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Lateralization of Interaural Time Differences Measured with the CCi-Mobile Research Platform

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INTRODUCTION

- Normal hearing listeners have sensitivity to frequency-dependent interaural level differences (ILDs) and interaural time differences (ITDs), enabling them to localize sounds [1].
- However, bilateral cochlear implant (BiCI) listeners can only utilize ILDs and ITDs in the envelope of sounds (ENV-ILDs and ENV-ITDs, respectively) when using their clinical processors [2].
- By playing sounds to clinical processors via the audio input ports, we have previously shown that BiCI listeners are sensitive to ENV-ILDs and ENV-ITDs of 30 Hz transposed tones [3].
- However, it is still unclear how ENV-ITDs contribute to lateralization in the presence of an ENV-ILD, as seen in the third panel of Figure 1.

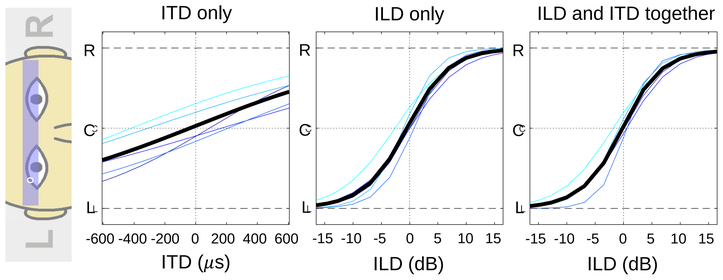


Figure 1: Lateralization responses of BiCI listeners presented with 30 Hz transposed tone complexes, measured with Direct Connect [3].

- If ENV-ITDs contribute to lateralization, it is important to ensure their accurate delivery for improved sound localization.
- Spurious ENV-ITDs delivered by unsynchronized processors could be degrading performance by disrupting the perceived location of a sound.

PURPOSE

This study was designed to determine the relative influence each envelope cue (ENV-ITD and ENV-ILD) has on perceived lateralization response location.

STIMULUS

- Stimuli were delivered through the CCi-Mobile research platform developed at UT-Dallas [4]. This platform allows for delivery of binaural stimuli through the ACE processing strategy using the same time-clock in the left and right CI processors.
- Raised-cosine acoustic stimuli were delivered to targeted single electrode pairs using center frequencies of patient's MAPs.
- All stimuli were scaled to each listener's comfort level.

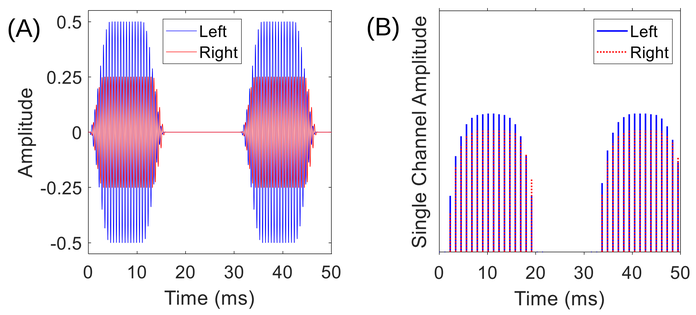


Figure 2: (A) acoustic stimulus, carrier frequency of 1688 Hz, ILD of -6 dB and ITD of -300 μs; (B) electrodogram of single channel stimulus processed by the CCi-Mobile.

Relative influence of ENV-ITD and ENV-ILD investigated using "coherent" cue pairs with and without a systematic shift:

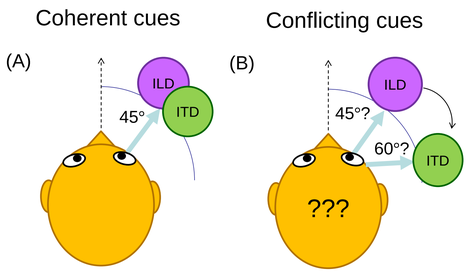


Figure 3: (A) Depiction of coherent cues, with corresponding ILD and ITD; (B) a coherent cue pair with a systematic shift in ITD applied.

- Coherent cues are calculated from head-related transfer functions and correspond to an ecologically valid sound, see Figure 3(A).
- Conflicting cue pairs are generated by applying a systematic shift in either ENV-ITD or ENV-ILD.

METHODS

- Three BiCI listeners completed a lateralization experiment in three phases:
  1. Determine best electrode pair for ENV-ITD sensitivity at 32 Hz.
  2. Determine best modulation rate for ENV-ITD sensitivity.
  3. Determine lateralization responses to
     - 3.1. ENV-ITDs only.
     - 3.2. Coherent cues from a spherical head model [4].
     - 3.3. Conflicting cues with systematic shift of $\pm$300, $\pm$600 μs or $\pm$10, $\pm$20 dB.

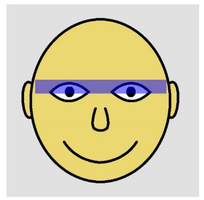


Figure 4: Interface listeners used to indicate perceived location of a stimulus.

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 pairs generated with a spherical head model [4].

ID	Age	Etiology	Years BI	Pulse Rate	100 pps JND (μs)
IBO	54	Otosclerosis	5	1200	100
IDA	52	Progressive	5	900	468
IDH	20	Unknown	14	1200	165

Table 2: Participant information.

MAXIMIZING ENV-ITD SENSITIVITY

- All listeners have previously shown ITD sensitivity using direct stimulation of 100 pps pulse trains (Table 2).
- Stimuli were delivered to electrode 12 in the left ear for all listeners. Right electrodes were varied along electrode 12 $\pm$2.
- Listeners responded to an ITD of $\pm$600 μs, indicating if they heard the sound to the left or right. Percent correct above 71% was used to select the parameters for each subject.

Phase 1: Best electrode pair for ENV-ITD sensitivity

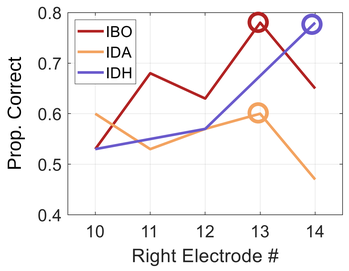


Figure 5: Proportion correct for each subject when completing the ITD electrode matching. Left electrode for all subjects was channel 12. Circle indicates best pair.

- Modulation rate: 32 Hz.
- Listeners IBO and IDH were able to identify >71% for at least one pair of electrodes, but IDA could not. This was consistent with IDA's larger ITD just noticeable difference threshold (see Table 2).
- Best pair:
  - IBO: L12, R13
  - IDA: L12, R13
  - IDH: L12, R14

Phase 2: Best modulation rate for ENV-ITD sensitivity

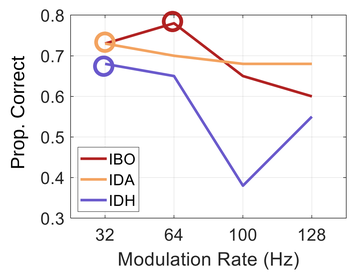


Figure 6: Proportion correct for each subject when completing the rate comparison task. Circle indicates best pair.

- Listeners IBO and IDA were able to identify >71% correct for at least one modulation rate, but IDH could not.
- IDH reported hearing a single sound, but moving across the head.
- Best rates:
  - IBO: 64 Hz
  - IDA: 32 Hz
  - IDH: 32 Hz

LATERALIZATION RESULTS

Phase 3.1: Lateralization with ENV-ITDs

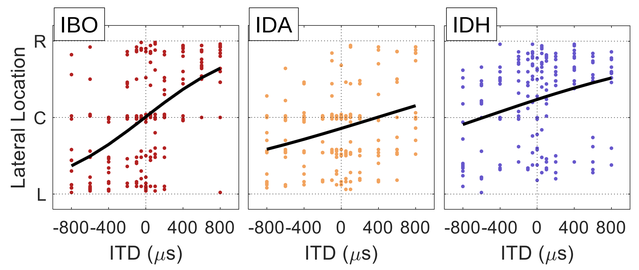


Figure 7: Lateralization curves obtained with only ENV-ITDs.

- None of the listeners were able to consistently and fully lateralize the stimuli when only ENV-ITDs were present.
- Responses were comparable to those in Figure 1 for only ITD cues in the envelope of a transposed tone complex.

Phase 3.2: Lateralization with Coherent Cues

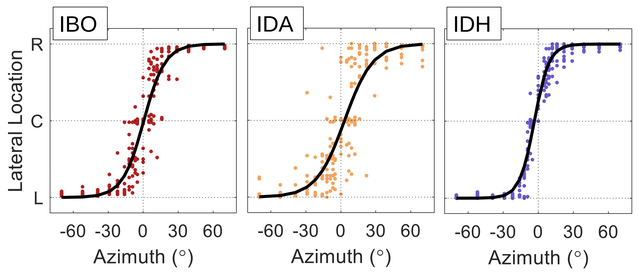


Figure 8: Lateralization curves obtained with coherent cue pairs.

- All three participants were able to lateralize stimuli with coherent cue pairs.
- As with Figure 1, it is unclear how much ENV-ITDs and ENV-ILDs contributed; this curve is a listener-specific reference that will be used to compare to responses to competing cues in Phase 3.3.

Phase 3.3: Responses to systematic shifts in ENV-ITDs and ENV-ILDs

Expected Responses: Histograms of perceived response location

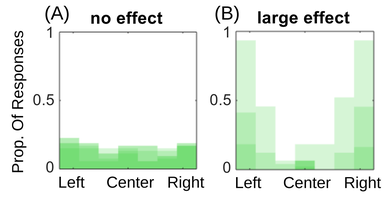
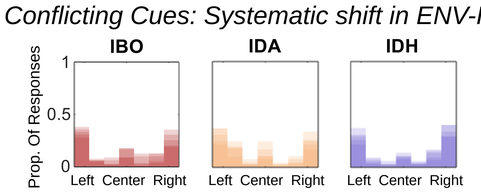


Figure 9: Example data of expected results: Plots are normalized histogram of lateralization responses. Responses to each systematic shift of ENV-ILD or ENV-ITD are superimposed to reveal how much distributions overlap.

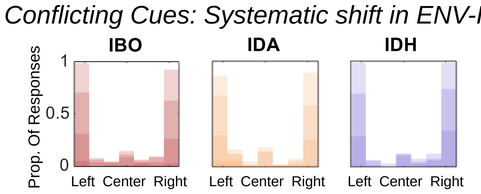
- Lateralization responses are binned by location and plotted in a histogram. Responses to each condition are superimposed.
- If the systematic shift has no effect, by plotting all conditions together, the distribution will be the same across conditions; see Figure 9(A).
- If the conditions have an impact on a listener, they are likely to shift the distribution of their responses to either side. This will lead to a histogram with large responses on either side; see Figure 9(B).

Conflicting Cues: Systematic shift in ENV-ITD



- None of the listeners showed a response to the systematic shift in ENV-ITD applied to the stimuli. Their response histograms did not change even when a shift of $\pm$600 μs was applied.

Conflicting Cues: Systematic shift in ENV-ILD



- In contrast, all listeners had a meaningful response to the systematic shifts in ENV-ILD. Their response histograms demonstrated that for the largest shifts, listeners were most likely to respond as having heard the sound entirely to one side or the other.

Figure 10: Distributions of each listener's responses for systematic shifts in ENV-ITDs (top) and ENV-ITDs (bottom).

SUMMARY

- Listeners were able to lateralize acoustic stimuli delivered through the CCi-Mobile, discriminating between left and right ENV-ITDs and lateralizing combinations of ENV-ITDs and ENV-ILDs.
- Listeners were not sensitive to a systematic shift of the ENV-ITDs, but were sensitive to a systematic shift in ENV-ILDs. This means that sensitivity to envelope ITDs alone did not translate to sensitivity to envelope ITDs when ILDs were also present.
- These preliminary results suggest that ENV-ILDs completely dominate lateralization responses for BiCI listeners, with ENV-ITDs having no perceivable influence.

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