Predicting the auditory motion tracking abilities of bilateral cochlear implant users and typical hearing listeners using binaural cues

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Introduction

- **Bilateral cochlear implant (BICI)** users have reduced access to the binaural cues that **typical hearing (TH)** listeners use for sound localization: **Interaural time differences (ITDs)** and **interaural level differences (ILDs)** [1]:

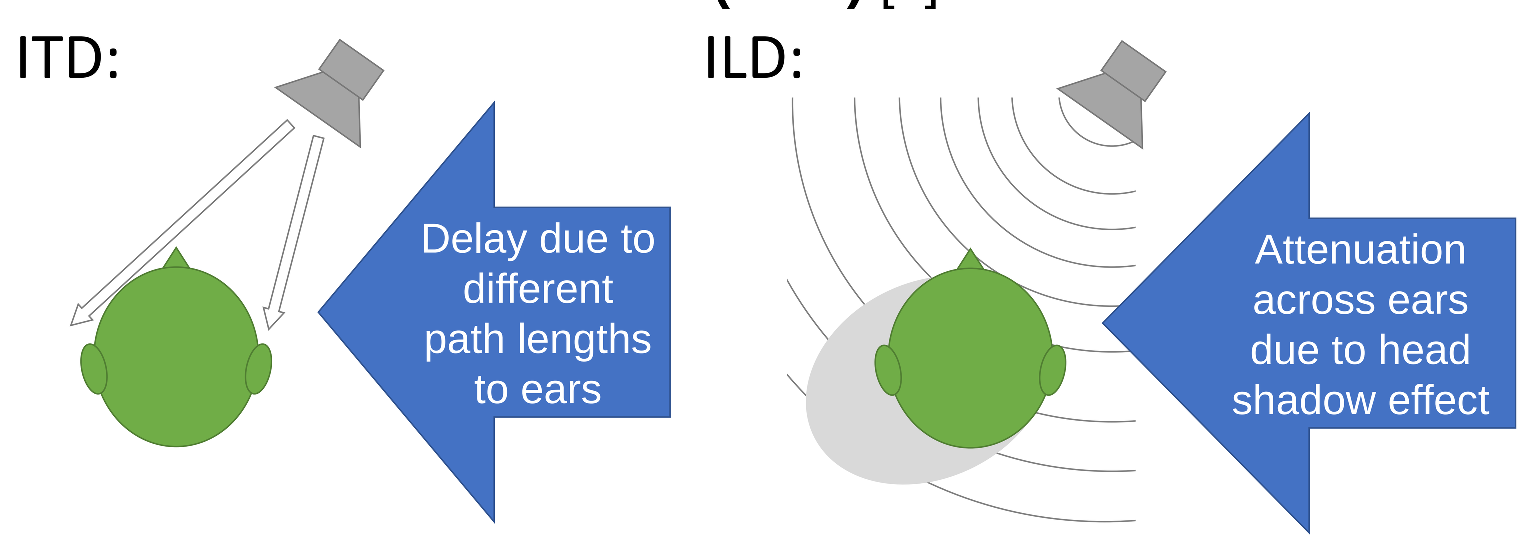

Figure 1: Schematic depictions of interaural time differences (ITDs) and interaural level differences (ILDs).

- TH listeners perform better then BICI users on measures of **auditory motion tracking ability**, e.g., identifying 1) the **start location of a moving sound** and 2) **how far it moved** [2]
- Studies on static sound localization reveal that TH listeners depend on ITDs [3] while BICI users seem to rely on ILDs [1]
- Effects of **dynamic binaural cues** have been considered in simulation [4] but it is unknown how dynamic cues impact the auditory motion tracking abilities of BICI users
- **HYPOTHESIS:** ITDs and ILDs from a stimulus will predict the auditory motion tracking abilities of NH listeners, but only ILDs will predict the auditory motion tracking of BICI users

Methods

- **Auditory motion responses** for **ten TH** and **ten BICI listeners** from a previously published dataset [1] were modeled using estimated **acoustic binaural cues** as predictors
- Stimuli were white noise bursts presented from loudspeakers spaced by 10° between ±90° and that moved 0°, ±20°, or ±40°
- ITDs and ILDs were derived from stimuli recorded with a KEMAR mannikin, and calculated as a function of time:

$$ILD[t] = 10\log_{10}\left(\frac{\sum_k x_{right}^2[t,k]}{\sum_k x_{left}^2[t,k]}\right)$$

$$ITD[t] = \frac{10^6}{f_s}\arg\max_m \sum_{n=0}^{2k-1} x_{left}[t,n+m]x_{right}[t,n]$$

- Each listener's normalized response data were fit with a linear regression for each cue type, or predictor
- **Response start location** was compared to ILD, ITD, or start angle at $t = 0$ while **response range of motion** was compared to change in ILD (ΔILD), ITD (ΔITD), or true range of motion

Results

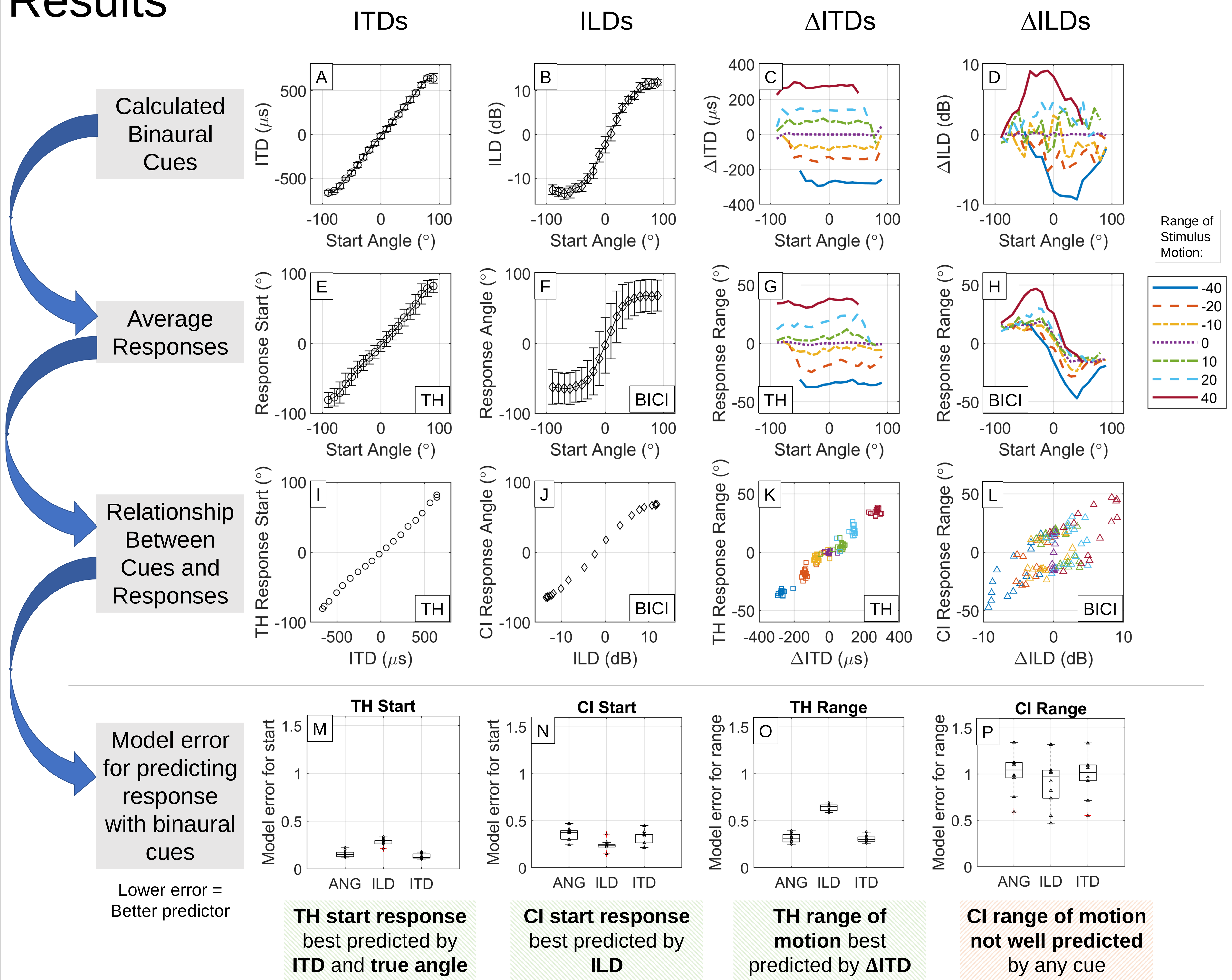

Figure 2: Summary of measured binaural cues (A through D), average TH and CI responses (E through H), responses as a function of binaural cues (I through L), and model error for each predictor (M through P). ANG = True stimulus angle or change in angle.

Binaural cues varied with start angle and range of motion:

- ITDs followed 1st order polynomial (panel A) while ILDs were sigmoidal and non-monotonic (panel B)
- ΔITD varied with range of stimulus motion rather than start angle (panel C), while ΔILD followed a complicated interaction between start angle & range of motion (panel D)

TH listener responses for start location and range of motion were well predicted by the ITDs measured in the stimulus:

- TH responses (panels E&G) closely matched ITDs and ΔITD (panels I&K)
- The stimulus start angle and stimulus range of motion predicted TH responses as well as ITDs, according to model error (panels M&O)

BICI listener start angle response was best predicted by ILDs, but range of response motion was not well predicted by any one cue:

- BICI start location responses (panel F) were predicted by ILDs (panels J&N)
- BICI response range of motion (panel H) was not predicted well by ΔILD alone (panel P), but seemed to be a complex interaction between start angle and stimulus range of motion (panel L)

Discussion

- Response start locations of TH listeners are well predicted by ITDs and response start locations of BICI listeners are well predicted by ILDs, a finding that is consistent with the cues used by each group for stationary sound localization [1,3]
- While ΔITD is sufficient to predict TH response ranges, ΔILD cannot adequately predict BICI response range of motion
- CI processing such as automatic gain control likely distorts ILDs, making it difficult to predict performance using acoustic stimuli [4]
- Further research is needed to determine what cues drive the perception of auditory motion by BICI users
- Improved delivery of ITDs from the acoustic stimulus may improve the accuracy of BICI listener tracking of auditory motion

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