Production of the /t/-/k/ Contrast in Children with Cochlear Implants and Children with Normal Hearing

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Background
- Cochlear Implants (CIs) are recommended by doctors for 12-month-old children who have severe sensorineural hearing loss.
- CIs are remarkable prosthetic devices, but they’re not perfect.
- Children with CIs demonstrate delays in speech development.
- CI processing spectrally degrades the speech signal.
- Spectral degradation may especially impact acquisition of speech contrasts that rely on spectral cues, such as /t/ and /k/.
- Less is known about the types of errors observed.

Participants
- n (children) = 52
- n (sessions) = 80
- Matched for age, sex, and maternal education

<table>
<thead>
<tr>
<th>Age (months)</th>
<th>CI</th>
<th>NH</th>
</tr>
</thead>
<tbody>
<tr>
<td>M : F</td>
<td>16 : 24</td>
<td>16 : 24</td>
</tr>
<tr>
<td>EVT-2 100 (15)</td>
<td>98 (19)</td>
<td>118 (11)</td>
</tr>
<tr>
<td>PPVT-4 100 (15)</td>
<td>94 (23)</td>
<td>121 (11)</td>
</tr>
<tr>
<td>GFTA-2 100 (15)</td>
<td>74 (20)</td>
<td>92 (12)</td>
</tr>
</tbody>
</table>

 Experimental Task
- Word repetition task
- 16 familiar /t/-initial tokens
- 16-18 familiar /k/-initial tokens
- Tokens balanced across front- and back-vowel contexts
- Words pre-recorded and presented over loudspeakers
- Words paired with an image presented on a computer screen
- Sessions were recorded for later transcription and analysis

Reliability
- 20% of files were used to assess reliability.
- Agreement on overall phonemic accuracy:
  - 95% / 97% for children with CI / NH
- Transcriber agreement for incorrect:
  - Manner: 97% / 100% (CI/NH)
  - Voicing: 100% / 100% (CI/NH)
  - Place: 96% / 100% (CI/NH)

Analysis
- We ran 2 mixed-effects models (one for front-vowel context and one for back-vowel context) predicting accuracy based on Group (CI or NH) and Target Consonant (/t/ or /k). & PhonemicAccuracy ~ Group * TargetC + (1 + TargetC | ID)
- We ran a Dirichlet regression using forward and backward selection. The final model predicted production category (Correct, Manner error only, Place error only, Voicing error only, and Voicing + Place error) from Group (CI or NH), Age, and their interaction. Age was also included as a predictor for the Correct category only. & Correct ~ Group * (Age + Age²)
- Error Category ~ Group * Age

Results
- Overall, children with CIs produced /t/ and /k/ less accurately than children with NH.
- Children with NH demonstrate rapid gains in accuracy between 36-46 months, then plateau.
- Children with CIs demonstrate accelerating gains in accuracy from 36-60 months.
- At 36 months, there are group differences related to the types of errors observed.
- For children with CIs, place errors persist while other types of errors decrease steadily from 36-60 months.

Transcription
1. Segment word boundaries and code response context
2. Manner transcription (stop, affricate, other)
3. Place transcription
   - [t] or [k] (correct)
   - [θ] or [ð] (substitution)
   - [θ] intermediate, closer to [t]
   - [θ] intermediate closer to [k]
   - [θ] other (e.g., labial, glottal)
4. Tag burst and voicing onsets
   - VOT > 20ms (correct)
   - VOT < 20ms (incorrect)

Future Directions
- Additional child-level predictors of overall accuracy or faster rate of growth? (e.g., age, experience, vocabulary, auditory environment and language input in the home, approach to therapy)
- Is there an effect of vowel context on the type of error produced?
- Are correct productions of /t/ and /k/ more robustly differentiated acoustically for children with NH compared to children with CIs?

Clinical Implications
- Clinicians should understand that the rate and timing of growth is different for children with CIs.
- There may be little gain in correct /t/ and /k/ productions before 48 months for children with CIs.
- Targeting differences in manner of articulation early on may be important for children with CIs.

Acknowledgments

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Learning to Talk participants and their families for making this work possible!

References:

An infant with a cochlear implant.

Research Questions
1. Do 3-5-year-old children with CIs produce /t/ and /k/ less accurately than their peers with NH?
2. Do 3-5-year-old children with CIs produce the same types of error patterns as their peers with NH?