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Cochlear Implants in Adults: Effects of Age and Duration of Deafness on Speech Recognition

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Objective: Unexplained outcome variability exists among adults with cochlear implants (CIs). Two significant predictors are age and duration of deafness, with older patients and those with longer durations of deafness generally demonstrating poorer speech recognition. However, these factors are often highly correlated. Thus, it is unclear whether poorer outcomes should be attributed primarily to age-related declines or to the experience of auditory deprivation. Our aim was to examine the effects of aging and duration of hearing loss on outcomes for postlingually deaf adults with CIs.
Study Design: Retrospective review of adults who received CIs from 1983 to 2014.
Setting: Tertiary adult CI program.
Patients: Sixty-four adult patients with postlingual hearing loss beginning after age 12 years, full electrode insertion, normal cochlear anatomy, and availability of postoperative outcome measures.
Intervention: Cochlear implantation with 12 months or greater of device use.
Main Outcome Measures: Postoperative pure-tone averages (0.5, 1, 2, and 3 kHz) and recognition of words in sentences (Hearing in Noise Test and AzBio).
Results: Age at postoperative testing had a negative partial correlation with AzBio scores, when controlling for duration of deafness, whereas duration of deafness had a positive partial correlation with AzBio scores, when controlling for age. No other effects were identified.
Conclusion: Older age at testing was associated with poorer recognition of words in difficult sentences, suggesting that cognitive aging may negatively impact CI outcomes. Further studies are needed to examine how a long duration of auditory deprivation affects CI outcomes. **Key Words:** Adult—Cochlear implants—Deafness—Hearing loss—Sensorineural—Speech perception.

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Cochlear implants (CIs) provide benefits to most adult patients with acquired sensorineural hearing loss (1,2). Postlingually deaf adults with CIs can recognize, in open-set, approximately 70% of words in sentences in quiet (3–5). However, unexplained outcome variability remains. Previously identified predictors of speech recognition outcomes include pre- versus postlingual hearing loss, amount of residual hearing before implantation, previous hearing aid use, and hearing loss etiology (6–12). Device and anatomic factors such as partial insertion of the electrode array and congenital inner ear malformations have also been shown to negatively impact speech perception outcomes (13,14).

Two factors in particular, which are typically correlated, play roles in outcomes for adults with CIs, and deserve further exploration. These are the age of the patient and the duration of hearing loss experienced. The normal aging process is associated with changes in the central nervous system, associated with declines in processing abilities, working memory, verbal information recall, and temporal processing (15). In the CI literature, speech recognition performance has been significantly poorer for older adults using CIs (usually defined as over age 65 yr) than younger adult CI users (8,16–18), or in other cases, older adults have demonstrated a trend toward poorer performance (9,19,20). This trend is not universal, however. Examining post-CI Hearing in Noise Test (HINT) scores, Park et al. (21) did not identify significant speech recognition differences when parsing patients into age groups (<50, 50–65, or >65 yr). On the other hand, Budenz et al. (22) found that those in their older CI user cohort (>70 yr) performed worse on postimplant consonant–nucleus–consonant words and phonemes and City University of New York Sentences (CUNY) in quiet and in noise.

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Hiel et al. examined the effect of CI user age (<40, 40 to 70, and >70 yr) on hearing capacity index scores in quiet at 1, 3, 6, 12, 24, and 60 months post-CI. They found that outcomes were significantly better in their youngest group versus the older groups only at 1 year postimplantation (23).

Although older adults may generally perform more poorly than younger peers with CIs, some authors have found duration of deafness to play a greater role than age (24–28). For example, in the study by Budenz et al. (22), correlational analyses showed that poorer speech recognition initially associated with older age could actually be attributed to longer duration of deafness. Two large studies of adult CI users support these findings. Leung et al. (9) applied models of prediction to postoperative outcomes of monosyllabic word recognition in 749 adolescents and adults with CIs. In that study, duration of deafness was more strongly associated with outcomes than age. The most significant factor associated with poorer outcome was a higher ratio of duration of deafness to age at implantation, representing the percentage of life lived in deafness. Interestingly, this ratio was most predictive of outcomes for patients younger than age 65 years. Conversely, a small group of 10 patients over age 65 demonstrated the reverse: duration of deafness exceeding 25 years predicted better postoperative word recognition. The authors of that study suggested that for this older cohort, previous auditory experience might have conferred an advantage, despite a long duration of deafness. The second relevant study, and its longer-term follow-up, also examined the influence of multiple factors on speech recognition in 808 and then 2251 patients from multiple CI centers (29,10). In both those reports, longer duration of hearing loss was the factor that most strongly predicted poorer performance; however, older age at implantation also predicted poorer outcomes.

Although previous studies suggest that both older age and longer duration of deafness are predictive of poorer speech recognition abilities with CIs, two points are noteworthy. First, postoperative outcome measures of speech recognition consisted almost entirely of recognition of monosyllabic or multisyllabic words in isolation in quiet. Although word recognition serves as a reasonable assessment of a patient's access to the acoustic-phonetic properties of the speech signal, it is not as informative regarding the ability to recognize and repeat sentences, which require more intact linguistic and cognitive skills (i.e., ''top-down processing''). These skills may be particularly relevant when examining speech recognition in older patients, because older listeners tend to rely more heavily on semantic and lexical constraints, but also may demonstrate poorer performance because of added memory demands when compared with younger listeners (30,31). Second, the previous studies incorporated adult patients who may not have been truly postlingually deaf. For example, the study by Lazard et al. (10) included CI recipients whose hearing loss was deemed severe-to-profound after age 15 years. The sample in the report by Leung et al. (9) consisted of adolescents and adults who underwent implantation at age 14 years or older. It is probable that in both studies, some of these patients had significant hearing losses before their teenage years, which may have impacted their speech and language development and affected CI outcomes. It is well known that prelingual status, reflecting poorer early spoken language development, plays an enormous role in speech recognition outcomes; for prelingually deaf patients, later age at implantation negatively impacts outcomes (32,33). Including patients with prelingual hearing loss in a study of adults with CIs could skew results.

To address these two main limitations of previous reports, this study aimed to more thoroughly examine the effects of age and duration of hearing loss on CI outcomes, specifically recognition of words in sentences in quiet, for a group of entirely postlingually deaf adults. The hypothesis was that both older age and longer duration of deafness would be independently associated with poorer sentence recognition. Determining whether age or duration of deafness is most strongly related to outcomes could suggest differential approaches to managing adults with CIs. For example, discovering that the aging process, seems to contribute to poorer outcomes might suggest that older CI recipients, regardless of duration of deafness, could benefit from more intensive postoperative aural rehabilitation to improve central auditory processing. On the other hand, if duration of deafness plays the greatest role, it might suggest a greater role for postoperative rehabilitation approaches even for younger users with long durations of deafness. More generally, knowledge of factors explaining CI outcomes should assist clinicians in preoperative counseling, postoperative diagnostics for poorly performing patients, and postoperative aural rehabilitation strategies.

METHODS

Subjects

This study was approved by The Ohio State University Institutional Review Board. Charts were reviewed for all 254 adult patients who underwent cochlear implantation by five surgeons at our center from June 1983 through November 2014. Inclusion criteria for data analyses were postlingually deaf adults over age 18 years who spoke American English as a primary language; patients were considered postlingually deaf if they reported onset of hearing loss at or after the age of 12 years. This conservative cutoff of 12 years was taken as the criterion for postlingual deafness to ensure that our sample was composed exclusively of individuals with general proficiency with their primary language. All individuals had been evaluated by a staff Neurotologist at our institution and implanted with a contemporary standard CI device from Cochlear or Advanced Bionics (no MED-EL devices were used). Surgical candidacy was established with bilateral severe-to-profound sensorineural hearing loss determined by pure-tone audiogram and lack of benefit from amplification, as well as the aided speech recognition testing used at the time to determine candidacy (see Supplemental Digital Content, http://links.lww.com/MAO/A436, for details of changing candidacy requirements over time). All individuals had at least 12 months of CI experience before collection of reported outcome measures. Patients were excluded for any of the

TABLE 1. *Patient characteristics*

	N	Number (%)	Mean (SD)
Sex: female	64	36 (56.3)	
Age at postoperative testing, years	64		66.4 (15.1)
Age at implant, years	64		60.3 (15.4)
Patients with age <65 years at implant		35 (54.7)	
Patients with age >65 years at implant		29 (45.3)	
Duration of deafness, years	48		23.1 (13.8)
Duration of implant use, years	64		5.8 (4.1)
Etiology of hearing loss			
Autoimmune		2 (3.1)	
Chronic otitis		2 (3.1)	
Ménière's		10 (15.6)	
Meningitis		2 (3.1)	
Noise-induced hearing loss		9 (14.1)	
Otosclerosis		2 (3.1)	
Ototoxicity		1 (1.6)	
Progressive during adulthood		30 (46.9)	
Progressive during childhood		3 (4.7)	
Sudden hearing loss		2 (3.1)	
Unknown		1 (1.6)	
Device			
Cochlear		56 (83.6)	
Nucleus 22		2 (3.0)	
Nucleus 24		1 (1.5)	
Nucleus 24C		9 (13.4)	
Freedom		44 (78.6)	
Advanced Bionics		8 (11.9)	
Clarion		6 (9.0)	
CII		2 (2.2)	
Med-El		0 (0)	
Implanted ear			
Right		36 (56.3)	
Left		19 (29.7)	
Bilateral		9 (14.1)	
Preoperative hearing			
Better-ear PTA, dB HL	55		102.2 (14.8)
Better-ear SDS, % correct words	38		11.7 (19.2)
Best-aided bilateral HINT score, % correct	33		15.1 (16.2)
Postoperative outcomes[a]			
Best PTA, dB HL	64		26.5 (5.3)
Best AzBio score, % correct	28		72.9 (23.2)
Best HINT score, % correct	31		81.3 (19.4)

CI indicates cochlear implant; HINT, hearing in noise test sentences; PTA, pure-tone average; SD, standard deviation.
[a]Outcomes reported as best score at 12 months or greater of CI use.

following: inner ear malformation or labyrinthitis ossificans on preoperative imaging, incomplete electrode insertion at the time of surgery (based on the surgeon's operative dictation), single sided deafness as a diagnosis, or implantation with short-electrode array devices for electric-acoustic hearing. Additionally, patients were excluded if they did not have postoperative outcome data collected after 12 months or longer of CI use. Patients with unilateral and bilateral implants were included, although only nine patients had bilateral implants. Patient characteristics are listed in Table 1.

Measures

Data collected/computed were the following as primary independent variables: age at most recent postoperative testing, age at onset of hearing loss in years (per patient report), duration of deafness in years, and age at implantation. Of note, duration of deafness was computed as age at most recent postoperative testing age minus age at onset of hearing loss; this was the information available from patients' medical records. Although duration of severe-to-profound hearing loss would likely serve as a better variable to relate to postoperative outcomes (e.g., see Blamey et al. (6)), most patients did not have a longitudinal series of audiograms in the medical records, nor did we have detailed information regarding the duration of hearing aid use for most patients to use as a surrogate marker of duration of deafness. Covariates were also collected, as they could contribute to outcomes: duration of CI use, preoperative pure-tone average (pure-tone average (PTA), 0.5, 1, 2, and 3 kHz), and preoperative unaided word recognition. Information on use of preoperative ipsilateral hearing aid until the time of implantation, continued use of contralateral hearing aid after implantation, sex, and side of implantation were also assessed. Outcome measures considered in analyses were the best CI-aided ipsilateral postoperative HINT (34) total word scores (presented at 70 dB SPL soundfield) and AzBio (35) total word scores (presented at 60 dB SPL) measured in quiet at 12 months of CI use or longer, along with best postoperative CI-aided PTA, using free-field warble tones. Best postoperative PTA was defined as the lowest PTA measured at 12 months of CI use or longer. Data were included for the best postoperative testing results for patients with bilateral implants, using their best CI-aided score while listening with one implant, such that individual patients are included in data analyses only once. Mean duration of CI use at the time of postoperative testing was 6.4 years (SD 4.9 years, range 1.0–28.1 yr).

RESULTS

Details regarding statistical analyses can be found in the Supplemental Digital Content, http://links.lww.com/MAO/A436. Sixty-four patients met criteria for inclusion. Generally patients underwent postoperative assessment using one type of sentence materials, with a general change from use of HINT to AzBio at our CI center in 2011.

Before addressing our primary analyses of interest, we examined covariates to see if they have effects on outcomes. Independent samples *t*-test analyses were performed to examine whether group effects on outcome measures existed: whether the patient used a hearing aid up until the time of CI surgery (yes or no), continued use of a contralateral hearing aid in the postoperative period (yes or no), gender, side of implant, unilateral versus bilateral implants, implantation of the better or the worse ear based on preoperative PTA, and implantation before

TABLE 2. *Mean values (and SDs) and results of t tests examining factor effects on postoperative outcome measures*

	PTA (dB HL)	p Value	AzBio Sentences (% Correct)	p Value	HINT Sentences (% Correct)	p Value
Used hearing aid up until surgery						
Yes	27.8 (5.9)	0.16	65.7 (25.2)	0.29	80.8 (15.8)	0.57
No	26.6 (4.2)		76.3 (22.0)		73.4 (27.0)	
Continued use of contralateral aid						
Yes	27.4 (4.0)	0.55	68.5 (19.3)	0.54	81.2 (22.4)	0.47
No	26.4 (5.8)		74.0 (23.4)		74.0 (28.6)	
Sex						
Female	26.8 (5.1)	0.99	66.3 (27.0)	0.20	76.5 (20.5)	0.58
Male	26.9 (6.0)		75.1 (19.3)		81.1 (27.7)	
Side of implant						
Right	25.8 (5.2)	0.66	71.1 (23.8)	0.26	76.6 (25.3)	0.26
Left	26.4 (5.2)		75.9 (23.0)		80.9 (21.7)	
Unilateral or bilateral implants						
Unilateral	27.3 (5.6)	0.11	74.0 (23.6)	0.22	77.3 (24.7)	0.48
Bilateral	23.9 (3.4)		80.2 (13.1)		86.5 (11.5)	
Implanted ear (preoperative PTA)						
Better	26.8 (5.3)	0.48	63.6 (27.0)	0.18	79.6 (21.8)	0.81
Worse	28.0 (5.6)		74.6 (19.5)		77.3 (29.3)	
Date of implantation						
Before October 2005	27.3 (5.5)	0.68	68.3 (23.6)	0.19	73.9 (30.0)	0.41
After October 2005	26.7 (5.6)		74.8 (22.0)		81.1 (19.3)	

For patients with bilateral implants, side of implant is better performing ear.
PTA indicates pure-tone average.

or after October of 2005 (the median date of implantation for our center, used to evaluate whether performance was significantly better for patients with more contemporary versus earlier devices), with results shown in Table 2. Additionally, bivariate correlations were run among outcome measures and duration of CI use, better-ear unaided preoperative PTA, and better-ear preoperative SDS, with results shown in Table 3. None of these analyses revealed significant correlations of these factors with outcome measures of AzBio, HINT, or PTA.

Next, bivariate correlation analyses were performed to look for correlations among our outcome measures of AzBio, HINT, and PTA, with our main independent measures pertaining to age (age at implantation, age at postoperative testing) and duration of hearing loss. Results are shown in Table 4. Notably, postoperative AzBio and HINT scores were strongly—but not perfectly—correlated, but only eight patients had scores on both AzBio and HINT testing. Postoperative AzBio score negatively correlated with age at postoperative testing (Fig. 1). Postoperative HINT and PTA did not correlate with any of the independent measures evaluated. Importantly, and as expected, the three parameters age at implant, age at postoperative testing, and duration of deafness all correlated with each other. This supported our assumption that older patients with CIs also had longer durations of deafness, so it would be necessary to tease apart the effects of older age and longer duration of hearing loss on outcome measures.

Partial correlation analyses were performed to accomplish this goal. Age at implant and age at postoperative

TABLE 3. *Bivariate correlation analyses among outcome measures and patient factors*

		Duration of CI Use	Better-ear Preoperative PTA	Preoperative Better-Ear Unaided SDS
Postoperative PTA	*R*	−0.096	0.115	0.036
	p value	0.450	0.414	0.814
	N	64	53	45
Postoperative AzBio	*R*	−0.276	0.186	0.234
	p value	0.155	0.385	0.320
	N	28	24	18
Postoperative HINT	*r*	0.145	−0.016	0.213
	p value	0.436	0.936	0.318
	N	31	28	19

PTA indicates pure-tone average; SDS, speech discrimination score.

TABLE 4. *Bivariate correlation analyses among outcome measures and age and deafness factors*

		Postoperative PTA	Postoperative AzBio	Postoperative HINT	Age at Implantation	Age at Postoperative Testing	Duration of Deafness
Postoperative PTA	*r*	1	−0.352	−0.121	0.159	0.169	0.123
	p value		0.066	0.518	0.210	0.183	0.417
	N	64	28	31	64	64	46
Postoperative AzBio	*r*		1	0.865	−0.283	−0.394	0.320
	p value			0.006	0.144	0.038	0.146
	N			8	28	28	22
Postoperative HINT	*r*			1	−0.241	−0.212	−0.247
	p value				0.191	0.252	0.245
	N				31	31	24
Age at implantation	*R*				1	0.965	0.434
	p value					<0.001	0.003
	N					64	46
Age at postoperative testing	*R*					1	0.347
	p value						0.018
	N						46
Duration of deafness	*R*						1
	p value						
	N						

testing were so strongly correlated ($r = 0.97$) that only age at testing was included in partial correlation analyses. First, we assessed for correlations with postoperative AzBio scores. There was a moderate negative partial correlation between AzBio score and age at postoperative testing ($r = -0.66$, $p = 0.001$), when controlling for duration of deafness. There was also a significant positive partial correlation between AzBio score and duration of deafness, when controlling for age at postoperative testing ($r = 0.57$, $p = 0.007$). For postoperative HINT scores, there was no significant partial correlation between postoperative HINT score and age at testing ($r = -0.18$, $p = 0.412$) when controlling for duration of deafness, nor was there a significant partial correlation between HINT score and duration of deafness ($r = -0.16$, $p = 0.462$) when controlling for age at testing. Finally, for postoperative PTA, there was no significant partial correlation between PTA and age at testing ($r = 0.10$, $p = 0.491$) when controlling for duration of deafness, nor for PTA and duration of deafness ($r = 0.08$, $p = 0.603$) when controlling for age at testing. To summarize, the only significant findings were that there was a negative partial correlation between AzBio score and age at testing, as well as a positive partial correlation between AzBio score and duration of deafness.

Two final considerations regarding the effects of aging on AzBio scores, but not on HINT scores, needed to be addressed: first, it could be that patients who were tested using AzBio sentences were older than those tested using HINT sentences, potentially leading to differential effects of age on patients tested using AzBio versus HINT sentences. This possibility was examined using an independent-samples *t* test, and no mean difference in age was found for those tested using AzBio sentences (mean 66.4 yr, SD 13.2) and those tested using HINT sentences (mean 68.1 yr, SD 16.8). Second, it could be that patients tested using AzBio sentences had better residual hearing before implantation than those tested using HINT sentences. Again, no mean difference in preoperative PTA was found for those tested using AzBio sentences (mean 104.1 dB HL, SD 10.6) and those tested using HINT sentences (mean 101.2 dB HL, SD 16.4).

DISCUSSION

The factors contributing to postoperative speech recognition outcomes in adult CI users are incompletely understood. Two factors previously examined were patient age and duration of deafness, with inconsistent findings. Previous studies have included heterogeneous samples of adult patients, some of whom may have experienced prelingual hearing loss, which is known to affect outcomes. Our goal was to further examine the contributions of age and duration of deafness on outcomes within a sample of exclusively postlingually deaf adult CI users.

Both age and duration of deafness were independently associated with AzBio scores; older patients tended to perform more poorly on recognition of more challenging sentences. Interestingly though, in this sample of postlingually deaf CI users, a longer duration of deafness actually predicted better AzBio scores. This finding was surprising and contrary to the findings of most previous studies, in which longer duration of deafness tended to correlate with poorer speech recognition (25–28). However, the present study differed in that it incorporated only patients whose hearing loss started after age 12 years, thus ensuring that all patients were truly postlingually deaf. Additionally, those studies generally assessed speech recognition using isolated words, whereas we used sentence materials.

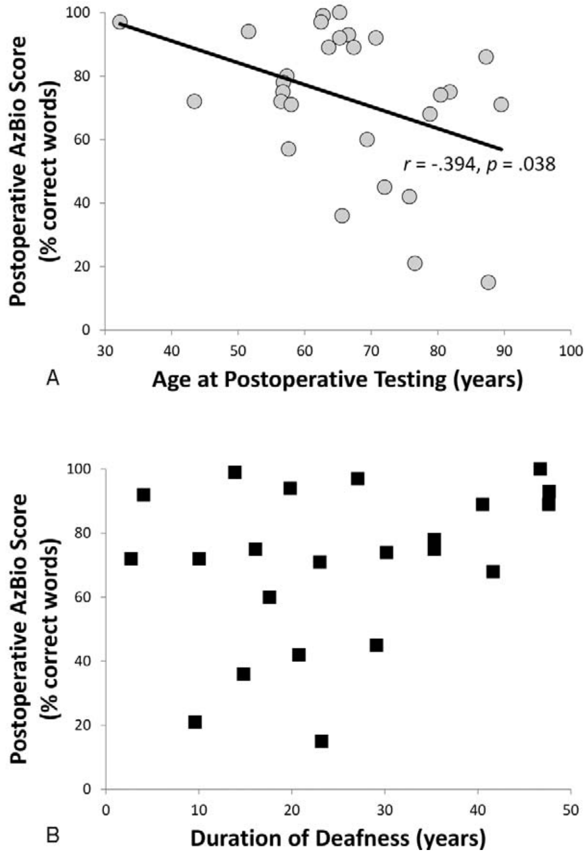

FIG. 1. Scatter plot of postoperative AzBio score versus age at postoperative testing (*A*), and postoperative AzBio score versus duration of deafness (*B*). Trendline in (*A*) shows significant negative bivariate correlation between AzBio score and age at postoperative testing. No significant bivariate correlation was identified between AzBio score and duration of deafness.

Our findings are somewhat consistent with those reported by Leung et al. (9), who reported that in older adult CI users (65 yr of age and older), patients with longer duration of hearing loss actually performed better, when the duration of deafness was 30 years or more. The authors of that study purported that ''a foundation of central auditory processing in the older cohort may actually mitigate the disadvantages of advanced age at implantation.'' As a result, elderly patients may be able to capitalize on their retained auditory and language abilities to overcome age-related declines in speech processing. This idea is consistent with the findings of several groups who identified, using electrophysiological measures, stable phonetic memory traces in patients with CIs, even after many years of deafness (36–39).

Although Leung et al. suggested a possible neutral or even advantageous effect of age on CI outcomes, our results are in agreement with other studies suggesting a detrimental effect of the aging process, independent of duration of deafness (8,16,17). This detrimental effect was observed for the relatively difficult AzBio sentences. On the other hand, no significant correlations were found between either postoperative PTA or HINT and age at postoperative testing. These latter tasks are arguably easier than AzBio sentence recognition (the first consists of simply responding that a tone was heard, and the second involves recognizing short, easy, high-context sentences). The AzBio sentences consist of more difficult sentences that are generally longer in length, and are spoken by multiple talkers who were instructed to speak in a casual style, rather than in a clear, enunciated style. Support for the more challenging nature of the AzBio sentences comes from a study by Gifford et al. (4), who compared speech perception performance of 156 adult, postlingually deaf CI users alongside 50 hearing aid users, using sentence recognition in quiet with both HINT and AzBio sentences. In that study, only 0.7% of CI users reached ceiling performance for AzBio as compared with 28% for HINT sentences.

Work from several authors supports the idea of an aging-related decline that could contribute to poorer speech recognition in older adults: Tremblay et al. (40) noted delayed auditory cortical processing times in both older adults with normal hearing and peers with hearing loss when compared with younger individuals. Aging may contribute to a unique type of disorder of central auditory processing not solely explained by declines in peripheral auditory sensitivity (41–43).

This study should be appreciated in the context of literature supporting the notion that neurocognitive processes have an influence on CI performance—processes that may be affected by aging itself. Working memory is one such process and has been found to explain 10 to 30% of variability in speech recognition in noise for hearing aid users, although results are not unanimous (44–47). Another cognitive skill that has been examined as contributory to post-CI performance is perceptual closure, the ability to create meaningful linguistic wholes from sensory fragments (48). The influence of aging on these and other cognitive factors thought to affect post-CI speech recognition is an area of active investigation by our group.

Several limitations should be noted regarding the findings of this study. First, during 2011, our center's standard postoperative assessment testing measure changed from HINT to AzBio sentences. AzBio sentences are thought to have greater ecological validity and are known to be more challenging than HINT sentences (4). Certainly, a single measure of recognition of words in sentences throughout the study period would have been ideal. On the other hand, including both HINT and AzBio scores permitted us to differentially examine for effects of age and duration of deafness on recognition of the easier HINT versus the more challenging AzBio sentence materials.

Second, several patients did not have complete data for a number of measures. Clearly, this limitation introduces a confounding issue regarding selection bias: perhaps the patients who were performing very well (or very poorly) failed to follow up for longer-term testing. This finding reaffirms the need for an organized, prospective approach to clinical data collection (49).

A third limitation was that information regarding progression of hearing loss (i.e., when hearing loss became severe) was not available from medical records, so our measure of duration of deafness was not ideal. Several studies have identified longer duration of severe hearing loss as associated with poorer CI outcomes, whereas we were limited to considering duration of any degree of hearing loss. Additional limitations of the current study include its retrospective nature with inherent observational bias associated with inclusion of data only from patients who followed up. Although a central motivation of this study was to limit heterogeneity in a sample of CI users, as the study spanned a period over 30 years, we could not account for evolving techniques and practices in the operating room and audiology booth. This concern is tempered, however, by the fact that outcomes did not differ significantly for patients implanted before 2005 versus those implanted after 2005.

CONCLUSION

In postlingually deaf adult CI users, younger age was associated with better postoperative AzBio sentence recognition; surprisingly, longer duration of hearing loss correlated positively with sentence recognition. Our findings suggest that neurocognitive declines associated with aging may play a negative role in outcomes among adult CI users. It is possible that older adults with long durations of deafness may be able to better capitalize on retained language abilities from a previously developed foundation of central auditory and language processing. Additional studies are needed to investigate the effects of prolonged auditory deprivation on speech processing by older adults with postlingual deafness.

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