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# Sensitivity to interaural timing differences in children with bilateral cochlear implants

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WAISMAN CENTER

Binaural Hearing and Speech Laboratory

*Conference on Implantable Auditory Prostheses*
*Lake Tahoe, CA*
*July 12-17, 2015*

## Introduction

•Bilateral implantation in children is partly motivated by the attempt to activate binaural circuits in the auditory system, in order to achieve better spatial hearing abilities. The important auditory cues ideally provided would be interaural time and level differences (ITDs and ILDs).
•Previous research, in which children were tested using synchronized research processors with low rate, 100 pulses per second (pps), pulsatile stimulation on pitch matched electrode pairs, suggest that children generally have sensitivity to ILD cues, but sensitivity to ITD cues is weak or absent (Ehlers et al., 2015).
•This lack of ITD sensitivity may arise from two possible factors:

1. Pitch matching may not be a reliable way for identifying anatomical mismatch in place of stimulation for congenitally deaf children, if they have learned pitch through their clinical maps (c.f. Reiss et al., 2008).
2. Providing children with low rate stimulation may not be close enough to what is found in their everyday listening environment. If children are provided with higher rate amplitude modulated stimuli, they may demonstrate the ability to use ITD cues.

•To examine these two factors in greater detail, ITD sensitivity will be compared to direct pitch comparison data and high rate amplitude modulated stimuli will be compared to low rate stimuli.

## Aims

**Experiment I: Relationship of pitch matching and ITD sensitivity:**

•The aim of the first experiment was to determine whether pitch matching tasks can identify the best electrode pair for ITD sensitivity in children with BiCIs.
•It was hypothesized that for children who did not previously show ITD sensitivity at a pitch matched pair, they might show ITD sensitivity at a different interaural electrode pair, which is better matched for anatomical stimulation. This result would suggest that pitch-matching is not beneficial for some subjects in the pediatric population as their results may merely be a representation of their perception based on the frequency allocation tables in their clinical MAPs.

**Experiment II: Relationship of stimulation rate and ITD sensitivity**

•The aim of the second experiment was to determine whether the rate of stimuli affects ITD sensitivity in children with BiCIs.
•It was hypothesized that subjects who do not demonstrate sensitivity to low rate stimulation (100pps) may demonstrate ITD sensitivity to high rate (1000 pps) amplitude modulated (AM) stimuli because this is closer to their clinical processor rate.

## General Methods

**Participants:**

•16 children with bilateral Cochlear Nucleus devices participated in previous research (Ehlers et al, 2015) where ITD sensitivity was measured on pitch matched electrode pairs using low-rate stimulation. Of that 16, data is also shown for five subjects on the two experiments conducted in the current study and are shown in yellow at the top of the table.

**Table 1: Participant Characteristics**

| Subjects | Sex | Age at first test (yrs) | Age at current test | Age of ID (mos) | Age at 1st implant (mos) | BiCI Exp. (yrs, mos) |
|---|---|---|---|---|---|---|
| CIAY | M | 12 | 15 | 36 | 62 | 9, 12 |
| CIEH | M | 9 | 10 | birth | 13 | 9, 0 |
| CIDJ | F | 10 | 14 | 12 | 19 | 9, 0 |
| CIAW | M | 12 | 15 | 2 | 15 | 9, 9 |
| CIAG | M | 12 | 14 | Birth | 21 | 11,10 |
| CIEB | F | 11 | N/A | 19 | 43 | 7,3 |
| CIDX | M | 10 | N/A | birth | 29 | 8,2 |
| CIEV | F | 11 | N/A | birth | 32 | 2,0 |
| CIFF | M | 10 | N/A | 1 | 13 | 4,7 |
| CIEC | M | 9 | N/A | birth | 28 | 7,2 |
| CIEU | F | 13 | N/A | 6 | 51 | 3,9 |
| CIAP | F | 14 | N/A | 16 | 42 | 9,7 |
| CIBK | M | 15 | N/A | 17 | 26 | 8,1 |
| CIBO | F | 14 | N/A | 25 | 34 | 10,4 |
| CIDQ | F | 12 | N/A | birth | 46 | 7,11 |
| CIAQ | M | 17 | N/A | 14 | 48 | 9,4 |

**Stimuli**

•A 300 ms, constant amplitude pulse train with a 25 µs pulse width was presented. Stimulation varied between experiments:
  •Ehlers et al, 2015: 100 pps
  •Experiment I: 100 pps
  •Experiment II: 100 pps, 1000 pps, 1000 pps with 100 Hz AM
•Stimuli were presented at a self-reported comfortable level.
•Stimuli were presented via a bilaterally synchronized pair of L34 Speech Processors (Cochlear Ltd).

**Figure 1: L34 Speech Processors which allow for the synchronization of timing between implants.**

**Procedure**

•Subjects' threshold, comfortable, and most comfortable levels were measured through the research processors for each stimulus separately (100 pps, 1000 pps, and 1000 pps with 100 Hz AM).
•Comfortable levels were loudness balanced between ears and for the different maps.

**Tasks:**

**Direct Pitch Comparison (DPC):**

•Subjects were asked to compare pitch of interaural electrodes for Δ0, Δ±2, and Δ±4, where Δ0 is defined as stimulation of the same numbered electrode in each ear. Negative numbers imply electrodes in the right ear were closer to the apex. For example, Δ-2 would be 12 (left)/14 (right).
•An electrode from each ear was stimulated sequentially. The subject reported whether the second sound was the "same", "higher", "much higher", "lower", or "much" lower in pitch than the first sound.
•The metric, µ, was calculated by giving the above responses values of 2, 1, 0, -1, and -2, respectively and summing together (Litovsky et al., 2012).
  •$\mu = (2)N_{much\ higher} + (1)N_{higher} + (0)N_{same} + (-1)N_{lower} + (-2)N_{much\ lower}$ , where N is the number of times a particular response was chosen.

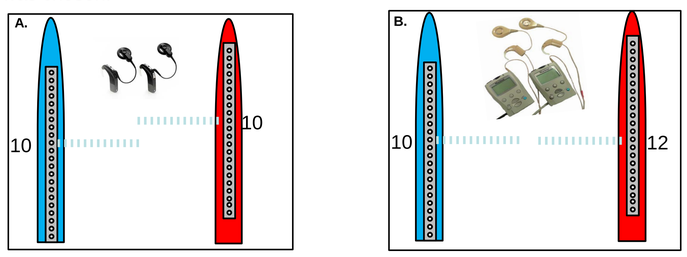


**Figure 2A: Electrode inserted at different depths between the ears, causing interaural mismatch when using clinical processors.**
**Figure 2B: Electrodes at the same insertion depth, matched by pitch when using research processors.**

**ITD Discrimination**

•ITD sensitivity was either measured on a range of interaural electrode pairs in-Experiment I or on the pitch matched electrode pair in Experiment II.
•ITD just noticeable differences (JNDs) were measured using a method of constant stimuli in a two interval, two alternative forced choice task.
•ITDs tested were ± 100, ± 200, ± 400, and ± 800 µs, although these varied for some subjects.
•Subjects were asked to report whether the sound moved to the right or to the left.

## Previous Research (Ehlers et al., 2015)

**Results: Direct Pitch Comparsion**

•The majority of subjects perceived no difference in pitch for the same numbered electrodes across the ears, which is reflected in the electrode pairs chosen for ITD testing (see Table 2).

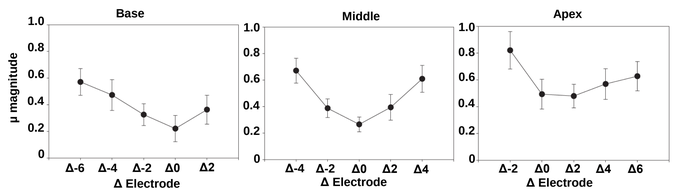


**Figure 3: Group average of the metric, µ, as a function of mismatch is shown for pairs at the base, middle and apex. A value of 0 indicates that the pitch was perceived as the same across ears. Larger values of µ imply that the pitch was perceived as increasingly different.**

| Subject | Chosen Electrode Pairs |
|---|---|
| CIAW | 14/16 |
| CIEB | 12/12 |
| CIDX | 12/12 |
| CIEV | 14/14 |
| CIFF | 14/14 |
| CIEC | 12/14 |
| CIEU | 14/14, 4/4, 12/12, 18/18 |
| CIAG | 12/10, 4/4, 12/12, 20/18 |
| CIAY | 12/12, 20/18 |
| CIDJ | 6/6, 12/12, 20/16 |
| CIAP | 4/4, 12/12, 20/16 |
| CIBK | 4/4, 12/12, 20/18 |
| CIBO | 4/4, 12/12, 20/18 |
| CIDQ | 4/4, 12/12, 20/20 |
| CIEH | 4/6, 12/14, 20/20 |
| CIAQ | 4/4, 12/13, 20/19 |

**Table 2: Chosen pitch-matched electrode pairs for each subject**

**Results: ITD Discrimination**

•The majority of subjects did not demonstrate ITD sensitivity.

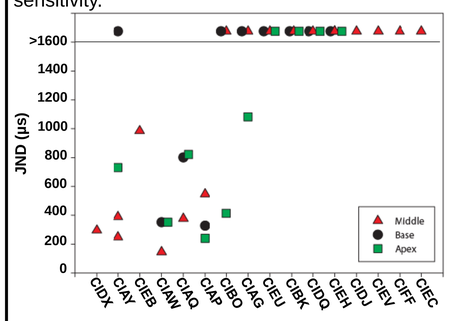


**Figure 4: Individual ITD JNDs for all subjects.**

**Results and Conclusions:**

•Only 50% of children who use cochlear implants showed sensitivity to ITDs.
•Lack of measureable ITD JNDs may be due to a persistent underlying mismatch, which was not identified via the pitch matching tasks. Alternatively, the stimuli used in this experiment are much lower in pulse rate than current clinical processing strategies. Stimuli that is more similar to their everyday listening environment may produce better ITD sensitivity.

## Experiment I: Relationship of pitch matching and ITD sensitivity

**Results:**

•For subjects that show ITD sensitivity (CIAY and CIAW), the pitch-matched pair yielded the lowest ITD JND.
•For the remaining subjects, no ITD sensitivity was found for all electrode pairs tested.

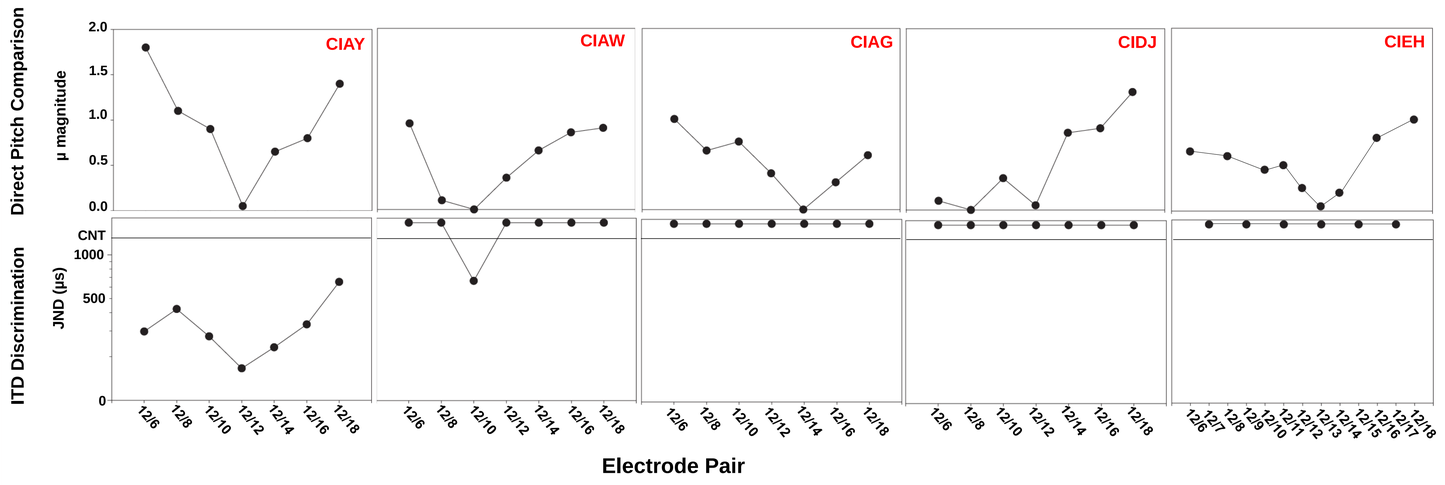


**Figure 5: Individual DPC (top panels) and ITD JND results (bottom panels)**

## Experiment II: Relationship of stimulation rate and ITD Sensitivity

**Results**

•CIAY showed sensitivity for all stimulus conditions. CIAY performed poorest on the 1000 pps unmodulated stimuli, but showed no difference between the 100 pps and the 1000 pps with 100 Hz AM stimuli.
•CIAW also showed sensitivity to the 100 pps and the 1000 pps with 100 Hz AM stimuli, but was not tested on the 1000 pps unmodulated stimuli due to time constraints.
•The remaining subjects did not show ITD sensitivity for all stimulus conditions.

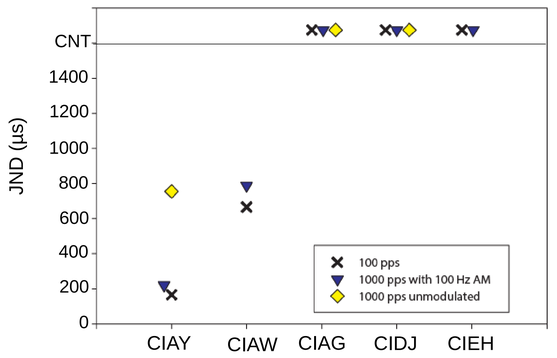


**Figure 6: Individual ITD JNDs for each stimulus condition.**

| Subject | Pitch Matched Pair | 100 pps JND | 1000 pps with 100 Hz AM JND | 1000 pps JND | ILD JND (CU) |
|---|---|---|---|---|---|
| CIAY | 12/12 | 165.83 | 212.51 | 754.52 | 1.02 |
| CIAW | 12/10 | 666.14 | 788.7 | DNT | 6.17 |
| CIAG | 12/14 | No Sensitivity | No Sensitivity | No Sensitivity | 5.75 |
| CIDJ | 12/12 | No Sensitivity | No Sensitivity | No Sensitivity | 2.1 |
| CIEH | 12/13 | No Sensitivity | No Sensitivity | DNT | 11.12 |

**Table 3: Individual ITD JNDs tested on a chosen pitch matched pair of electrodes for each stimulus condition. ILD JNDs are also shown from Ehlers et al, 2015.**

## Conclusions

•Previous research showed that 50% of subjects did not demonstrated sensitivity to ITDs even when tested at multiple places along the electrode array (Ehlers et al, 2015).
•Pitch matching appears to be an effective method for identifying an electrode pair that can yield ITD sensitivity in children who use cochlear implants.
•ITD sensitivity appears to be comparable for 100 pps and high rate amplitude modulated stimuli.
•The data suggest that factors other than anatomical mismatch and stimulus rate may be responsible for a lack of ITD sensitivity in this population. Early acoustic experience and/or binaural maturation may be required for ITD sensitivity.

## References

Ehlers, Godar, Kan, Todd, & Litovsky (2015). Sensitivity to Interaural Level Differences is More Prevalent Than Interaural Timing Differences in Children Who Use Bilateral Cochlear Implants. Presented at Association for Research in Otolaryngology. Baltimore, MD.
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## Acknowledgements

We would like to thank our listeners and Cochlear Ltd for providing the hardware and technical support. This work is supported by NIH-NIDCD (5R01DC008365, R. Litovsky) and in part by a core grant to the Waisman Center from the NICHD (P30 HD03352).