What Can Speech Acquisition Data Tell Us About Cochlear Implant Device Limitations?

Analyzing Accuracy, Error Patterns, and Spectral Features of Children's /t/ and /k/ Productions

Allison A. Johnson[a], Benjamin Munson[b], Danielle Bentley[c], & Jan R. Edwards[a]

[a] Dept. Hearing and Speech Sciences, University of Maryland-College Park | [b] Dept. Speech-Language-Hearing Sciences, University of Minnesota-Twin Cities | [c] CI Pediatric Therapy Centers, Middleton, WI

Why are there differences in speech acquisition for children who use CIs?

Auditory Deprivation?

CIs are FDA-approved for children 12 months and older; therefore, children experience at least 1 year of life without access to sound.

Possible effects of auditory deprivation:

- Similar developmental patterns of speech sound acquisition as children with normal hearing, but on a delayed timeline (e.g., Blamey, Barry, & Jacq, 2001; Spencer & Guo, 2012)
  - /t/ acquired by age 3 in children with normal hearing (Smit et al., 1990)
  - /k/ acquired by age 4 in children with normal hearing (Smit et al., 1990)
- Similar developmental errors produced during acquisition
  - Place errors (e.g., "tup" for *cup*)
  - Voicing errors (e.g., "gup" for *cup*)

Device Limitations?

CIs do not precisely mimic the processing done by a healthy cochlea. Sounds like /t/ and /k/ could be particularly affected because they have short duration, transient perceptual cues, low intensity, high-frequency components, allophonic variations, and are differentiated by spectral cues.

Possible effects of device limitations:

- Different patterns of speech acquisition
  - /k/ acquired before (or at the same time) as /t/
  - Different acoustic characteristics of productions
- Different types of errors produced/persist during acquisition
  - Place errors persist for spectral contrasts
  - Manner errors (e.g., "chup" for *cup*)

Methods

- 2 Groups matched for age, sex, and maternal education
- Picture-prompted, word repetition task
- 16 familiar /t/-initial words
- 16 familiar /k/-initial words
- Tokens balanced across front and back vowel contexts
- Initial sounds transcribed as:
  - Stop
  - Affricate
  - Other
- Stops transcribed as:
  - [t] or [k] (correct)
  - [$t] or [$k] (substitution)
  - [t:k] (intermediate, closer to [t])
  - [k:t] (intermediate, closer to [k])
  - [$other] (e.g., bilabial or glottal substitution)
- Stops with correct place of articulation and VOT > 20ms scored as "accurate"
- 95% / 97% inter-transcriber agreement on phonemic accuracy (for children with CIs / NH)
- Spectral analyses of stop bursts only for accurate productions

	CI n = 40	NH n = 40
Age in months	50.4 (9.8) 31 – 66	50.4 (9.5) 32 – 66
M : F	16 : 24	16 : 24
EVT-2 100 (15)	98 (19) 46 - 131 n = 39	118 (11) 88 - 134 n = 40
PPVT-4 100 (15)	94 (21) 40 - 139 n = 39	121 (11) 94 - 140 n = 22
GFTA-2 100 (15)	74 (20) 39 - 107 n = 36	92 (12) 67 - 113 n = 26

Research Question #1:

Do 3-5-year-old children with CIs produce /t/ and /k/ less accurately than peers with NH?

Mixed effects regression models predicted Accuracy based on Group (CI or NH), Target (/t/ or /k/), Vowel Context (Front or Back) and all interactions:

Accuracy ~ Group * Target * Vowel Context + (1 + Target | ID)

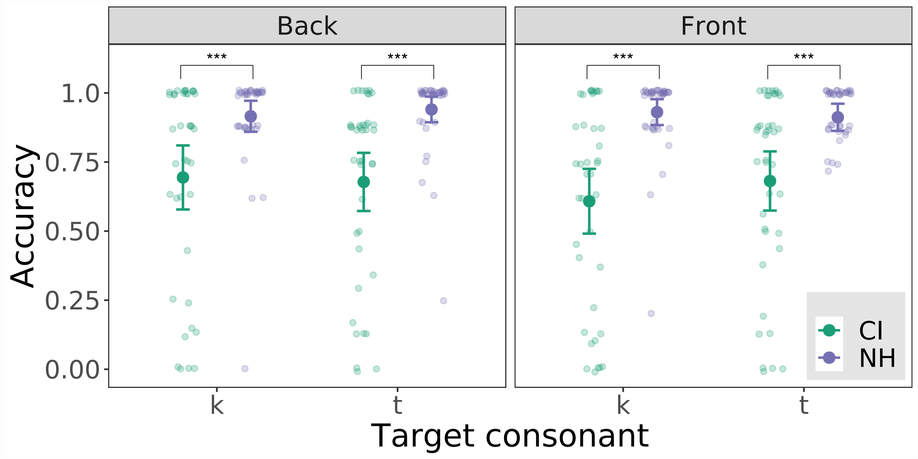

Figure 1. Results of overall accuracy analysis: Children with CIs produced both /t/ and /k/ less accurately than their peers with normal hearing in both front and back vowel contexts.

Research Question #2:

Do 3-5-year-old children with CIs produce the same types of errors as peers with NH?

Dirichlet regression models predicted production categories (Correct, Manner error, Place error, Voicing error, Place + Voicing errors) based on Group (CI or NH), Age, and the interaction; Age^2 was also included for the Correct category:

Correct ~ Group * (Age + Age^2)
Error Category ~ Group * Age

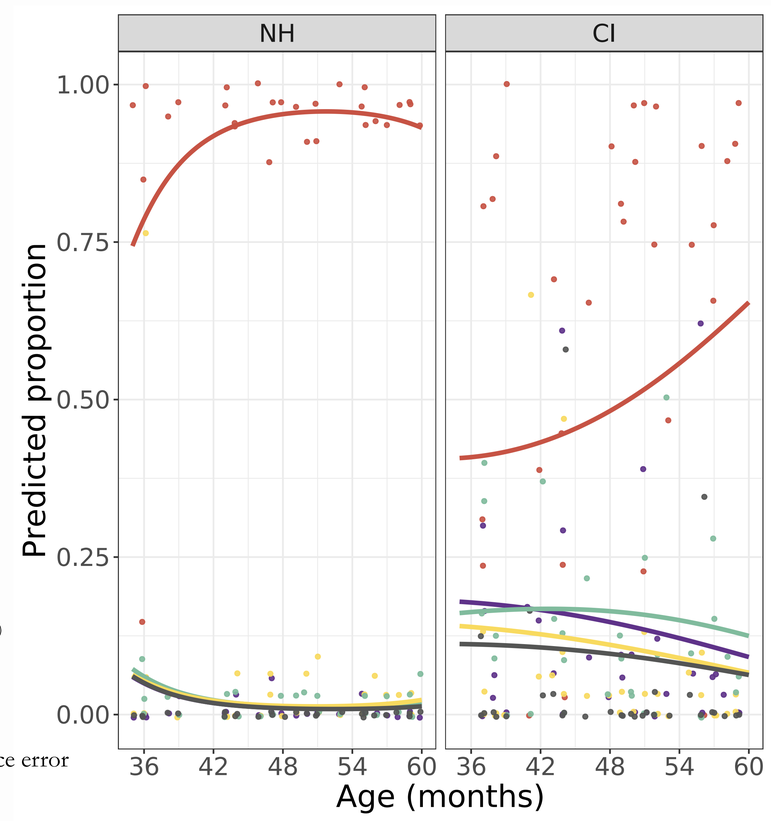

Figure 2. Results of error pattern analysis: Children with NH demonstrate rapid growth in correct productions and plateau between 36 - 48 months, while children with CIs demonstrate accelerating gains from 36 - 60 months.

There are group differences in the types of errors produced at 36 months: Children with CIs produce mostly manner and place errors, while children with NH produce mostly place and voicing errors. Place errors persist for children with CIs while other types of errors steadily decrease.

Research Question #3:

Do 3-5-year-old children with CIs produce /t/ and /k/ with similar spectral features as peers with NH?

Mixed effects regression models predicted Centroid Frequency based on Group (CI or NH), Target (/t/ or /k/) and their interaction:

Centroid ~ Group * Target * Vowel Context + (1 + Target | ID)

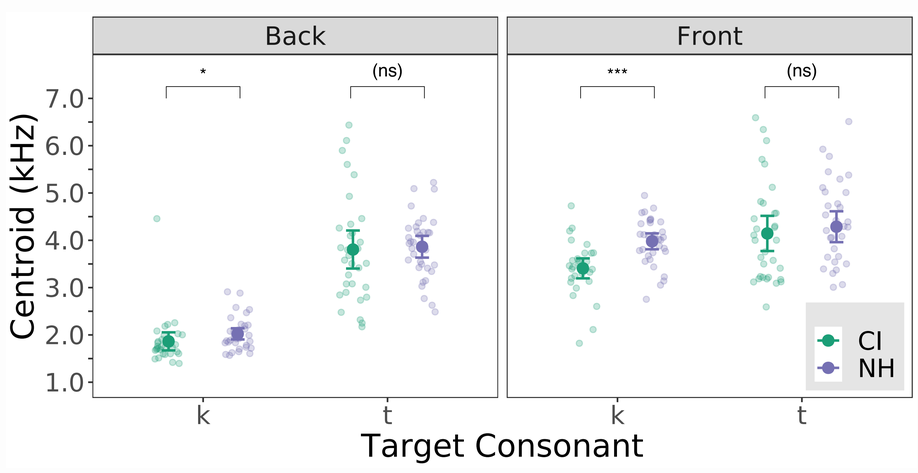

Figure 3. Results of spectral analysis: Children with CIs produce /k/ with lower Centroid frequency than children with NH, especially in front vowel contexts.

Conclusions

- Early research found that children with CIs show similar patterns of speech sound acquisition on a delayed timeline relative to children with NH, suggesting that early auditory deprivation is the primary cause for differences in speech acquisition.
- The current study analyzed /t/ and /k/ productions in depth to investigate the role of device limitations on speech acquisition:
- Children with CIs produced /t/ and /k/ less accurately than peers with NH, and they were more affected by vowel context.
- Children with CIs produced manner, place, and voicing errors, and place errors in particular persisted past age 5.
- Children with NH produced place and voicing errors at age 3, but quickly resolved most errors by age 4.
- Children with CIs produced /k/ with lower spectral energy compared to children with NH, especially in front vowel contexts. This may be due to better perception of lower frequencies, but difficulty perceiving allophones or coarticulation.

Clinical Implications

- Understand that the rate, timing, and patterns of growth are different for children with CIs
  - Target manner of articulation earlier to increase intelligibility
  - Target /k/ in back vowel contexts to facilitate learning of /k/
  - Use visual, tactile, and proprioceptive cues to support learning of different places of articulation

Future Directions

- Investigate additional child-level predictors related to higher accuracy or faster rate of growth (e.g., device experience, residual or early acoustic hearing, bimodal listening, language skills, rehabilitation approach)
- Investigate the effect of vowel context on error patterns
- Investigate the effects of spectral differences in production on perception and intelligibility
- Determine the impact of device limitations by studying other sounds vulnerable to signal degradation (e.g., /s/,/ ʃ/, /w/,/j/, /ɹ/, clusters)

Acknowledgments

Special Thanks:
Learning to Talk participants, their families, and the lab members who made this work possible.

Supported by:
NIDCD Grant R01 02932
T32 Grant DC05359-10
NSF Grant 1449815
NICHD Grant P30HD03352