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Comparison of Speech Recognition and Localization Performance in Bilateral and Unilateral Cochlear Implant Users Matched on Duration of Deafness and Age at Implantation

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Abstract

Objective—The purpose of this investigation was to compare speech recognition and localization performance of subjects who wear bilateral cochlear implants (CICI) with subjects who wear a unilateral cochlear implant (true CI-only).

Design—A total of 73 subjects participated in this study. Specifically, of the 73 subjects, 64 (32 CICI and 32 true CI-only) participated in the word recognition testing; 66 (33 CICI and 33 true CI-only) participated in the sentence recognition testing; and 24 (12 CICI and 12 true CI-only) participated in the localization testing. Because of time constraints not all subjects completed all testing. The average age at implantation for the CICI and true CI-only listeners who participated in the speech perception testing was 54 and 55 yrs, respectively, and the average duration of deafness was 8 yrs for both groups of listeners. The average age at implantation for the CICI and true CI-only listeners who participated in the localization testing was 54 and 53 yrs, respectively, and the average duration of deafness was 10 yrs for the CICI listeners and 11 yrs for the true CI-only listeners. All speech stimuli were presented from the front. The test setup for everyday-sound localization comprised an eight-speaker array spanning, an arc of approximately 108° in the frontal horizontal plane.

Results—Average group results were transformed to Rationalized Arcsine Unit scores. A comparison in performance between the CICI score and the true CI-only score in quiet revealed a significant difference between the two groups with the CICI group scoring 19% higher for sentences and 24% higher for words. In addition, when both cochlear implants were used together (CICI) rather than when either cochlear implant was used alone (right CI or left CI) for the CICI listeners, results indicated a significant binaural summation effect for sentences and words.

Conclusion—The average group results in this study showed significantly greater benefit on words and sentences in quiet and localization for listeners using two cochlear implants over those using only one cochlear implant. One explanation of this result might be that the same information

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from both sides are combined, which results in a better representation of the stimulus. A second explanation might be that CICI allow for the transfer of different neural information from two damaged peripheral auditory systems leading to different patterns of information summating centrally resulting in enhanced speech perception. A future study using similar methodology to the current one will have to be conducted to determine if listeners with two cochlear implants are able to perform better than listeners with one cochlear implant in noise.

Introduction

Since the inception of cochlear implants in the early 1980s, cochlear implantation has become a successful and widely accepted method of providing hearing to profoundly deafened listeners. Because of their success, several listeners have now received two cochlear implants. Although the number of patients receiving bilateral cochlear implants (CICI) is becoming more prevalent, the overall benefits have been reported on a limited number of recipients. In most cases, bilateral performance has been compared with unilateral performance by switching off one implant from a bilateral subject (Gantz, et al., 2002; Laszig, et al., 2004; Litovsky, et al., 2004, 2006; Schleich, et al., 2004). This design would not be ideal because the unilateral condition is not the bilateral listener's standard listening situation, thus, leading to a biased score for that test condition.

One might assume that two cochlear implants should be better than one because the implant user should be able to take advantage of interaural timing (ITD) and level differences (ILD) between two ears. However, Shannon et al. (2004, p. 366) noted that bilateral listeners "may not have sufficient residual auditory capacity in the central nervous system to make use of binaural cues." Research shows that CICI are beneficial for some individuals and in some conditions (e.g., Litovsky et al., 2004; Muller, et al., 2002; van Hoesel, 2004). Listeners with CICI typically have better localization when using both implants than when using one implant (Nopp, et al., 2004; Ramsden, et al., 2005; Tyler, et al., 2002a; van Hoesel & Tyler, 2003; van Hoesel, et al., 2002; Verschuur, et al., 2005). However, localization is still inferior compared with normal hearing and some bilateral implant users do not reveal any substantial benefit in localization (Litovsky, et al., 2004; Seeber, et al., 2004). In contrast, most bilateral users can take advantage of the head shadow effect and listen to the ear with the better signal to noise ratio (while ignoring the other ear) (Gantz, et al., 2002; Laszig, et al., 2004; Litvosky, et al., 2004; Muller, et al., 2002; Ramsden, et al., 2005; Schleich, et al., 2004; Tyler, et al., 2002b; van Hoesel, et al., 2002). Only a small number of CICI listeners show some evidence of a "binaural squelch" (Gantz, et al., 2002; Muller, et al., 2002; Schleich, et al., 2004; Seen, et al., 2005; Tyler, et al., 2002a,b) often with minimal or no benefit reported (van Hoesel & Tyler, 2003; van Hoesel, et al., 2002).

There are several reasons some cochlear implant recipients receive bilateral advantages whereas others do not. One reason might be because bilateral information may not be successfully integrated in the brain because of limited nerve survival, which might be asymmetrical, or because of independent processing of the devices. A second reason might be that many comparisons of bilateral and unilateral implants are done by asking bilateral patients to switch off one of their implants. Although this has the advantage of a within-subject control, van Hoesel and Tyler (2003), and Eddington (personal communication) expressed concerns that bilateral listeners might be at an unfair disadvantage because they routinely experience bilateral listening and lack everyday unilateral experience. Because there are arguments that bilateral cochlear implantation should become the standard surgical intervention for severely hearing impaired listeners and because many unilaterally implanted listeners are requesting a second device, it is vital to understand the benefits and possible limitations of bilateral cochlear implantation. Given the monetary cost and risks associated with surgical intervention in both ears, it is critical to verify the advantage of two devices in a systematic way. This study is designed to evaluate the benefit of unilateral versus bilateral implantation by studying performance in a group of simultaneously implanted subjects (CICI) and true CI-only implanted subjects who do not wear a hearing aid on the unimplanted ear and are matched by age at implantation and duration of deafness.

Materials and Methods

Subjects

Seventy-three adults who had used cochlear implants for at least 4 mos (with an average of 59 mos) participated in this study. Thirty-three subjects were implanted with Clarion devices (Advanced Bionics Corporation, Sylmar, CA); 38 subjects were implanted with Nucleus devices (Cochlear Corporation, Lane Cove NSW, Australia); and two subjects were implanted with Ineraid devices. A total of 33 of the subjects were simultaneously implanted CICI recipients and 40 subjects were unilaterally implanted subjects (true CI-only). None of the true CI-only subjects wore a hearing aid on their nonimplanted ears. Demographic information for these individuals is presented in Table 1.

Of the 73 subjects, 64 (32 CICI and 32 true CI-only) participated in the word recognition testing, 66 (33 CICI and 33 true CI-only) participated in the sentence recognition testing, and 24 (12 CICI and 12 true CI-only) participated in the localization testing. Some data collection occurred at different test sessions. Because of time constraints not all subjects completed all testing or completed all testing at the same test session.

In an attempt to decrease variability among comparisons between CICI and true CI-only subjects, the CICI subjects who participated in the speech perception and localization testing were matched by age at implantation and duration of profound deafness to the true CI-only subject. On average, subjects were matched by age at implantation within 1 yr for speech perception and localization testing as well as matched by duration of profound deafness within 1 yr for speech perception testing and less than 1 yr for localization testing. Although not a matching criterion, preoperative hearing thresholds at 500 Hz for the right and left ears were also compared. The number of months postimplantation at the time of the data collection for localization and speech perception is shown for each of the subjects in Table 1. If subjects did not participate in both speech perception and localization testing (because of time constraints), a not applicable (N/A) is placed in the appropriate column of the demographic table.

Procedures

All speech perception tests were presented in the sound field, in a 10′ × 9.3′ × 6.5′ sound-treated booth with a reverberation time (RT_{60}) at 1000 Hz at 0.079 sec under the following conditions: left-only, right-only, and bilateral for the CICI subjects and CI only for the true CI-only group. All conditions were randomized among subjects. Localization testing was conducted in the bilateral condition for the CICI subjects.

Speech Perception

Speech materials were always presented from the front. Speech perception was measured in quiet using commercially available Consonant-Nucleus-Consonant (CNC) monosyllabic words (Tillman & Carhart, 1966) and Hearing in Noise Test (HINT) sentences (Nilsson, et al., 1994) recorded with male talkers. CNC scoring was based on percent-correct performance at both the word and the phoneme levels and the HINT sentences were scored by dividing the total number of key words correctly identified by the total number of key words possible. Two lists of CNC words and four lists of HINT sentences were presented to each subject. Although, the same sentence and word lists used in this study may have been heard by these subjects in different studies, all speech perception lists were randomized between subjects and no subject received two of the same lists during this study. Speech materials were presented at 70 dB (C).

Localization

A localization test was administered using everyday sounds presented from one of eight loudspeakers (Dunn, et al., 2005) at 70 dB (C). Each of 16 different sound items (Kramer, 1998) was repeated six times and was presented randomly from one of the eight loudspeakers during the test. Thus, when the test is finished, a sound item will have been presented from each loudspeaker 12 times to achieve a total of 96 presentations for the entire test. The subject was told to identify the loudspeaker number from which the sound originated, but not to identify the sound itself. Subjects were not given listening samples of the sounds before test administration, but each subject was told what the sounds would be. Most bilateral subjects, however, had been given this particular test as part of the test battery of other studies. Localization performance was determined by calculating the average root mean square (RMS)-error in degrees. All presentations of the sounds were used to calculate the average RMS-error in degrees. For a detailed description of this scoring, see Dunn et al. (2005).

Results

Matching Subject Groups

HINT sentences (N = 33 CICI and N = 33 true CI-only) and CNC word (N = 32 CICI and N = 32 true CI-only) performance were collected on CICI and true CI-only subjects matched by age at implantation and duration of deafness. In Figure 1a, we show the average age at implantation, duration of deafness, and left and right preoperative thresholds at 500 Hz for both subject groups. This frequency was chosen because subjects who are candidates for long-electrode cochlear implants are severe to profoundly deafened and an auditory response would be more likely to be observed at this frequency. An independent-samples two-tailed *t* test showed that there was no statistically significant difference between the CICI subjects and true CI-only subjects in age at implantation ($t(64) = 0.29$, $p > 0.05$), duration of deafness ($t(64) = 0.04$, $p > 0.05$), and left ear preoperative thresholds ($t(64) = 1.74$, $p > 0.05$). A significant difference was found, however, for the right ear preoperative thresholds for CICI subjects and true CI-only subjects ($t(64) = 3.30$, $p < 0.01$).

Localization data were collected on 12 CICI subjects matched by age at implantation and duration of deafness to 12 true CI-only subjects. In Figure 1b, we show the average age at implantation, duration of deafness, and left-only and right-only preoperative threshold at 500 Hz for both subject groups. Again, an independent-samples two-tailed *t* test showed that there was no statistical difference between the CICI subjects and true CI-only subjects on age at implantation ($t(22) = -0.09$, $p > 0.05$), duration of deafness ($t(22) = 0.13$, $p > 0.05$) or left preoperative thresholds ($t(22) = 1.77$, $p > 0.05$). A significant difference was found, however, for the right ear preoperative thresholds for CICI subjects and true CI-only subjects ($t(22) = 3.76$, $p < 0.01$).

Speech Perception

Speech perception results for HINT sentences and CNC words presented in quiet from a 0° azimuth were transformed into Rationalized Arcsine Unit scores (Studebaker, 1985) to accommodate the ceiling effects demonstrated by the CICI listeners with the HINT sentences. Average Rationalized Arcsine Unit scores for speech perception performance for HINT sentences and CNC words presented in quiet from a 0° azimuth is shown in Figures 2 and 3, respectively, for the CICI and true CI-only subjects. A comparison in performance between the CICI score and the true CI-only score for sentences in quiet using an independent-samples two-tailed *t* test revealed a significant difference between the two groups with the CICI group scoring 19% higher ($t(64)=-3.06$, $p < 0.01$). A statistical difference was also found by an independent-samples *t* test for words in quiet when comparing the CICI and the true CI-only score, with the CICI subjects performing 24% higher ($t(62) = -4.41$, $p < 0.001$). Also in Figures 2 and 3, right CI, left CI, and CICI (bilat-listeners. Two-tailed paired *t* tests with the Bonferroni adjustment indicated a significant binaural summation effect for sentences (shown in Fig. 2) [right CI versus CICI: $t(32)=-4.92$, $p < 0.001$; left CI versus CICI: $t(32)=-2.90$, $p < 0.05$] and for words (shown in Fig. 3) [right CI versus CICI: $t(31) = -6.17$, $p < 0.001$; left CI versus CICI: $t(31) = -3.78$, $p < 0.01$] when both the cochlear implants were used together (CICI) rather than when either cochlear implant was used alone (right CI or left CI).

Localization

Average localization performance is shown in Figure 4, for the CICI and true CI-only subjects. A comparison in performance for localization abilities by an independent-samples two-tailed *t* test revealed a significant difference, between the two groups with the CICI group having a better RMS-error by 25.4° [$t(22) = 11.93$, $p < 0.001$].

Discussion

The goal of this article was to evaluate the benefit of bilateral versus unilateral implantation by comparing speech recognition and localization abilities in CICI and true CI-only listeners who were matched by age at implantation and duration of profound deafness.

The average group results in this study showed significantly greater benefit on both words and sentences in quiet for listeners using two cochlear implants over those using only one cochlear implant. These results were consistent with previous studies involving CICI listeners, and supported the hypothesis that CICI might be more beneficial over single cochlear implants. One explanation for these results, independent of cochlear implant type and configurations, is the fact that two ears have the advantage of providing the auditory system with redundant information, referred to as the binaural summation effect. It occurs due to a neural mechanism that combines or sums the information from each ear to provide an overall increase in loudness of the signal. For example, the loudness of a soft sound would be greater when listening with two ears compared with listening with one ear only. Binaural summation typically refers to either an improvement in threshold (typically around 3 dB for normal listeners) or a similar increase in loudness. Another way to think about the advantage of listening when the information is the same at each ear is that there are two versions of the same signal. Even though the information may be redundant, the mechanisms by which the same information from both sides is combined might involve a better representation of the stimulus because it is coded twice. It is also possible that CICI allow for the transfer of different neural information from two damaged peripheral auditory systems. It is most likely that each ear has independent differences in neural survival leading to different patterns of information summating centrally. This synergestic interaction most likely results in enhanced speech perception. A second explanation, and a possible limitation of this study, may be the fact that subjects were not matched based on the type of cochlear implant they have and thus, subjects in each group have various electrode configurations and signal processing strategies. In addition, subjects might have varying nerve survival patterns. This may all influence speech perception and localization results. However, despite this possible limitation, each subject was tested with their cochlear implants tuned and mapped to the best fit. Thus, true CI-only listeners and CICI listeners were fit to the best of the audiologist’s capabilities given the subject’s cochlear implant types and nerve survival.

The binaural summation results in this study showed significant effects of summation with both sentences and words for the CICI listeners. The binaural summation results in this study were measured by having our CICI listeners switch off one of their cochlear implants (temporary CI-only). This way of measuring summation is one of the most commonly used methodologies in our field because it is a within-subject design, thus reduces variability of a between-subjects design, and requires a smaller number of subjects to analyze results. One disadvantage of this methodology is that by having the CICI listener remove one of their CI’s, they are at an immediate disadvantage as this configuration does not characterize their everyday listening experience and in essence, changes how their brain codes speech. Thus, one may expect that the CICI listeners would do best in the CICI condition for two reasons: (1) binaural summation occurs due to a brain mechanism that sums the information from each ear to provide an overall increase in loudness of the signal, and (2) the listener is not

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used to processing sounds in the temporary CI-only condition that gives the CICI condition an immediate bias.

Furthermore, when comparing the right- and left-only scores from the CICI listeners to the scores from the true CI-only listeners, one may expect that both groups would score similarly or that the true CI-only listeners would score better because this configuration is similar to their standard listening condition. When comparing the results of the left- and right-only CICI group to the unilateral scores of the true CI-only group in this study, results showed no difference between the true CI-only group and the right-only CICI scores. In contrast, the true CI-only score was significantly worse than the left-only CICI score. One explanation of these findings is that the left ears may have had better nerve survival than the right in this group of CICI listeners. Implications for this finding highlight the need to reassess the commonly used methodology for measuring differences between unilateral and bilateral listening by having a CICI listener remove the effect of one cochlear implant during testing. For example, had we assumed that comparing bilateral score to the left-only CICI score represented how a true CI-only listener hears in that same situation, we would have overestimated their performance.

The average group results in this study also showed greater benefit on localization performance for listeners using two cochlear implants (CICI) over those only using one (true CI-only). One reason for this finding is that having two ears offers the advantage of computing differences in arrival time, called ITD, and ILD. Thus, when listening with one ear, it is not possible to compare ITD and ILDs forcing these listeners to rely on spectral cues, interactions of sound with the listener’s body (e.g., the head shadow effect), or head movements.

Although not used as matching criteria in the study, one possible limitation of this study is that the preoperative thresholds at 500 Hz were not matched in the right ears between the CICI and the true CI-only groups. Although matching by age at implantation and duration of deafness has been found to be more important variables for predicting postimplantation performance (Gantz, et al., 2002; Rubinstein, et al., 1999; van Dijk, et al., 1999; Waltzman, et al., 1995), future studies examining differences between true CI-only and CICI listeners could add residual hearing as a matching criterion.

Future research should also focus on comparing speech perception in spatially separated background noise. Oftentimes, researchers studying binaural advantages report that one of the predominant advantages of having two ears is listening in noise (Laszig et al., 2004; Muller, et al., 2002; Ramsden, et al., 2005; van Hoesel & Tyler, 2003; van Hoesel, et al., 2002). However, a future study using similar methodology to the current one will have to be conducted to determine if listeners with two cochlear implants are able to perform better than listeners with one cochlear implant in noise.

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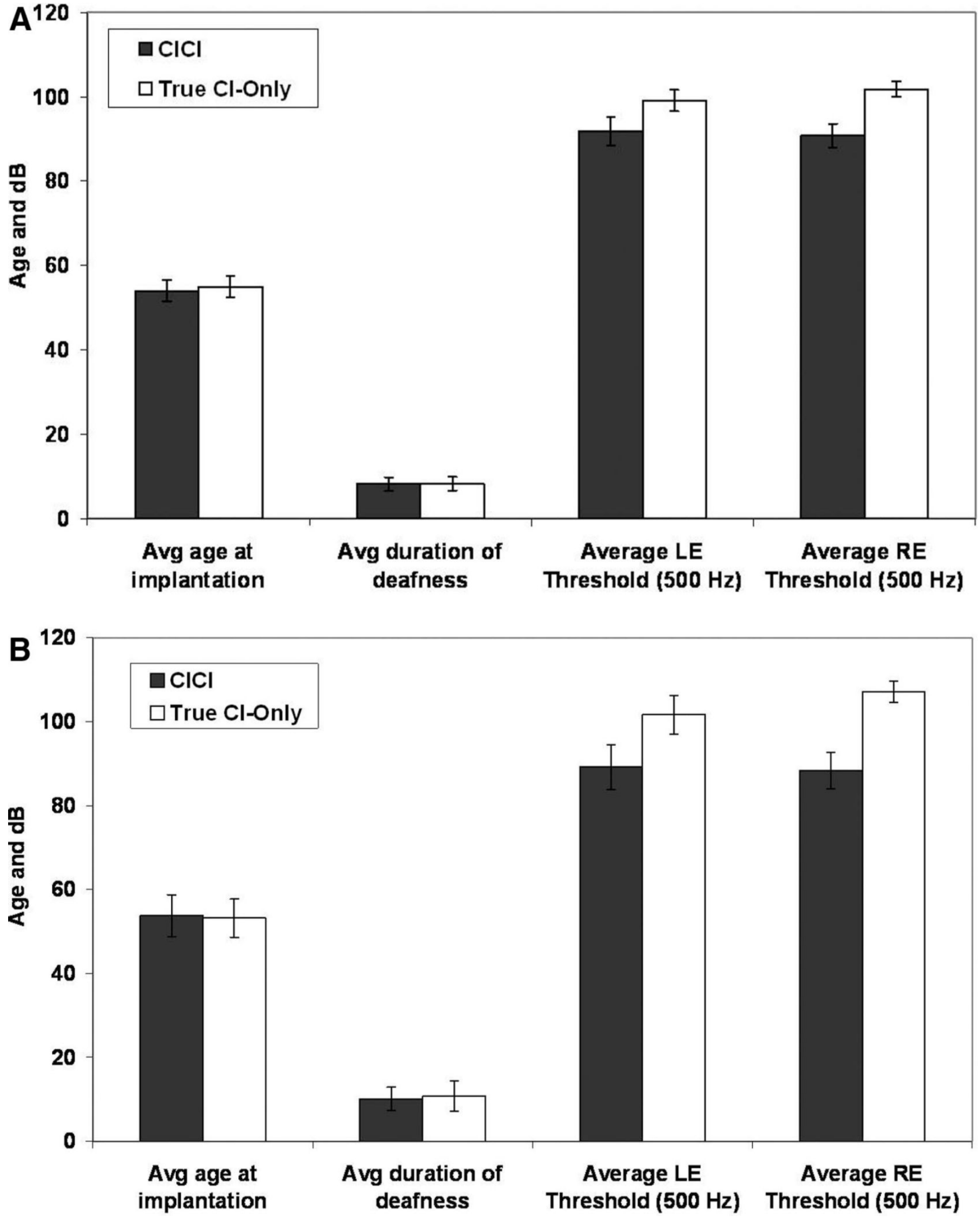

Fig. 1.

Panel A. Age at implantation, duration of deafness, and left and right preoperative threshold at 500 Hz for the 33 CICI and 33 true CI-only subjects who participated in the speech recognition tests. Panel B. Age at implantation, duration of deafness, and left and right preoperative threshold at 500 Hz for the 12 CICI and v12 true CI-only subjects who participated in the localization tests. Average scores are shown with ±1 standard error bars.

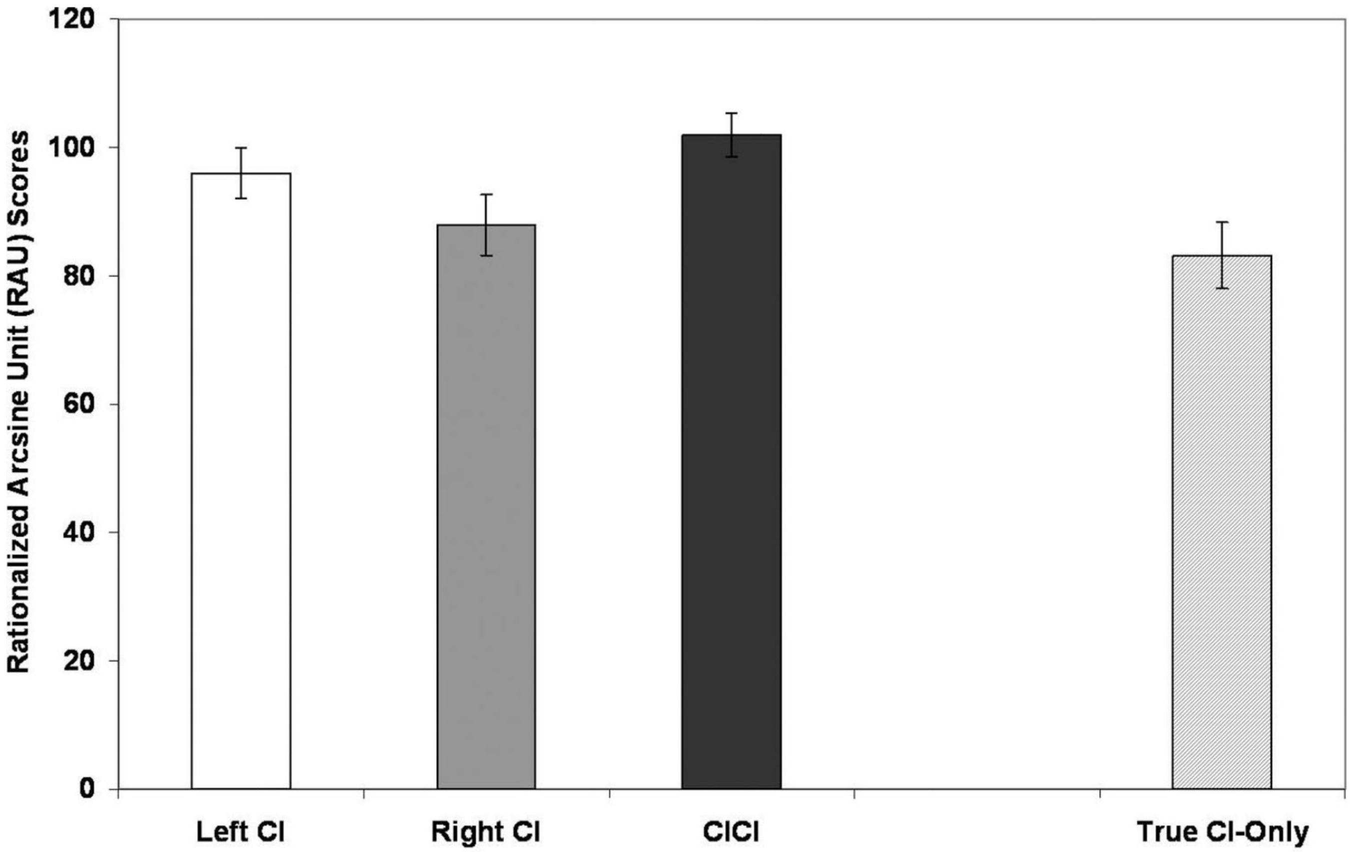

Fig. 2.
Sentence recognition performance (percent correct) in quiet with the left CI, right CI, and CICI (bilateral) conditions for the 33 CICI and 33 true CIonly subjects. Average scores are shown with ±1 standard error bars.

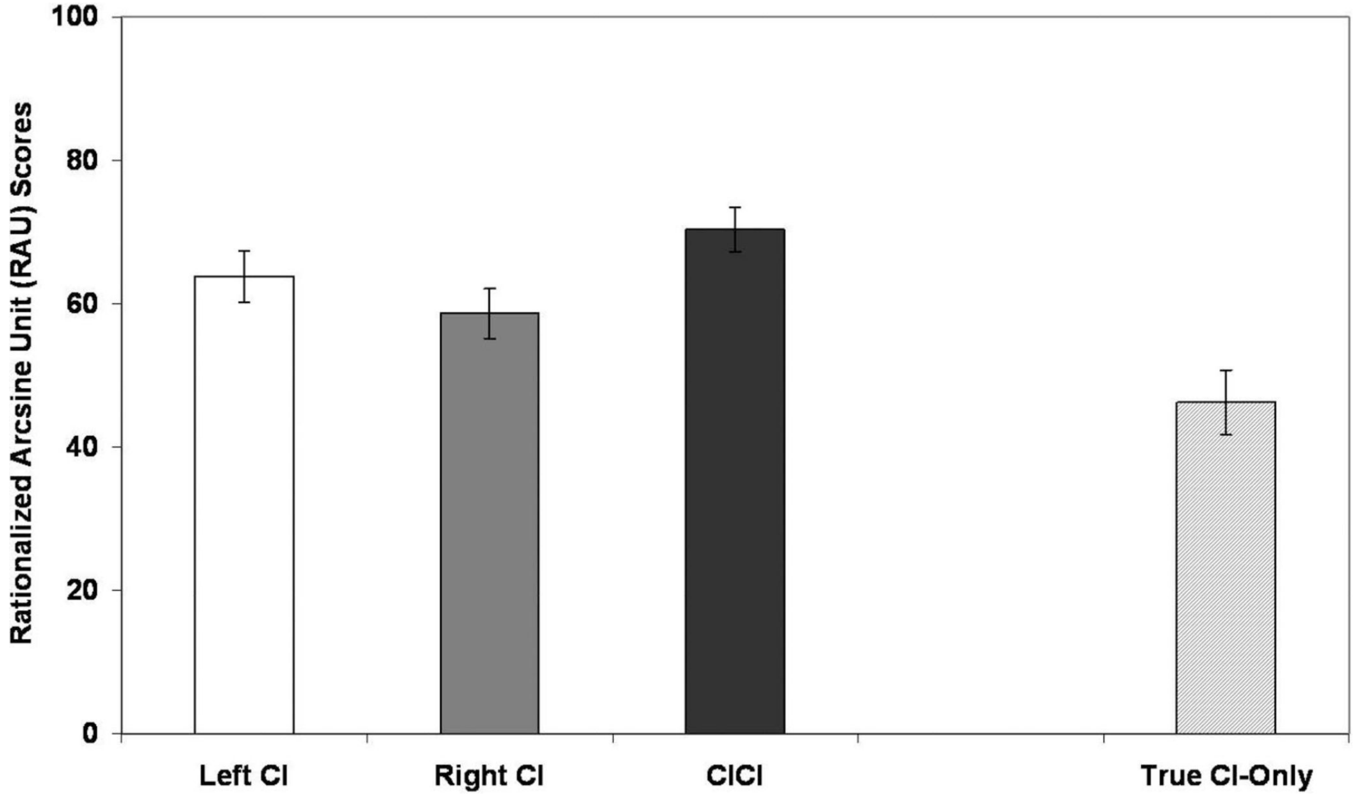

Fig. 3.
Word recognition performance (percent correct) in quiet with the left CI, right CI, and CICI (bilateral) conditions for the 32 CICI and 32 true CI-only subjects. Average scores are shown with ±1 standard error bars.

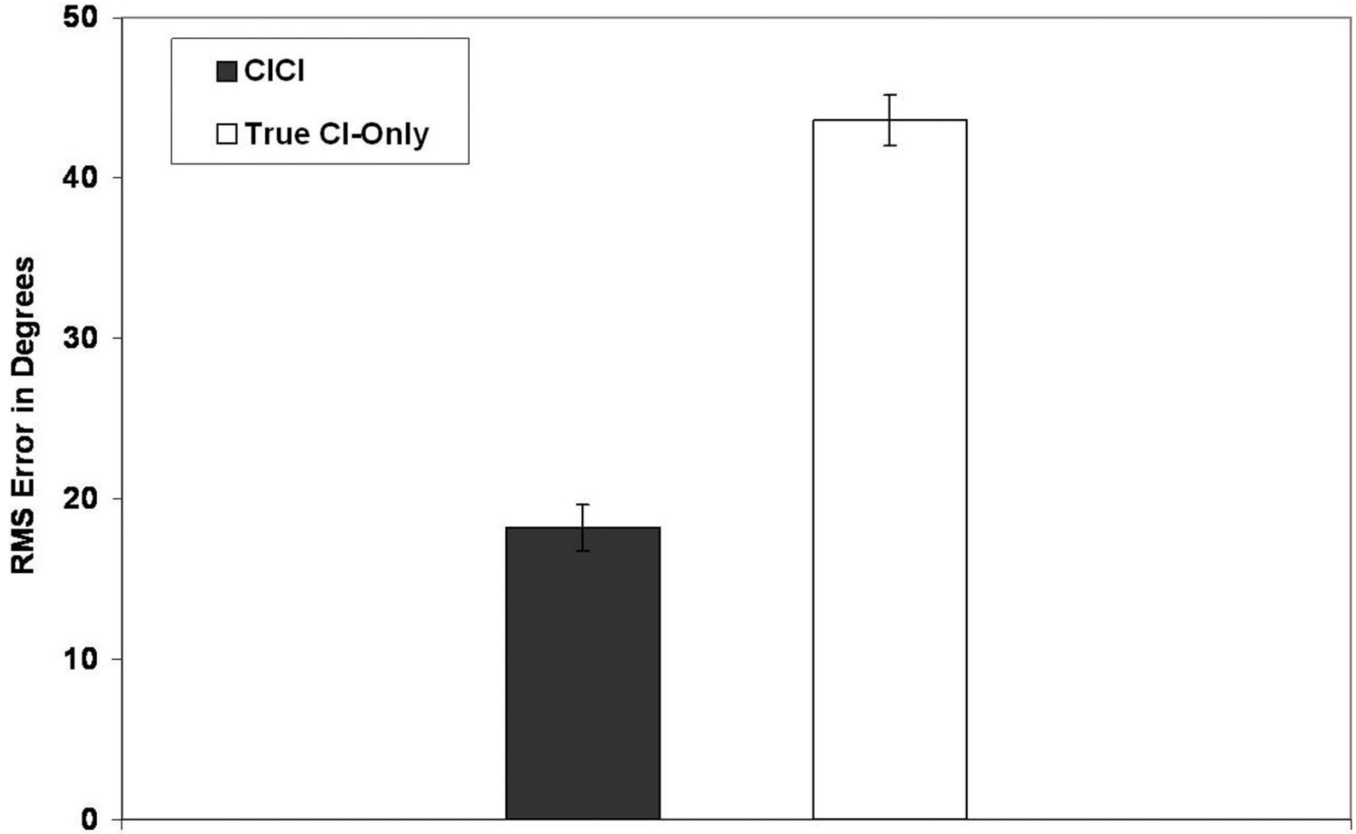

Fig. 4.
RMS-error in degrees for 12 CICI and 12 true CI-only subjects. Average scores are shown with ±1 standard error bars.

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TABLE 1

Subject demographics

Subject	Ear implanted	Age at implant (yrs)	Years deaf	Localization (mos postimplant)	Sentences (mos postimplant)	Words (mos postimplant)	Implant type	Strategy (local)	Strategy (sent and words)	Processor (local, sent and words)	LE PreOp threshold (500 Hz)	RE PreOp threshold (500 Hz)
H47b	B	51	35	N/A	24	24	CL HiFocus CII	N/A	CL CIS	CL CII BTE	90	75
H26b	B	76	25	24	48	48	CL HiFocus CII	CL CIS	CL CIS	CL platinum series PSP	80	90
H27b	B	60	6	N/A	36	54	CL HiFocus CII	N/A	CL HiRes paired	CL CII BTE	115	80
H40b	B	40	10	25	48	48	CL HiFocus CII	CL CIS	CL HiRes paired	CL CII BTE	105	100
H16b	B	54	0.2	N/A	36	36	CL HiFocus CII	N/A	CL HiRes paired	CL CII BTE	115	115
H22b	B	66	13	24	36	54	CL HiFocus CII	CL CIS	CL HiRes paired	CL CII BTE	115	85
H57b	B	32	4	12	12	34	CL HiFocus CII	CL HiRes sequential	CL HiRes sequential	CL auria	95	95
H36b	B	58	5	N/A	42	42	CL HiFocus CII	N/A	CL HiRes sequential	CL CII BTE	75	80
H48b	B	42	1	12	36	36	CL HiFocus CII	CL CIS	CL HiRes sequential	CL CII BTE	80	70
H17B	B	25	0	24	24	55	CL HiFocus CII	CL CIS	CLCIS/CL HiRes sequential	CL CII BTE	85	95
Z63b	B	62	5	N/A	4	4	CL HiRes 90K	N/A	CL CIS	CL auria	80	60
Z48b	B	71	12	N/A	6	12	CL HiRes 90K	N/A	CL CIS	CL auria	90	95
Z30b	B	57	5	N/A	24	DNU	CL HiRes 90K	N/A	CL CIS	CL auria	45	105
Z17b	B	65	5	N/A	12	12	CL HiRes 90K	N/A	CL HiRes sequential	CL auria	105	100
Z25B	B	66	0	N/A	12	18	CL HiRes 90K	N/A	CL HiRes sequential	CL auria	75	65
Z33b	B	54	28	N/A	12	18	CL HiRes 90K	N/A	CL HiRes sequential	CL auria	85	110
Z34b	B	31	14	N/A	12	24	CL HiRes 90K	N/A	CL HiRes sequential /CL CIS	CL auria	115	95
M22b	B	36	7	N/A	24	24	NU 24M	N/A	NU SPEAK	NU sprint	75	85

Subject	Ear implanted	Age at implant (yrs)	Years deaf	Localization (mos postimplant)	Sentences (mos postimplant)	Words (mos postimplant)	Implant type	Strategy (local)	Strategy (sent and words)	Processor (local, sent and words)	LE PreOp threshold (500 Hz)	RE PreOp threshold (500 Hz)
M54b	B	52	7	48	72	78	NU 24M	NU ACE	NU ACE	NU sprint	90	90
M46b	B	55	0.3	N/A	48	84	NU 24M	N/A	NU ACE	NU sprint	105	90
M58b	B	59	1	N/A	71	71	NU 24M	N/A	NU ACE	NU sprint	115	80
M61b	B	75	16	55	75	75	NU 24M	NU ACE	NU ACE	NU sprint	55	75
M52b	B	59	0.3	N/A	60	75	NU 24M	N/A	NU ACE	NU sprint	115	115
M64b	B	71	1.5	48	66	72	NU 24M	NU SPEAK	NU SPEAK	NU 3G	75	75
M35b	B	68	1	60	72	84	NU 24M	NU SPEAK	NU SPEAK	NU 3G	115	105
M63b	B	62	1	N/A	63	63	NU 24M	N/A	NU SPEAK	NU sprint	70	70
M45b	B	35	1	N/A	72	72	NU 24M	N/A	NU SPEAK	NU sprint	80	85
R36b	B	46	28	24	36	36	NU 24R	NU ACE	NU ACE	NU 3G	105	115
FIR47b	B	56	0.2	N/A	24	41	NU 24R	N/A	NU ACE	NU 3G	105	115
R40b	B	55	10	N/A	36	41	NU 24R	N/A	NU ACE	NU 3G	95	100
R28b	B	52	15	12	12	45	NU 24R	NU ACE	NU ACE	NU 3G	70	65
R87b	B	20	0.6	N/A	6	12	NU 24R (CA)	N/A	NU ACE	NU 3G	115	115
E14b	B	69	10	N/A	12	12	NU RP8	N/A	NU ACE	NU freedom	95	100
M15	R	69	10	100	N/A	N/A	NU 24M	NU ACE	N/A	NU sprint	115	110
R2	L	76	1	156	N/A	N/A	NU 24R	CL CIS	N/A	NU sprint	70	115
R15	R	39	3	60	N/A	N/A	NU 24R	NU ACE	N/A	NU sprint	110	110
R46	R	59	34	36	N/A	N/A	NU 24R	NU ACE	N/A	NU sprint	110	115
H19	L	32	0.5	52	N/A	N/A	CL HiFocus CII	CL CIS	N/A	CL CII BTE	90	115
H37	L	36	36	48	N/A	N/A	CL HiFocus CII	CL HiRes sequential	N/A	CL CII BTE	95	115
H6	R	44	5	57	N/A	N/A	CL HiFocus CII	CL HiRes sequential	N/A	CL CII BTE	115	100
CL1	L	75	1	N/A	82	82	CL 1.0	N/A	CL CIS	CL S-series	115	115
Z60	L	67	12	N/A	48	48	CL 1.0	N/A	CL CIS	CL platinum series PSP	115	115
M20	L	56	0.8	N/A	141	128	CL 1.0	N/A	CL CIS	CL platinum series BTE	115	115
CL2	L	36	1	N/A	144	144	CL 1.0	N/A	CL CIS	CL platinum series BTE	115	115
CL3	L	28	0.1	N/A	156	156	CL 1.0	N/A	CL CIS	CL S-series	105	100

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CL4	L	74	2	N/A	120	120	CL 1.0	N/A	CL CIS	CL S-series	85	105
CL5	R	59	1	N/A	120	120	CL 1.0	N/A	CL CIS	CL S-series	105	100
CL6	R	51	7	N/A	144	144	CL 1.0	N/A	CL CIS	CL S-series	110	105
H10	L	64	3	N/A	60	60	CL HiFocus CII	N/A	CL HiRes paired	CL CII BTE	95	85
H39	L	58	5	N/A	20	20	CL HiFocus CII	N/A	CL HiRes paired	CL platinum series PSP	85	110
H55	R	60	10	N/A	36	36	CL HiFocus CII	N/A	CL HiRes sequential	CL auria	80	85
Z16	R	71	0.2	22	22	22	CL HiRes 90K	CL HiRes sequential	CL HiRes sequential	CL auria	80	85
Z65	L	57	7	N/A	12	N/A	CL HiRes 90K	N/A	CL HiRes sequential	CL auria	90	100
H8	L	32	15	N/A	228	228	CL HiFocus CII	N/A	CL CIS	CL CII BTE	90	95
Z6	R	38	5	N/A	189	183	Ineraid	N/A	CL HiRes paired	CL auria	85	95
NU1	L	62	1	N/A	161	161	NU 22	N/A	NU SPEAK	NU esprit	115	115
NU2	R	54	28	N/A	192	192	NU 22	N/A	NU SPEAK	NU spectra	110	110
M44	L	77	20	N/A	12	12	NU 24M	N/A	NU SPEAK	NU sprint	100	115
M5	R	28	2	N/A	31	31	NU 24M	N/A	ACE	Sprint	90	85
M37	R	65	5	N/A	24	24	NU 24M	N/A	NU SPEAK	NU sprint	95	100
M5v1	R	31	5.5	N/A	30	30	NU 24M	N/A	NU SPEAK	NU esprit	115	105
M27	L	49	1	N/A	72	96	NU 24M	N/A	NU SPEAK	NU sprint	105	105
M37	R	47	27	N/A	96	96	NU 24M	N/A	NU SPEAK	NU sprint	100	95
M51	L	43	10	78	84	84	NU 24M	NU ACE	NU ACE	NU sprint	105	105
M33	R	72	10	84	72	84	NU 24M	NU ACE	NU ACE	NU sprint	125	105
R5	R	52	1	N/A	12	12	NU 24R	N/A	NU ACE	NU sprint	80	95
R30	L	63	5	N/A	36	36	NU 24R	N/A	NU ACE	NU 3G	115	115
R1	R	68	10	N/A	48	48	NU 24R	N/A	NU ACE	NU 3G	80	85
R43	R	48	38	N/A	48	48	NU 24R	N/A	NU ACE	NU sprint	75	110
Z75	L	59	0.1	N/A	24	24	NU 24R (CA)	N/A	NU ACE	NU 3G	70	85
Z59	R	73	18	N/A	12	12	NU RP8	N/A	NU ACE	nu freedom	115	95
E3	R	55	18	24	24	24	NU RP8	NU ACE	NU ACE	NU freedom	110	105

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E16	R	42	1	4	4	4	NU RP8	NU ACE	NU ACE	NU freedom	95	105

N/A indicates that data were not collected; DNU, data not used because matched listener does not have data; CL, clarion; NU, nucleus; B, bilateral; R, right; L, left.