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Factors contributing to speech perception scores in long-term pediatric CI users

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Speech perception measures represent major outcome variables documenting the benefits afforded by sensory devices for children with profound sensorineural hearing losses (SNHL). Children with profound SNHL using traditional hearing aids (HA) demonstrate modest closed-set word recognition consisting of accurate identification of suprasegmental characteristics and vowels (Geers & Moog, 1989). Cochlear implants (CI) provide significantly greater assistance for speech perception abilities in children with profound SNHL. Speech perception performance improves with longer CI experience for closed-set and open-set word and sentence skills in some children using CIs (Staller, Beiter, Brimacombe, Mecklenburg, & Arndt, 1991). Children with CIs outperform children with HAs with unaided thresholds in the profound (≥ 100 dB HL) SNHL range and often perform similarly to children with HAs whose thresholds fall in the severe range (i.e. 78–88 dB HL; Boothroyd, Geers, & Moog, 1991; Osberger et al., 1991; Boothroyd & Eran, 1994; Blamey, Sarrant et al, 2001). However, perceiving speech in demanding listening environments associated with soft levels of speech presentations or speech in noise remains a challenge for both adults and children using CIs (Dawson, Decker, & Psarros, 2004; Kong, Stickney, & Zeng, 2005; Skinner et al., 1994). Listening in noise presents the greatest challenge for adult CI recipients followed by listening at soft input levels (Firszt et al., 2004). Open-set word recognition scores decrease from approximately 42% to 20% in children using CIs when stimuli is presented at 70 and 50 dB SPL, respectively (Davidson, 2006). The adverse effect of demanding listening conditions is reduced with technological advances to CI systems. For example, front-end processing strategies, microphone and processor technology, and assistive technology (e.g. frequency modulated (FM) systems) are designed to aid listening to low level speech inputs and listening to speech in noise. Current speech processors provide greater input dynamic ranges (IDR), the range of acoustic signals mapped onto the CI user's electrical dynamic range, than previously reported. A major consequence of the greater IDR is an improvement in aided sound field thresholds, consonant, vowel, word and sentence recognition for signals presented at soft levels (Cosendai & Pelizzone, 2001; Davidson et al., 2009; Dawson, Vandali, Knight, & Heasman, 2007; Donaldson & Allen, 2003; Holden, Skinner, Fourakis, & Holden, 2007; Santarelli et al., 2009; Zeng et al., 2002). Children using the Nucleus 22 cochlear implant system (Cochlear Americas Corp, 13059 E. Peakview, Centennial, CO 80111) with processors employing more recent front end processing technology and wider IDRs (e.g. Freedom and the ESPrit 3G)

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demonstrate significantly higher speech perception scores at soft levels (50 dB SPL) and lower (better) aided thresholds than children using older generation Nucleus processors (e.g. ESPrit22 or Spectra; Davidson, Geers, & Brenner, 2010).

Speech perception performance also is positively influenced by increased experience listening with CIs. After a number of years, many children using CIs demonstrate open-set scores similar to scores obtained in post-lingually deafened adult CI recipients after six months of CI use. Children using CIs for an average of 4 years demonstrated open-set speech perception performance of 79%, 53% and 68% for phonemes, words and sentences, respectively (Dowell, Dettman, Blamey, Barker, & Clark, 2002). Eight and nine year old CI users with 4 to 6 years experience listening with their devices demonstrated average open-set word and sentence recognition scores of 48% and 57%, respectively (Geers, Davidson & Brenner, 2003). Post-lingually deafened adult CI users demonstrate the most substantial improvements in speech perception performance within the first year of receiving the CI (Helms et al., 1997); (Ruffin et al., 2007; Tyler, Parkinson, Woodworth, Lowder, & Gantz, 1997) while pediatric CI users continue to demonstrate gains in speech perception scores well beyond this time period. Waltzman et al (2002) reported that most children lack the linguistic competence required to complete open-set word or sentence recognition at the pre-operative and one-year post CI test interval and, consequently, were assigned a score of 0%. Mean open set word recognition scores were 9% at one year, 31% at three years and 65% after five or more years of CI use. Open-set sentence recognition scores were 18 % at one year, 51 % at three years and 81% at the final test interval. Beadle et al (2005) observed that one half to one third of children using CIs were rated significantly higher on measures of auditory performance as their CI experience increased from 5 to 10 years. Uziel et al (2010) reported that open-set word recognition scores increased significantly (~7%) in the time period between 5 to 10 years of CI use. These speech perception performance changes in children using CIs are accompanied by maturational and intervention factors, thus it is difficult to determine the unique contribution of hearing abilities alone to the changes observed in speech perception scores over time.

Maturational changes in typical hearing children are evident in several domains including anatomical, physiological, cognitive, linguistic, and speech production aspects. Thus, it is no surprise that changes in these domains also are evident in related communication measures administered to young children using CIs. Open-set word and sentence recognition tasks for children are designed to use age-appropriate vocabulary reflecting a child's lexical and speech production capabilities. As Paatsch et al (2004) point out, vocabulary probably plays less of role in the construction of open-set word and sentence recognition measures for adult listeners whose word and grammar knowledge is mature and who also may communicate with other individuals by writing messages, even if their speech is unintelligible. But the situation is more complex for the open-set testing of young children whose language and speech skills may be typical, delayed or disordered. Vocabulary for open-set test items must be carefully chosen to fall within the vocabulary of typical young children and theoretically motivated to provide informative analyses regarding performance both at a single point in time or across multiple test sessions spread out in time (Kirk, Pisoni, & Osberger, 1995.) Assessment of open-set speech recognition abilities in children using CIs across multiple time periods requires vocabulary items within their lexical and speech production developmental repertoires. Blamey and colleagues probed the independent contributions of speech production and language ability to open-set speech perception scores in children using either HAs or CIs (Blamey & Sarant, 2002; Blamey et al., 2001). Multiple linear regressions of a number of variables collected longitudinally evaluating speech perception, speech production and language skills revealed accuracy of open-set speech perception scores for monosyllabic words and sentences asymptotes at an equivalent language age of seven years. Moreover, the improvement in open-set speech recognition scores over time was primarily accounted for by improvements in speech production and language.

Multiple studies within the United States and other countries recognize the importance of documenting open-set speech recognition, language and speech production performance of children using CIs. Studies contained in this monograph detail the communication outcomes in a large group of children using CIs; first when the children are in elementary school (8 to 9 years of age) and second, when they are in high school (15 to 18 years of age). These studies elaborate on factors influencing speech production, language, literacy, and psychosocial measures in the same population over the same two test sessions.

The purpose of this article is to describe speech perception performance in one of the first large groups of children receiving CIs in North America. We describe two broad sets of analyses. In the first set of analyses, we examine performance between elementary (CI-E) and high school (CI-HS) ages. We investigate open-set speech perception abilities of pediatric CI recipients to document: a) changes in perception of words and sentences between CI-E and CI-HS test sessions, b) effects of lexical difficulty on word perception scores using word lists differing in the frequency of occurrence of words in the language and density of words within the lexical neighborhoods, as measured by one-phoneme substitutions, c) effects of demanding listening conditions (i.e., speech in noise and low input levels) on open-set speech recognition at the CI-HS test session, and d) differences in visual-only (V) and auditory-visual (AV) performance at the two test sessions. In the second set of analyses, we examine open-set word and sentence recognition at CI-E and CI-HS in relation to speech production and language measures obtained at these two test intervals. These analyses examined speech production measures (consonants correct), language measures (equivalent language ages) and open-set word and sentence performance (percent correct) using an approach similar to that used by Blamey and colleagues (2001). Although this model cannot be applied directly to the current data set, the analyses presented in subsequent sections suggest prospective consideration of this approach in the assessment of open-set word and sentence recognition tasks.

METHODS AND MATERIALS

Participants

This study involved a North American sample of 112 teenagers (CI-HS) who received a CI between 1990 and 1996 when they were between 1.8 and 5.4 years of age. The participants were drawn from a larger sample of 181 children who participated in a previous research study between 1996 and 2000 when they were between 8.0 and 9.11 years of age (Geers, Brenner, & Davidson, 2003). Data collection for the CI-HS project occurred between 2004 and 2008 when the students ranged in age from 15.0 to 18.5 years and their average duration of CI use was 13 years 3 months. Geers et al (2010) describe this population in depth, comparing the characteristics of the 112 children returning to participate and those 72 children who did not participate in the follow-up. Fifty-four children were in simultaneous communication programs during preschool and early elementary grades while 58 children were primarily enrolled in oral communication programs (Geers, Brenner, & Tobey, 2010).

Table 1 summarizes the speech processor systems used at the CI-HS Session. Over half of the CI-HS students upgraded to more recent Nucleus processors from Cochlear Americas Corporation (Cochlear Americas, 13059 E. Peakview, Centennial, CO 80111) (i.e. Freedom and ESPrit 3G) while many CI-HS participants continued to use older generation processors (i.e. ESPrit 22, SPRint and Spectra). Speech processor technology was rank ordered from 1 to 4 with one representing the oldest technologies (e.g., Spectra) and four representing the most recent technologies (e.g., Freedom). Two CI-HS teenagers were implanted with Advanced Bionics Corporation technology (Advanced Bionics Corporation, 25129 Rye Canyon Loop, Valencia, CA 91354) one student used the Advanced Bionics Platinum Speech body processor (PSP) while the other teenager used a Platinum behind-the-ear (BTE) processor. The majority of the teenagers (n=90) used the Nucleus 22 internal CI system, 20 teens used the Nucleus 24, one adolescent used the Advanced Bionics C1.0 system and one participant used the C1.2 system. Fourteen CI-HS participants experienced a CI failure followed by explantation and reimplantation with a new internal device. Eight used bilateral cochlear implants. None of the teenagers used a hearing aid in the opposite ear and 73% reported that they did not use an FM system in their educational environment.

Aided sound-field detection thresholds were obtained at the CI-HS evaluation using frequency modulated (FM) tones at octave frequencies from 250–4000 Hz. The CI-HS participants were seated approximately 1 to 1.5 m from the loudspeaker at 0° azimuth using their CI as typically worn. A standard Hughson-Westlake procedure was used to obtain thresholds in 5 dB increments (Carhart & Jerger, 1959). The group average aided thresholds in dB HL at 250–4000 Hz were as follows: 250 Hz: 32 (SD 12); 500 Hz: 30 (SD 11); 1000 Hz: 29 (SD 10); 2000 Hz: 29, (SD 9); and 4000 Hz: 33 (SD 9).

The CI-HS teenagers reported high satisfaction with their CI: eighty percent of the teenagers reported wearing their CI all of the time and 20% of the teenagers reported wearing it some of the time. No one reported being a non-user of the device. Ninety-one percent of the CI-HS teenagers reported difficulty understanding the speech of others when not wearing their implant and 96% of the sample relied heavily on their CI and stated they would replace it if broken.

Speech Perception Measures

Speech perception tests were administered during the CI-E and the CI-HS test sessions using a digitized presentation of recorded stimuli via a laptop computer connected to an Anchor, Model AN-100 loud speaker positioned at 0 degrees azimuth, approximately 3 feet away. All test stimuli were calibrated using a type 2 sound level meter placed at the level of the child's implant microphone. Speech perception tests were administered in quiet at a level of 70 dB SPL at both the CI-E and the CI-HS sessions. In addition, the LNT was administered at a soft level of 50 dB SPL and the BKB sentences were administered at 10 dB signal to noise ratio (BKB sentences at 60 dB SPL and multi-talker babble noise at 50 dB SPL) at the CI-HS session.

Lexical Neighborhood Test (LNT; Kirk, Pisoni, & Osberger, 1995)—Open set word recognition was tested using two equivalent, monosyllabic, 50-word lists from the LNT. List difficulty was based on the frequency of occurrence of words in the language and density of words within the lexical neighborhoods, as measured by one phoneme substitution. Each 50-word list was composed of 25 "easy" words (high frequency with few lexical neighbors) and 25 "hard" words (low frequency with many lexical neighbors) whose order was randomized across the list. Items were presented in quiet at a loud conversational level (70 dB SPL) at both the CI-E and CI-HS test sessions. In addition, an alternate list was presented at a soft level (50 dB SPL) at the CI-HS test session. The student was instructed to repeat what he/she heard. Responses were scored as correct if the response was recognizable as the target word. Dependent variables were percent correct for hard word lists (LNT-H) and for easy word lists (LNT-E)

Bamford Kowal Bench Sentences (BKB) (Bamford & Wilson, 1979)—Open set sentence recognition at both test sessions was assessed with BKB sentences. These sentences were devised to include vocabulary, grammar and sentence length appropriate to the linguistic abilities of most hearing impaired children 8 years of age and older. The test consists of 16 simple sentences that the student repeats word-for-word. Only 50 key words are scored for accuracy. The test was administered in quiet at 70 dB SPL at both the CI-E and CI-HS test sessions. BKB sentences were administered at 60 dB SPL with multi-talker babble noise at 50 dB SPL (10 dB SNR) at the CI-HS session. The dependent variable was percent of keywords correctly repeated.

Children's Audio-Visual Enhancement Test (CAVET; Tye-Murray & Geers, 2001)—Two equivalent CAVET word lists were administered at both CI-E and CI-HS test sessions: one list assessed visual speech perception through lipreading only (V) and the other list assessed audio-visual speech perception through lipreading and listening combined (AV). The lists were designed to estimate gains in speech perception when auditory information was added to lipreading in face-to-face interactions. Each list consists of 20 words within the vocabulary of a first grade child. Half of each list consisted of low-visibility words to reduce ceiling effects. The remaining 10 items in each list were easy to lipread to reduce floor effects. Floor and ceiling effects were thus avoided in the V condition so that improvement may be measured in the AV condition. The word lists were recorded and administered through a VCR with a 12" monitor placed 3 feet from the subject with sound calibrated at 70dB SPL. V stimuli were presented with sound turned off. The dependent variable was the percentage of items correctly repeated.

Speech Production Measure

Consonant Production using McGarr Sentences (McGarr, 1983)—Thirty-six sentences varying between three, five and seven syllables were presented for imitation at the CI-E and CI-HS sessions. Children were prompted to say the sentences with a verbal or sign elicitation and a written version. Responses were recorded on a DAT recorder. Speech-language pathologists transcribed the sentence productions using transcription techniques used by Shriberg and colleagues (1991) which were subsequently analyzed using a computer software package, CASALA (Computer Aided Speech and Language Analysis; Serry, Blamey, & Grogan, 1997). The dependent variable was the percentage of consonants correctly imitated (Tobey, Geers, Sundarrajan, & Lane, 2010).

Language Measures

Test for Auditory Comprehension of Language (TACL; Carrow, 1985)—The TACL was used to estimate language age at the CI-E session. Stimulus items were administered using simultaneous speech and sign/finger spelling. Prior to all testing, focus groups determined agreed upon signs and sign/finger spelling to insure similar elicitation across items. Children responded by selecting one of three pictures that best depicted the stimulus items in each of three subscales: Word Classes, Elaborated Sentences and Bound Morphemes. The dependent variable was equivalent language age based on a normative sample of typically-developing children (NS-TD).

Peabody Picture Vocabulary Test-III (PPVT; Dunn & Markwardt, 1989)—The PPVT was used to estimate language age at the CI-HS session. This is a test of one-word receptive vocabulary in which the examiner provides a label and the student selects one of four pictures that best represents the label. Form IIIA was administered using standard administration of spoken stimulus words (OC administration). Form IIIB was administered using sign or finger spelling to accompany the spoken word (SC administration; See Geers & Sedey, 2010 for a detailed presentation of administration procedures). The dependent variables were equivalent language age based on a normative sample of typically-developing children (NS-TD). The higher score (whether OC or SC administration) was used to represent language age for each student.

RESULTS

Average scores on the speech perception, speech production and language tests are summarized in Table 2 for each test session. The following questions were addressed using data from this battery of measures.

How Does Open-Set Speech Recognition For Words and Sentences Change Between Elementary and High School Ages?

Open-set recognition scores for words and sentences increased significantly as a function of increased age and listening experience. Figure 1 shows the individual and group mean scores on the LNT in quiet at 70 dB SPL with rank ordered data points depicting scores for 109 of the 112 participants at the CI-E test session and columns representing scores of all 112 participants at the CI-HS test session. LNT scores at the CI-E test session were not available for three CI-HS adolescents (their CI-HS scores are represented by columns at the far right of graph). The scores for both test sessions show considerable variability, ranging from 0% to over 90% correct. The mean group scores at CI-E and CI-HS were 50.6% vs.60% respectively, reflecting a significant improvement in scores obtained across the two test sessions (paired t (108) = 5.73, p < .0001). Two CI-HS participants demonstrated substantially reduced LNT scores at the CI-HS test session. Both CI-HS participants experienced internal device failures requiring explantation and reimplantation with a new internal device, and had used this device for a minimum of 3 years. Figure 2 shows the individual and group mean scores for the BKB sentences at 70 dB SPL in quiet with rank ordered data points representing the CI-E test session and columns representing the CI-HS test session. Individual scores at both test sessions ranged from 0–100%. The mean group scores improved significantly from the CI-E to the CI-HS test sessions (63.2% and 80.3% respectively; paired t(111) = 7.68, p < .0001). The same two CI-HS participants demonstrated substantially lower scores at CI-HS as was shown for the LNT in Figure 1.

How does LNT Performance on Hard vs. Easy Lists Compare at Elementary and High School Ages?

Mean scores on Easy and Hard LNT word lists are presented in Table 2 for the CI-E and CI-HS test sessions. Scores were significantly higher for easy word lists than for hard lists at both CI-E (paired t(108) = 4.18, p < .0001) and CI-HS (paired t(111) = 6.39, p < .0001). The mean difference in easy vs. hard lists at CI-E was ~ 4% and increased to ~7% at CI-HS.

How is Open-Set Recognition Influenced by Optimal and Degraded Listening Conditions?

The CI-HS group mean LNT word recognition score of 60% (SD=23%) at 70 dB SPL decreased significantly to 47% (SD=24%) when presentation level was reduced to 50 dB SPL (paired t (111) = 7.89, p < .0001) Fifty percent of the CI-HS group demonstrated a greater than 10% decrease in LNT scores in the soft relative to the loud conversational speech conditions. Mean scores for Easy and Hard LNT word lists are compared in Table 2, and show that scores for the easy word list are 4 % higher than scores for the hard word list at 50 dB SPL (paired t(111) = 3.52, p< .001) and 8% higher at 70 dB SPL (paired t(111) = 6.39, p< .0001).

BKB sentence scores presented in quiet at 70 dB SPL to CI-HS students resulted in a mean accuracy level of 80% (SD=27%). Significant decreases in performance were observed when an equivalent list of sentences was presented at 60 dB SPL with 10 dB SNR of multi-talker babble. The scores decreased to 52% (SD=26%; paired t(111) = 16.59, p< .0001). Eighty five percent of the CI-HS students demonstrated more than a 10% decrease in the noise condition.

How does Performance Change Between Elementary and High School Ages as a Function of Visual-Only or Auditory-Visual Conditions?

The performance differences associated with V and AV performance on the CAVET at the CI-E and CI-HS test sessions are shown in Table 2. Significant increases were observed between V and AV conditions. AV performance was 43% higher than V performance during the elementary school session and 45% higher during the high school test session. An average increase of 6.5% (paired t(111) = 4.20, p<.0001) in V-only performance and 8.5% (paired t

(111)=5.77, p< .0001) in AV performance was observed between elementary and high school years.

What is the Relation of Open-Set Speech Recognition Scores to Speech and Language levels?

Average speech production and language scores, which are summarized in Table 2, also improved significantly across the two test sessions. Language age scores increased from 7 to 14 years (paired t(108) = 48.36, p<.0001) and percent of consonants correctly produced increased from 68% to 96% (paired t(105) = 19.72, p< .0001). Increases in speech perception scores between elementary and high school test sessions were examined in relation to speech and language changes occurring simultaneously.

Rather than using conventional linear regression models, we compared our results to a model proposed by Blamey and colleagues (2001). This non-linear model takes into account the expected effects of change in speech production and language scores over time and predicts that speech perception scores for each child will increase steeply as their speech perception, speech production and language skills improve until the child reaches an equivalent language age of about 7 years (Blamey et al., 2001; Blamey & Sarant, 2002; Paatsch et al., 2004).

In order to examine the possible application of this model to our data we selected age-equivalent scores based on normative tables from the TACL administered at CI-E and the PPVT administered at the CI-HS test session; a measure of speech production (percentage of consonants correctly produced on McGarr Sentences at the two sessions); and open-set speech recognition for LNT words and BKB sentences at the two test sessions. Figure 3 shows the relationships between the open-set word recognition (LNT scores) presented at 70 dB SPL relative to equivalent language age scores obtained at the CI-E and CI-HS test sessions. Figure 4 illustrates a similar relationship between language age scores and percent correct on the open-set sentences (BKB scores), achieved in quiet at the CI-E and CI-HS test sessions. Both quantitative and qualitative similarities are evident in the two figures relative to data analyzed in previous studies by Blamey and colleagues (2001a;Blamey et al, 2002). The calculated curves of the data sets for LNT and BKB performance relative to the age-equivalent language scores asymptote at similar equivalent language ages, around 10 to 11 years. Figure 5 depicts the relation between language age scores and McGarr sentences, consonants correct scores, which also asymptotes at a language age of about 10 to 11 years. Taken overall, the similarities in performance across measures of open-set speech recognition (LNT and BKB) and production (percent correct McGarr consonants) relative to equivalent language ages from the TACL and PPVT suggest the changes observed in overall speech perception scores between CI-E and CI-HS test sessions are closely associated with concomitant changes in speech production and language. This relation is linear only up to an age-equivalent language score of about 10 years and a consonants correct score of about 90%. Increases in speech perception scores above this level of language and speech production ability may be viewed as exclusively perceptual changes.

How Does Speech Perception Performance at Elementary Age for Children Returning at High School Compare to those that Did Not Return?

Table 3 shows average speech perception scores at the CI-E test session of the 112 children returning for follow-up testing compared with the 72 students who did not return. While the groups were similar in the duration of deafness prior to receiving a CI and in lipreading-only speech perception, CI-HS participants exhibited significantly higher auditory speech perception skills at CI-E than non-participants.

DISCUSSION

The data in this study suggest that increases in speech perception over time are highly associated with concomitant changes in speech production and language, which also improved significantly over time. First, we noted that perception of words in a vision only (lipreading) and an auditory-visual condition improved significantly over time. This result suggests that speech perception improvement was affected by linguistic as well as auditory experience. Next we noted that the effect of lexical difficulty on LNT scores increased with age as evidenced by the greater difference between easy vs. hard lists at CI-E (4%) than at CI-HS (7%). The children's increased language knowledge as they got older may have influenced the difficulty of the "hard" word list due to an increase in the number of lexical neighbors available to them when formulating a response. This difference was reduced substantially when the word lists were presented in a more challenging listening condition (i.e., at 50 dB, SPL), which increased the importance of sensory perception relative to linguistic knowledge. Finally, the similarities across measures of open-set speech recognition (LNT and BKB) and production (percent correct McGarr consonants) plotted against equivalent language ages from the TACL and PPVT suggest the changes observed in overall speech perception scores between CI-E and CI-HS test sessions are reflective of speech and language changes over that time period. The relationships between perception scores, production scores, and age are curvilinear, rather than linear, and are similar to relations among these variables observed independently by Blamey and colleagues (2001) in another large longitudinal study. Taken together, these results suggest that more than just auditory experience contributes to change over time in speech perception. This is not surprising, since responding correctly in a speech perception test requires not only auditory perception but also lexical knowledge of the stimulus items and articulation of the spoken response.

We were unable to separately estimate the individual contributions of audition, language and speech production to speech perception scores with our current data set. Unlike the studies initiated by Blamey and colleagues (Blamey, et al., 2001; Paatsch, Blamey, Sarant, Martin, & Bow, 2004) speech production measures used in this study (consonants correct, McGarr sentences) did not use the same stimulus items as the perception measures (LNT and BKB), thus providing only indirect estimates of production error in the perceptual tasks. However, the application of this model to examining change in speech perception scores over time provides useful information. Such a model permits charting the progress of perception, production and language gains over time for individual children and potentially could be used to indicate where assistance is required.

It is likely that the current CI-HS sample does not represent the entire population of teenagers receiving CIs in early childhood and may overestimate speech perception skills in a more representative group of CI users. These participants outperformed the 72 students who did not return for follow-up on speech perception measures at CI-E. Families who felt their children were benefitting from a CI would be more likely to return for follow-up testing. Some of the families who declined to participate may have done so because their child was either no longer using the CI or they did not achieve the level of outcomes with the device that the family had hoped. These sample selection factors may have resulted in our overestimating speech perception levels to be expected for adolescents with long-term use of CIs. On the other hand, the CI-HS students who participated in this study do not have some of the advantages available to more recently implanted children. Advances in implant technology along with revised candidate selection guidelines that include children under 2 years of age and those with significant amounts of pre-implant residual hearing may result in even better speech perception levels. As the current population of CI children with these advantages reaches adolescence, speech perception scores, especially in degraded listening situations, may be substantially higher.

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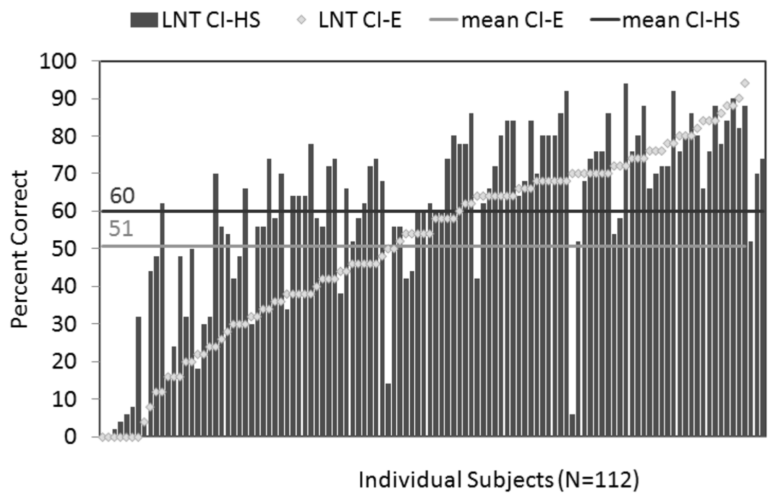

Figure 1.

Individual rank ordered percentage correct scores for LNT words at 70 dB SPL in quiet for sessions CI-E (diamonds) and CI-HS (bars). Mean group scores are shown for sessions CI-E (grey line) and CI-HS (bold line).

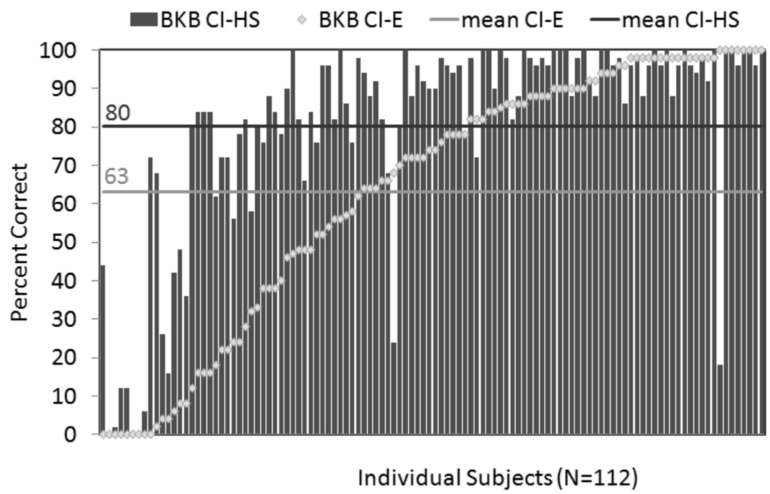

Figure 2.
Individual rank ordered percentage correct scores for BKB sentences scores at 70 dB SPL in quiet for sessions CI-E (diamonds) and CI-HS (bars). Mean group scores are shown for sessions CI-E (grey line) and CI-HS (bold line).

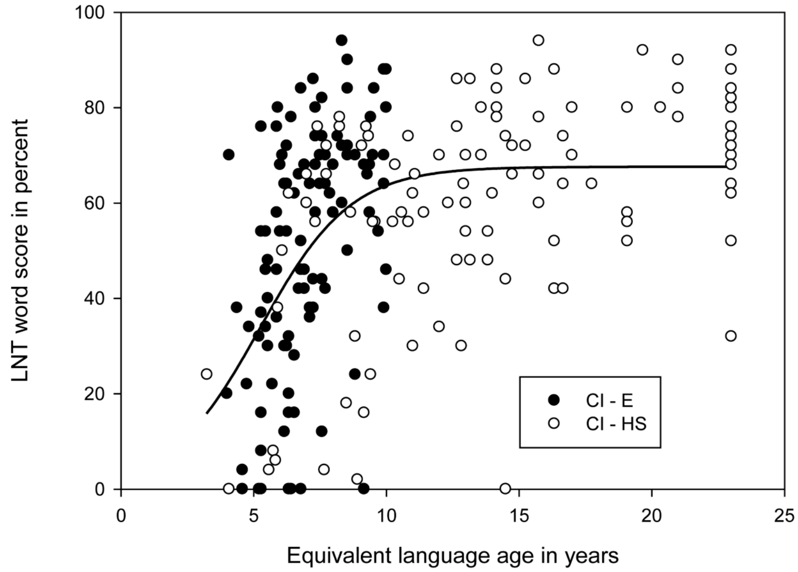

Figure 3.
Percentage correct LNT words at 70 dB SPL in quiet plotted against equivalent language age from the TACL (CI-E) and PPVT (CI-HS). Filled circles repesent CI-E scores and open circles are CI-HS scores.

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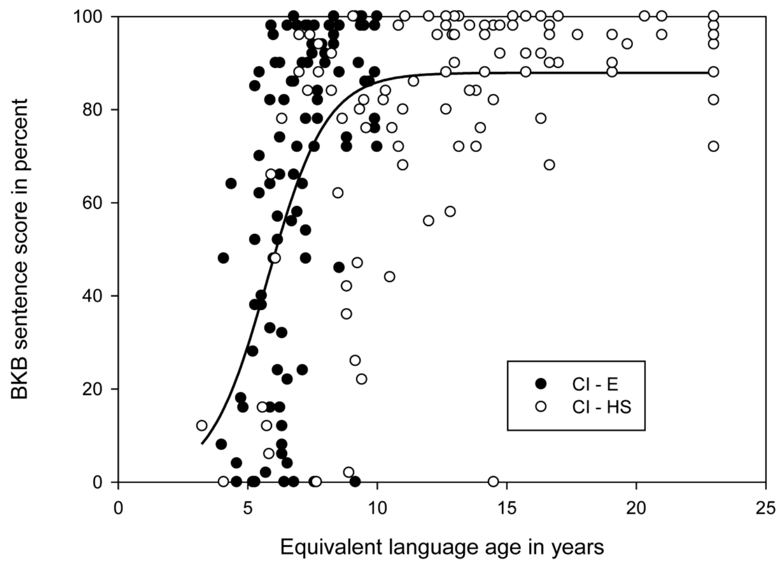

Figure 4.
Percentage correct words in BKB sentences at 70 dB SPL in quiet plotted against equivalent language age from the TACL (CI-E) and PPVT (CI-HS). Filled circles repesent CI-E scores and open circles are CI-HS scores.

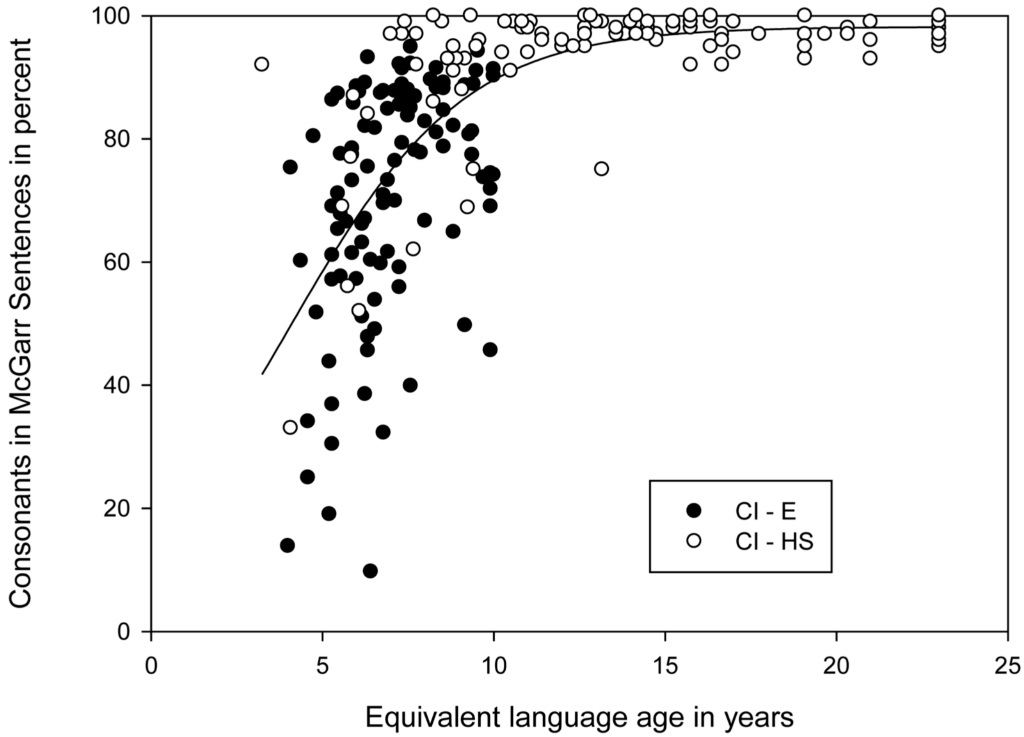

Figure 5.

Percentage correct consonants from the MCGarr Sentences plotted against equivalent language age from the TACL (CI-E) and PPVT (CI-HS). Filled circles repesent CI-E scores and open circles are CI-HS scores.

Table 1

Number of adolescents at CI-HS using each speech processor (ranked by generation of technology)

Ranking	Processor	Number of Students
1	Spectra[1]	12
2	ESPrit 22[1]	23
3	Sprint[1]	1
3	ESPrit 3G[1]	58
4	Freedom[1]	16
2	AB PSP[2]	1
2	AB BTE[2]	1

[1] Cochlear Corporation Devices

[2] Advanced Bionics Corporation Devices, PSP = Platinum Speech Processor, BTE = Platinum Behind the Ear Processor

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Table 2

Mean speech perception, speech production and language age equivalent scores of the 112 follow-up participants measured in elementary grades (CI-E) and high school (CI-HS)

	CI-E			CI-HS		
Characteristic	Mean	SD	Easy/Hard	Mean	SD	Easy/Hard
% LNT @ 70 dB SPL	50.6	24.9	52.8/48.7	60.1	23.4	63.8/56.4
% LNT @ 50 dB SPL	-	-	-	47.2	24.2	49.3/45.0
% BKB Sentences in Quiet	63.2	34.2	-	80.3	26.8	-
% BKB Sentences in Noise	-	-	-	52.0	26.3	-
Language Age Equivalent	7.1[a]	1.6	-	14.4[b]	5.5	-
%Phoneme Production[c]	67.8	18.1	-	96.0	7.7	-
%CAVET - V	39.6	18.9	-	46.1	15.5	-
% CAVET -AV	82.3	19.1	-	90.8	11.2	-
% CAVET - AV-V	42.7	21.2	-	44.7	14.4	-

[a]Test for Auditory Comprehension of Language (TACL)

[b]Peabody Picture Vocabulary Test

[c]McGarr Sentences

Table 3

Characteristics measured during the CI-E test session of participants returning and those unable to return for follow-up testing

	Returned (n = 112)	Did not return (n = 72)
LNT Percent Correct *	51[a]	39
BKB Percent Correct *	63[b]	47
CAVET Visual Percent Correct	40	35
CAVET Auditory-Visual Percent Correct *	82[c]	73
Duration of Deafness (months)	37.1	37.4

*Significant mean differences at $p<.01$

[a] $F(1,179) = 7.61$, $p < .01$

[b] $F(1,182) = 8.54$, $p < .004$

[c] $F(1,182) = 7.18$, $p < .01$