Sensitivity to binaural cues in normal hearing children and children who use cochlear implants

Erica Ehlers, Yi Zheng, Alan Kan, Shelly Godar, & Ruth Litovsky
University of Wisconsin-Madison, USA
e-mail: eehlers@wisc.edu

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Introduction

Binaural hearing provides a listener with cues that aid in sound localization, namely inter-aural time and level differences (ITDs and ILDs). In addition, ITDs in the envelopes of modulated high frequency carriers may also be exploited. Although patients with bilateral cochlear implant (BCIs) are known to have improved sound localization abilities compared to single CI users, children with BCIs still perform notably poorer than their normal hearing (NH) peers (Girco-Cabu and Litovsky, 2010).

One reason for this gap in performance is that CI speech processing algorithms discard the detailed temporal structure of the original sound, making it difficult to gain access to ITD information. A second reason is that pre-lingually deafened children also lack early access to acoustic binaural input during particularly important developmental years, therefore their auditory system may be insensitive to binaural cues.

The aim of this study was to investigate the sensitivity of children who use BCIs to ITDs and ILDs and to compare their sensitivities to NH children participating in a CI simulation.

Methods

Participants

Eight children with bilateral Cochlear Nucleus devices (Nucleus 24, Freedom, NS) participated in three experiments.

Eleven NH children (ages 8-10 yrs) participated in similar tasks while listening to CI simulations using vocoders.

Table 1: BCI Information

<table>
<thead>
<tr>
<th>BCI Subjects (n=8)</th>
<th>Sex</th>
<th>Age (yrs)</th>
<th>Early Hearing Loss (mos)</th>
<th>Age at implant (yrs, mos)</th>
<th>Bilateral Experience (yrs, mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIAY</td>
<td>M</td>
<td>9</td>
<td>110</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>CIHA</td>
<td>M</td>
<td>11</td>
<td>25</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>CIAY</td>
<td>M</td>
<td>12</td>
<td>42</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>CIHA</td>
<td>M</td>
<td>10</td>
<td>19</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>CIEU</td>
<td>F</td>
<td>11</td>
<td>19</td>
<td>43</td>
<td>7</td>
</tr>
<tr>
<td>CIEC</td>
<td>M</td>
<td>9</td>
<td>28</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>CIEU</td>
<td>F</td>
<td>13</td>
<td>19</td>
<td>31</td>
<td>3</td>
</tr>
<tr>
<td>CIHA</td>
<td>M</td>
<td>10</td>
<td>19</td>
<td>43</td>
<td>7</td>
</tr>
</tbody>
</table>

Stimuli

- 250 ms, constant amplitude, 100 pulses per sec (pps) pulse train with a 250μs pulse width was presented at a self-reported comfortable loudness level.
- Stimuli were presented via a bilaterally synchronized pair of Nucleus Implant Communicators (NICs).
- NH children listened to a Gaussian Envelope Pulse Train (4kHz center frequency, 100pps) at Efrim’s ET-5R headphones.

Procedure

- Subjects’ threshold, comfortable, and most comfortable levels were measured through the NICs.
- A pitch matched pair was positioned at pitch magnitude estimation and direct pitch comparison.
- NH subjects and subjects with BCIs both completed lateralization and discrimination tasks. Children with BCIs completed the tasks using the pitch matched pair.

Table 2: Electrode pairs tested for each subject (Left/Right)

<table>
<thead>
<tr>
<th>CIAY</th>
<th>CIHA</th>
<th>CIEU</th>
<th>CIIE</th>
<th>CIEC</th>
<th>CIEF</th>
<th>CIFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/14</td>
<td>12/14</td>
<td>12/14</td>
<td>12/14</td>
<td>12/14</td>
<td>12/14</td>
<td>12/14</td>
</tr>
</tbody>
</table>

Experiment 1: Pitch Matched Pairs

- Eight children and subjects with BCIs both completed lateralization and discrimination tasks. Children with BCIs completed the tasks using the pitch matched pair.

Experiment 2: Lateralization

- Subjects were asked to report the perceived lateral position of the stimuli by clicking a position in the red zone of Fig. 4. Testing was completed using the pitch matched pair found in Exp. 1.
- Subjects were given 20 repetitions of the following conditions for all three stimuli:
  - ITD Conditions:
    - ±0, ±50, 200, 400, 800, 1600 μs
    - ±0, ±1, 2, 5, 10, 20 current units (CU)

Experiment 3: Discrimination

- Subjects were asked to report whether the sound moved to the right or to the left.
- “An adaptive two down, one up task was used, where the last of 6 reversals were averaged to determine the subjects’ just noticeable difference (JND) for ITDs and ILDs.

- ILDs: JNDs were measurable for all children who used BCIs. NH children showed lower JNDs than the children who use BCIs.

- ITDs: JND measurement was attempted with all children who used BCIs but CIUE and CIFF were the only subjects with measurable Jnds. CIEU and CIIEF had higher JNDs than their NH peers. For both ITD and ILD cues, NH children performed similarly to adults (Kan et al., 2011).

Conclusions

- Using research procedures with pitch matched electrodes, children with BCIs show some ability to differentiate lateral positions using ILDs. In contrast, their ability to use ITDs is not well developed.
- Children with BCIs show sensitivity to ILDs on tasks of discrimination with all subjects having measurable JNDS. ITD sensitivity was measurable in only two subjects who both had early exposure to normal acoustic hearing.
- In NH children, stimuli that mimicked the processing of cochlear implants, performance was comparable to NH adults.
- This suggests that the lack of ITD sensitivity in pre-lingually deafened children who use BCIs may be due to the lack of access to fine binaural timing information that is necessary during the early years of life.

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REFERENCES


Figure 1: Diagram showing interaural mismatch. Electrode locations on uncoiled cochlea shows mismatched spectral shifts.

Figure 2: Individual pitch magnitude estimation data.

Figure 3: Percent the subject responded to interaural electrodes as “same.”

Figure 4: Graphical user interface used to capture the perceived lateral position of the stimuli.

Figure 5: Individual ILD Lateralization Data for subjects with BCIs.

Figure 6: Individual ITD Lateralization Data for subjects with BCIs.

Figure 7: Group mean ITD and ILD data for NH children.

Figure 8: ILD JNDS for NH subjects and subjects with BCIs.

Figure 9: ITD JNDS for NH subjects and subjects with BCIs.