from the fitted curves (Fig. 6):
  - **Lateralization offset**, the value of the fitted curve at 0°.
    - Coherent cues = 0
    - Competing cues ≠ 0
  - **Lateralization range**, absolute difference between fitted curve at the minimum and maximum cues.
    - Coherent cues = 1
    - Competing cues < 1

RESULTS

Group Offset



Group Range

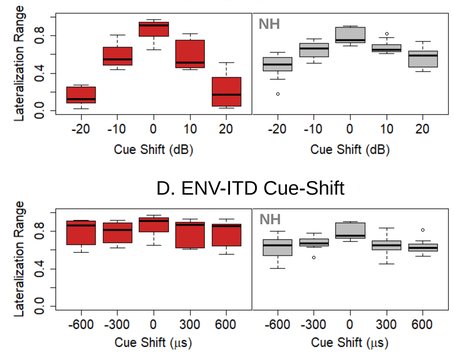


Fig. 7: Group lateralization offset for (A) ILD cue-shift, (B) ENV-ITD cue shift; group lateralization range offset for (C) ILD cue-shift, (D) ENV-ITD cue-shift. NH data (gray) presented for comparison.

- F-tests revealed significant differences in means for ILD cue-shifted offset and range [$F(4,25)=166.6$, $p<0.001$], [$F(4,25)=24.9, p<0.001$] and no significant differences for ITD cue-shifted offset and range [$F(4,25)=3.3$, $p=0.0258$], [$F(4,25)=0.3$, $p=0.863$].

Example Lateralization Curves

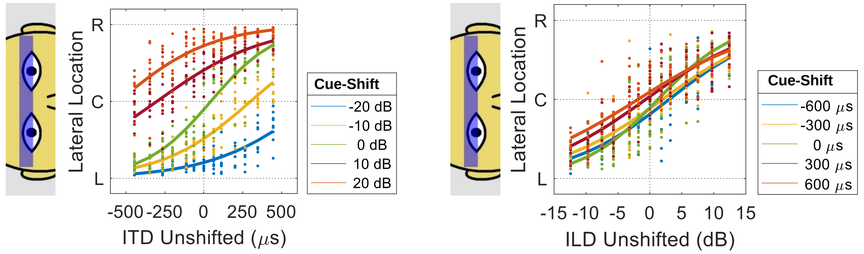


Fig. 8: Lateralization curves for BiCI listener IBY. One binaural cue is held constant; the other has been adjusted.

SUMMARY

1. As with NH listeners, a cue-shift in ILD contributed to a change in lateralization range and offset. Unlike NH listeners, a cue-shift in ENV-ITDs did not contribute to a change in lateralization.
2. This suggests that BiCI listeners most likely use only ILDs for lateralization when both ILDs and ENV-ITDs are present.
3. If delivering ITDs to BiCI patients with high-rate envelope modulations does not have an impact on lateralization in BiCI listeners when ILDs are also present, other methods of delivering ITDs may be necessary.

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