PS-631

Lateralization of Competing Interaural Cues in Envelope-Modulated High-Frequency Tones

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INTRODUCTION

- Bilateral cochlear implants (BiCIs) do not provide binaural hearing with fidelity.
- BiCI users appear to use interaural level differences (ILDs) more than interaural time differences (ITDs) for sound localization [1].
- Several factors may be playing roles:
  - Cochlear implants stimulate with high stimulation rates, where ITDs are not perceived.
  - Clinical processors only provide envelope cues and not temporal fine structure.
- A previous study found that NH listeners use both envelope ILDs and envelope ITDs to lateralize sounds [2].
- By understanding how NH listeners weigh envelope ITDs and ILDs, we hope to be able to restore binaural hearing to BiCI users.

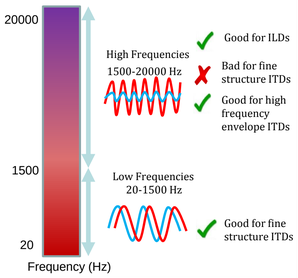

Figure 1. Frequency dependence of interaural cues in normal hearing listeners.

PURPOSE

To investigate how normal hearing listeners weight binaural cues in the envelopes of high frequency modulated tones.

METHODS

- *Participants:*
  - NH listeners aged between 21 and 37 who passed an audiometric hearing screening at 20 dB HL.
- *Task:*
  - Listeners responded to a single interval stimulus by indicating the perceived intercranial position on a graphical user interface. Stimulus conditions were randomized.

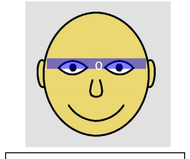

Figure 2. Lateralization GUI.

- *Stimulus:*
  - 4 kHz tone modulated with raised-cosine ramp envelope generated in MATLAB.
  - Cosine roll-off adjusted to reduce off-frequency ITD cues.
  - Low-frequency distortion products masked with pink noise.

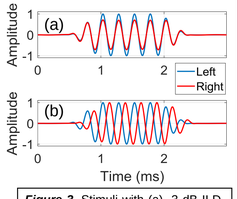

Figure 3. Stimuli with (a) -3 dB ILD, (b) 100 μs ITD.

- *Equipment:*
  - Participants sat in a sound booth and were presented stimuli via an RME Babyface soundcard and Sennheiser HD600 circumaural headphones.

EXPERIMENT 1

Understanding the effect of presentation level and modulation rate on ITD sensitivity

- This experiment explored the parameter space to create a stimulus that provides sensitivity to ITDs in Experiment 2.

METHODS

- *Procedure:*
  - Ten participants were presented with blocks of all conditions and lateralized each ITD cue 20 times.
- *Stimuli:*
  - Eight conditions:
    - Sound levels: 40, 65 dB-SPL.
    - Envelope modulation rates: 32, 64, 128, 256 Hz.
  - Nine ITD values:
    - 0,$\pm$50,$\pm$100,$\pm$200,$\pm$400 μs.

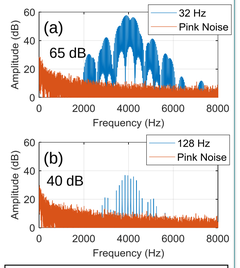

Figure 4. Examples of stimuli spectra.

ANALYSIS

- Lateralization data were converted to a d' statistic to estimate just noticeable difference (JND) thresholds for each condition using the method in Litovssky et al (2010) [3].

How well can subjects discriminate left and right stimuli?

- Effect of level:
  - Higher presentation level led to significantly better performance (Fig. 5, solid lines).
- Effect of rate:
  - At lower levels, performance was best at 128 Hz (Fig. 5, dotted yellow line).
  - At higher levels, there was less variability across rates.

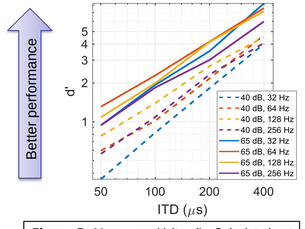

Figure 5. Mean sensitivity d'. Calculated, at each left-right pair (e.g. $\pm$ 50 μs), as the difference between the two means divided by a pooled estimate of their standard deviation.

What is the estimated smallest noticeable difference?

- Effects of level:
  - At lower presentation levels, estimated JNDs were higher, indicating poorer sensitivity.
  - At higher levels, inter-subject variance was lower.
- Effects of rate:
  - Relative minima occur at 64 and 128 Hz, suggesting a "sweet spot", in agreement with previous research [4].

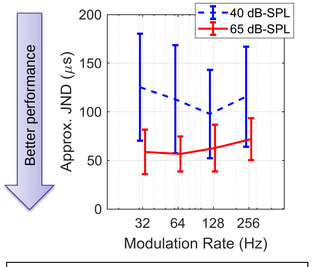

Figure 6. Just noticeable differences, calculated with a threshold of 1, averaged across subjects. Error bars indicate standard deviation.

EXPERIMENT 2

Comparing the relative weighting of envelope ITD and ILD cues in modulated high-frequency tones

METHODS

- *Procedure:*
  1. Participants responded to "natural" ITD and ILD pairs.
  2. Participants responded to a reduced set of "natural" pairs with an additional imposed ITD or ILD.
- *Stimuli:*
  1. ITD and ILD pairs logarithmically spaced from 0 to $\pm$70°.
  2. Additional biasing values:
     - ITDs: $\pm 300, \pm 600\ \mu s$.
     - ILDs: $\pm 10, \pm 20\ dB$.
  - Parameters determined in Exp. 1: 128 Hz, 65 dB-SPL.

Angle (°)	ITD (μs)	ILD (dB)
0	0	0
5.1	63.5	1.8
6.8	84.8	2.4
9.1	113.3	3.2
12.2	150.9	4.3
16.3	200.5	5.7
21.8	264.9	7.5
29.2	346.5	9.7
39.1	445.5	12.4
52.3	555.5	15.1
70.0	655.3	17.3

Table 1. "Natural" ITD and ILD pairs computed from an 8-cm radius spherical head model [5].

ANALYSIS

- The data were analyzed following the methods in Macpherson and Middlebrooks (2002) to calculate the effect of changing an ITD or ILD from the "natural" cue pair on lateralization response [6].
- Unitless "cue weights" were derived in order to compare how each subject weighed envelope ITDs and ILDs.

How much does adding an ITD or ILD shift the perceived lateral location of a stimulus?

How to calculate cue weights:

Step 1: Fit responses to unbiased "natural" stimuli with logistic functions (Fig. 7, green curves).

Step 2: Map responses from biased stimuli (Fig. 7, non-green curves) to corresponding natural ITD or ILD cue values.

Step 3: Plot all data points from Step 2 as a function of bias (Fig. 8).

Step 4: Perform linear regression and take slope as cue weight.

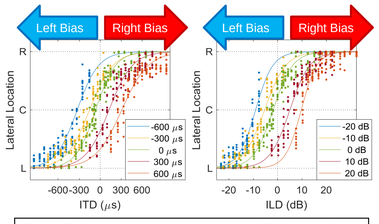

Figure 7. Lateralization curves for subject TNV with different colors indicating different amounts of cue bias. (a) ITD, (b) ILD. Fit function: $f(x) = \frac{1}{1+e^{-slope(x-horizontal\ bias)}}$.

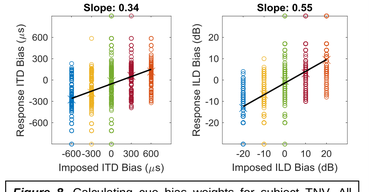

Figure 8. Calculating cue bias weights for subject TNV. All responses for each bias are plotted at the same axis value. Bias weights are the slopes of the linear fits of this data, in black. The means for each cue bias are plotted as X's on the distributions.

BIASED CUE WEIGHTS

- *How to interpret bias weights:*
  - Listeners who perceived the stimulus as being closer to a biased cue than the original "natural" cues will have a larger cue weight for that type of cue.
  - A weight of zero indicates that the imposed bias had no effect.
  - If subject has equal weight for ITDs and ILDs, their cue weights would fall on the dotted line in Fig. 9.
- *Observations:*
  - Four participants had larger ILD than ITD cue weights and one participant had near equal cue weights.
  - All cue weights fell within the range of 0.4 to 0.6.
  - The results are potentially consistent with prior work on envelope cues [2] that while ILDs are dominant, envelope ITDs may have similar weights for this task.

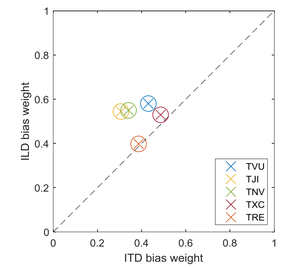

Figure 9. ITD bias weights plotted on the horizontal axis and ILD bias weights plotted on the vertical axis for each participant. Dashed line has a slope of unity.

DISCUSSION

- **Both envelope ITDs and ILDs contributed to the spatial perception of a modulated high frequency tone in NH listeners.**
- **Envelope ILDs were the more dominant cue for most participants.**
- **Future studies will investigate whether BiCI users weigh ITDs and ILDs similar to NH listeners. We hope to find that envelope ITDs will improve sound lateralization in BiCI users.**

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