Speech Perception and Speech Production Skills of Children with Multichannel Cochlear Implants

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The acquisition of speech perception and speech production skills emerges over a protracted time course in congenitally deaf children with multichannel cochlear implants (CI). Only through comprehensive, longitudinal studies can the full impact of cochlear implantation be assessed. In this study, the performance of CI users was examined longitudinally on a battery of speech perception measures and compared with subjects with profound hearing loss who used conventional hearing aids (HA). The average performance of the multichannel cochlear implant users gradually increased over time and continued to improve even after 5 years of CI use. Speech intelligibility was assessed from recordings of the subjects' elicited speech and played to panels of listeners. Intelligibility was scored in terms of percentage of words correctly understood. The average scores for subjects who had used their CI for 4 years or more exceeded 40%. *Key words: cochlear implantation, multichannel CI, children, speech production skills.*

INTRODUCTION

Speech perception and speech production skills of children with prelingual deafness who have received the Nucleus multichannel cochlear implant continue to improve over a long time-course (1–4). The purpose of this longitudinal study was to document performance trends in children who have used their device for as long as 5 years. A second aim was to document how speech perception skills of CI children compare with those of children with different levels of hearing impairment who use conventional hearing aids. Children with hearing levels between 90 to 100 dB HL were viewed as setting the "gold standard" of performance for profoundly hearing impaired children because they have the potential to develop good speech perception skills and intelligible speech with hearing aids. In a previous study we documented that after 1.5 years of Nucleus implant use, the gold hearing aid users achieved higher scores on all perception measures (5). However, large improvements in speech perception beyond 1.5 years have been demonstrated. We believe that the Nucleus users will approach a "gold standard" of performance given adequately long experience with their device.

MATERIAL AND METHODS

Subjects

Speech perception skills were examined in 50 subjects with prelingual deafness who received the Nucleus multichannel CI. Their mean age at onset was 0.8 years and the mean age at implantation was 5.0 years.

The speech perception skills of the implanted subjects were compared with those of subjects who used conventional hearing aids. The hearing aid users were divided into 3 groups, based on their unaided thresholds at 500, 1,000, and 2,000 Hz. Gold hearing aid users demonstrated levels of 90 to 100 dB HL at 2 of 3 frequencies. Silver hearing aid users demonstrated hearing levels of 101 to 110 dB. Bronze hearing aid users demonstrated thresholds > 110 dB. The characteristics of the hearing aid subjects are shown on Table I. All 28 of the bronze hearing aid subjects eventually received a Nucleus CI and have been subsequently followed as CI subjects.

Procedures

Speech perception: The subjects were tested on a battery of speech perception measures. All recorded tests were played on an audio cassette recorder, routed through an audiometer to control for presentation level, and delivered via a loudspeaker in a sound-treated booth. The child was seated facing the loudspeaker approximately 3 feet away. The stimuli were presented to the child at approximately 70 dB SPL. The presentation level was calibrated before each child was tested by placing a microphone in the

Table I. *Characteristics of hearing aid subjects*

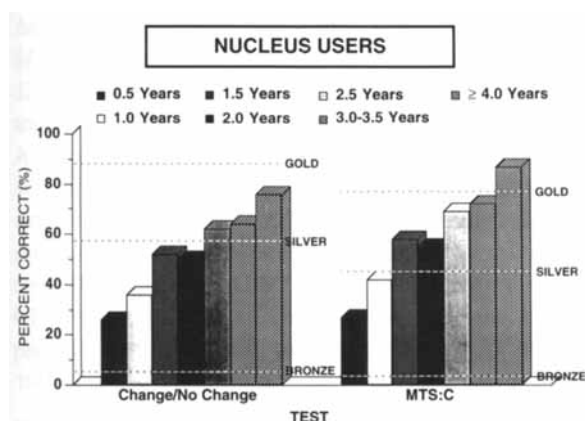|	Gold 21	Silver 10	Bronze 28
Mean pure tone average (DB HL)	94	104	>110
Mean age at onset of deafness (years)	0.7	0.4	0.7
Mean chronological age (years)	10.2	8.2	7.0

Fig. 1. Change/No Change and MTS : Categorization tests. Mean scores of Nucleus users as a function of post-implant use in years. The mean scores of the Bronze (PTA > 110 dB HL), Silver (PTA-94 dB HL), and Gold (PTA = 104 dB) HA users are shown by the dashed lines.

Fig. 3. Common Phrases test. Mean scores of the Nucleus users as function of post-implant use in years. The test was administered with combined auditory and visual cues or with auditory cues only.

approximate location of the child's head and implant microphone. All live-voice tests were administered while the child was in the sound-treated booth or in a quiet room. For the live-voice testing, a hand-held screen, covered with a dark, mesh fabric that is used on loudspeakers, was placed in front of the clinician's face.

The Change/No Change test (6) assesses detection of a change in a suprasegmental or segmental feature of speech in a sequence of 10 nonsense syllables. There are 7 subtests, each of which contrasts a different feature of speech (syllable duration, intonation, fundamental frequency, talker gender, vowel height, vowel place, consonant manner). All 10 syllables are the same on a no-change trial, whereas the last 5 syllables differ from the first 5 on a change trial. The child is instructed to respond "same" on a no-change
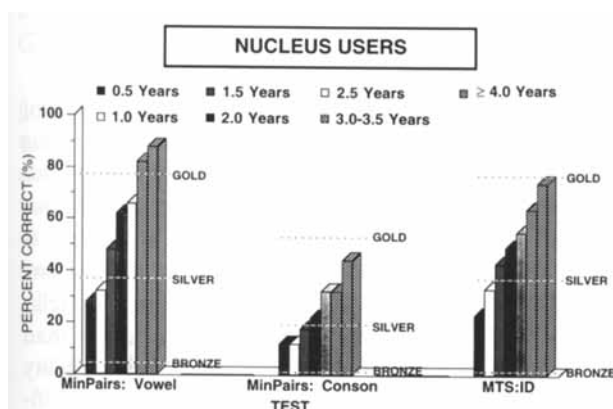
trial, and "different" on a change trial. Scores are averaged across the 7 subtests.

The Monosyllable-Trochee-Spondee (MTS) test (7) is administered by live voice. It consists of 12 pictured nouns with 3 different stress patterns. Each item is presented two times in random order, and the subject's score is averaged across the two trials. Each response is scored for stress-pattern categorizaiton (MTS : Categorization) and word identification (MTS : Identification). Chance level of performance is 33% on the the stress-pattern categorization task and 8% on the word identification task.

The Minimal Pairs test (8) consists of pairs of pictured words, with members of a pair differing in terms of vowel height, vowel place, consonant man-

Fig. 2. Minimal Pairs and MTS : Identification tests. Mean scores on the vowel and consonant items of Nucleus users as a function of post-implant use in years.
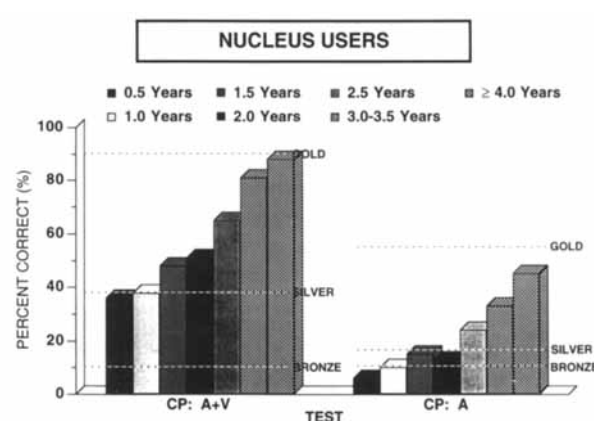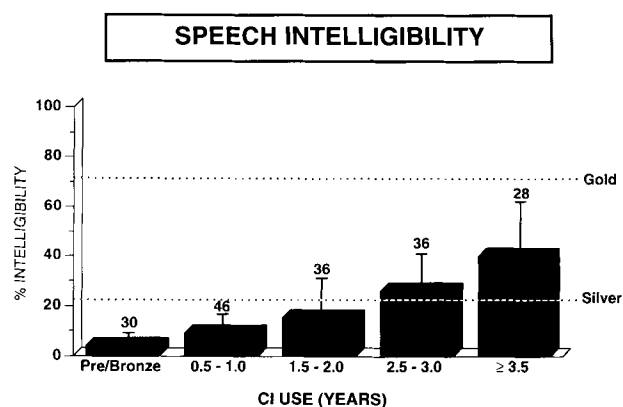

Fig. 4. Mean speech intelligibility scores as a function of length of CI use. The first bar shows the mean scores for Bronze (PTA > 110 dB HL) HA users. The dashed lines show the mean scores for the Silver (PTA = 103 dB HL) and Gold (PTA = 93 dB HL) HA users.

ner, consonant voice, or consonant place. The test consists of 20 word pairs, 12 with consonant contrasts and 8 with vowel contrasts. Each word in a pair is presented as a test item but in random order, totaling 80 items on the entire test. The test is administered via a live voice. Performance on the Minimal Pairs test is analyzed in terms of the vowel and consonant items correctly identified. Chance level of performance is 50%.

The Common Phrases test (6) assesses understanding of familiar phrases used in everyday situations. There are 6 lists with 10 phrases each that are either simple commands or questions. The phrases are presented in two conditions: auditory only and auditory-plus-visual (lip reading) cues. The test is always administered in the audtiory-plus-lip reading condition first. If the child does not correctly repeat at least two of the phrases when both auditory and visual cues are present, testing is not performed in the auditory-only condition, and the child is assigned a score of zero for the condition. Performance is scored in terms of the percentage of phrases correctly repeated by the child.

Speech intelligibility: Each subject produced 10 sentences that were repeated after an examiner's spoken model. Children under 6 years were administered one list from the Beginner's Intelligibility Test (BIT). The BIT utilizes objects and pictures to convey the target sentence, and an imitative response is elicited. Older children (> 6 years) who could read were given the Monsen Sentences Test. For this procedure, children read the sentences, and then imitated the examiner's spoken model. Each subjects' sentence productions were audio recorded, digitized, randomized, and then played to panels of listeners who transcribed what they thought the subject had said. Panels consisted of 3 listeners with no prior experience in listening to the speech of persons with hearing loss. Each set of 10 sentences produced by one subject was evaluated by a single panel. The listeners evaluated more than one set of sentences but each set was produced by a new subject, and contained a sentence list not previously heard by the panel. Individual subject intelligibility scores were calculated by averaging the number of words correctly understood across the 3 listeners (9).

Subjects were tested in the pre-CI condition and at 6-month intervals thereafter. However, some subjects entered the study after receiving their implant or were available for testing on a yearly basis only.

RESULTS

Speech perception

Scores of the implanted subjects gradually increased over time on all measures of speech perception. Fig. 1

shows that the largest changes in performance on the Change/No Change test occurred during the first $1\frac{1}{2}$ years of implant use. The mean score of the CI subjects was higher than that of the Bronze HA users after only 6 months of implant use. After more than 4 years of device use, the mean score of the CI subjects surpassed that of the Silver HA users and were similar to that of the Gold HA users. This same trend was observed on the MTS : C except that it appeared earlier. That is, the CI children's ability to recognize stress patterns of words surpassed the Silver HA users and matched the Gold HA users after only 2 years of CI use.

Closed set word recognition was measured using the Minimal Pairs Tests and the MTS : Identification test. Performance on the Minimal Pairs test was analyzed in terms of percentage of words correctly identified on the basis of vowel and consonant distinctions. In Fig. 2, the performance of the Nucleus users on the vowel items surpassed the Gold and Silver HA users at the last post-implant interval. A large improvement in consonant perception by the CI subjects was also observed. Consonant perception was better for the Nucleus users than the Silver HA users. The mean score on the MTS : Identification was substantially higher than that of the Silver HA users and approached the score of the Gold HA users.

Open-set speech recognition was measured using the Common Phrases Test (see Fig. 3). When this test was measured auditory only, the mean score of the Nucleus users was initially low, ranging from 0 to 47, but improved over time. After 2.5 years the mean score was 20% and after 4 years, the scores were in the 40% ranging and approached the scores of the Gold HA users. A large difference between Nucleus and the Silver HA users was observed on the auditory + visual and the auditory only conditions. This suggests that the implanted subjects have better integration of auditory and visual cues than do Silver HA users.

Speech intelligibility

Mean speech intelligibility scores for the groups of subjects were calculated at yearly intervals. Following the pre-CI interval, data from pairs of consecutive intervals were combined. Gradual improvement over time in speech intelligibility for the CI subjects is demonstrated in Fig. 4. After only 6 months to one year of experience with their device, the speech intelligibility of the CI subjects was significantly better than in the pre-CI condition ($p = 0.001$). Intelligibility scores of each successive interval were also significantly greater than those of the preceding interval ($p < 0.02$). The scores of the CI subjects after 1.5 to 2.0 years remain lower than the Silver HA group.

After that time, however, the CI subjects surpass the Silver HA group. At the last interval, representing 3.5 or more years of CI use, the average intelligibility of the CI subjects is double that of the Silver HA group. After 3.5 or more years of CI use, approximately 40% of the elicited sentences produced by the CI subjects wre intelligible, compared with 72% for the Gold HA group. Although the average score for the CI subjects remained lower than that of the Gold HA users, some CI subjects approached a level of intelligibility comparable to that of this group.

DISCUSSION

The results of this study demonstrate that children with Nucleus multichannel cochlear implants achieve significant improvements in closed- and open-set speech preception abilities with increased device experience. After 2 years of implant use, the speech perception performance of implanted children surpassed that of the Silver hearing aid users and by 3.5 years, the mean scores of the implant users were roughly 20–40% higher than those of the Silver hearing aid users and are similar to those of the Gold HA group selected measures. As expected, the CI children perform best on vowel-feature recognition, as the Nucleus processor strategy they employed at the time of testing (either F0F1F2 or MPEAK) functioned primarily as a formant extractor. However, the similarities in performance to the Gold HA group in the auditory-plus-visual modality is encouraging, as this more closely approximates natural listening situations. The present findings suggest that Silver HA users may obtain more benefit from a CI than from conventional amplification. Broadening of implant candidacy seems well justified. It may be that as children are implanted at a younger age, and thus obtain auditory experience that is equivalent to that of age-matched children who use HA's, the performance of CI children will eventually equal that of the Gold HA users.

Although improving at a slower rate, speech intelligibility of the pre-lingually deafened children with multichannel cochlear implants increased considerably over time. The average speech intelligibility of the CI subjects prior to receiving their devices was close to 0%. After 3.5 years of the implant use, the average speech intelligibility of this group improved to 40%. The scores of the CI group exceeded those of the Silver HA group after 2 years of implant use, and this advantage increased over time.

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