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Clinical and Psychosocial Risk Factors of Hearing Outcome in Older Adults with Cochlear Implants

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Abstract

Objectives—To identify psychosocial determinants of speech perception (SP) outcome in older adults after cochlear implant (CI) surgery.

Study Design—Retrospective study

Methods—Subjects received their CI at 45y or older and had at least 12m of device experience. Independent variables consisted of the Charlson co-morbidity index, history of depression, hearing loss and amplification use, residential status, education and gaps in SP data. Regression models were evaluated for associations with open-set SP gains at 3m and 12m, and in the 6m-to-12m time interval.

Results—Every 10% increase in the proportion of life spent using a hearing aid was associated with a 2–3% decrement in SP gain within the first 3 months of CI use. Later and overall SP gains were negatively impacted by poorer general health, lower education level and residence in assisted-living facilities. Patients with gaps in SP data at later time points were also more likely to have poorer health and to live in assisted living facilities. The absence of 2 or more evaluations was associated on average with 6.3% lower SP outcome compared to subjects with 1 or fewer missing data points. Age at CI had no influence on the size of incremental gains in SP after CI.

Conclusions—Auditory deprivation and the influence of psychosocial and health factors on engagement in post-surgical rehabilitation services, may impact CI outcomes more than has been previously reported. These findings have policy implications and highlight the need for more effective delivery of hearing rehabilitation services to an aging population.

Keywords

older adult; speech perception; psychosocial; general health; cochlear implant outcomes; co-morbidity

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Introduction

Hearing loss prevalence approximately doubles every decade of life from the second through seventh decades ¹. Currently, over 16 million adults in the United States over 70 years of age have hearing loss, ² and more than 150,000 of these adults likely have severe to profound sensorineural hearing loss making them eligible for cochlear implant (CI) intervention ¹. Aging of the population and changing candidacy requirements are likely to result in a steady growth in the number of older individuals who meet auditory criteria for the CI.

Hearing disability poses obvious challenges to communication, which forms the basis of social interchange and the maintenance of social networks. There is also growing evidence that hearing loss may accelerate disability in several other domains of the aging experience. Prospective aging studies have found, for example, that hearing loss is an independent risk factor for dementia ³, poor general health ⁴ and falls ⁵. Findings in other studies suggest possible associations with functional impairment ^{6,7} and mortality ⁸. Hearing intervention therefore has significant relevance for successful aging, the preservation of independence and social participation for as many years as possible.

There has been limited if any attention paid to how the unique challenges of aging including downstream effects of hearing loss itself impact the outcome of CI rehabilitation. Declining social functioning ^{7,9–11} for example may place older patients at a disadvantage in their ability to fully engage in the services, practice and self-motivation required for successful hearing rehabilitation with hearing aids or CIs. A systematic review of the CI literature ¹² revealed very limited efforts to measure psychosocial influences on speech perception (SP) outcomes, communication function or quality of life. Length of deafness, baseline SP and age at CI surgery were the predominant independent variables reported in these analyses. Studies examining the relative benefits experienced by younger versus older patients usually demonstrated comparable results, although three papers reported smaller or slower gains in older patients ^{13,14,15}. Consistent with the first author's unpublished observations, Verniere et al ¹³ reported a significant correlation between SP and quality-of-life measures in younger but not older patients.

It is reasonable to postulate that pervasive effects of hearing loss on function and quality of life in the later years pose additional demands on the rehabilitation process beyond the mere restoration of SP. A conceptual model has been proposed that shows the continuum of consequences of hearing loss and the intervening factors that mediate perceived and actual effects of the CI intervention ^{12,16}. Such a model can guide evaluations of how these factors interact to affect communication and other functions critical to the maintenance of independence during aging, as well as health-related quality of life (HRQoL). This study's first goal was to determine how hearing history, medical history and psychosocial factors differentially influence SP results at early versus later phases of the SP growth-curve following CI surgery. We evaluate whether hearing history has a greater influence on early gains while general health and psychosocial factors reflecting the capacity to engage in sustained learning and practice of new listening skills influence later gains. The study's second goal is to examine patterns of gaps in evaluative measures and to identify risk factors for incomplete engagement in the rehabilitation process as well as its impact on SP results.

Methods

This is a retrospective cohort study of adults with severe to profound sensorineural hearing loss who first received CI surgery and audiological services at 45y of age and older between 2000 and 2008 at the Johns Hopkins Listening Center. Subjects were included in the study if they were English speaking and had at least 1 year of CI experience. After obtaining approval from the Johns Hopkins Institutional Review Board, the patient database was queried for a list of these patients, and their CI candidacy questionnaires and clinical records were examined. Information was abstracted about the history of hearing loss, other co-morbidities, psychiatric history, education history, work history, and living arrangements including type of facility and co-habitation. Details of the surgical procedure including number of electrodes inserted in the cochlea, intra- and post-operative complications and discharge status were also noted. The Charlson co-morbidity index (CCI)¹⁷ was calculated based on each subject's known diagnoses. A combined age and co-morbidity index (CACI) was also calculated according to Charlson et al.¹⁸.

Audiological data were abstracted from clinical encounters during CI candidacy, designated time point C0, and at post-activation time points roughly corresponding to 3, 6 and 12 months, designated as C1, C2 and C3, respectively. Baseline pure tone average (PTA) was calculated separately for each ear, as the average of pure tone thresholds measured in a sound booth at 500Hz, 1000Hz and 2000Hz, and then averaged for both ears. Baseline and post-operative open-set SP scores were also abstracted. Consonant Nucleus Consonant (CNC) word lists and the Hearing in Noise Test (HINT) sentence lists conducted in quiet were examined to assess SP performance. The CNC test uses a series of 50 monosyllabic words presented each time with a carrier phrase¹⁹. Subjects were scored on the number of correctly repeated words (CNC-W score) and individual phonemes (CNC-P score). The HINT test was presented as a series of 20 sentences in quiet with no carrier phrase²⁰. Recordings of the SP tests were presented at 70dB SLP and scored as the percentage of correct responses (range 0 to 100%). Subjects were allowed to adjust their hearing aids (preoperatively) or speech processor (postoperatively) for optimal perception of speech. Gaps in outcome data are referred to as "missing outcomes" or "missingness".

Statistical Analysis

In order to identify potential analysis bias associated with missing outcome data at each time point, t-tests were used for continuous variables and Fisher's exact test for categorical variables, to compare patients with available versus missing evaluation outcomes at each time point. A pattern mixture analysis was performed to where we examine patterns of missingness and their potential effect on subsequent analyses²¹. Linear mixed model analyses were performed to evaluate within-patient changes in each of the three SP outcomes between baseline and subsequent post-activation time intervals. A step-wise approach was used to establish a model that evaluated the relationships between patient characteristics and SP gains for C0 to C1 (early gain), C2 to C3 (late gain) and C0 to C2/C3 (overall gain). For the late scores (at C2/C3) and overall gains (C0 to C2/C3), evaluations at C2 were used if there were none available at C3. The criteria for a factor's inclusion in the final model was a p-value for entry of 0.1 and a p-value for removal of 0.2. Some

exploratory analyses of relationships between independent variables were conducted with either χ^2 analysis or multiple regression models.

Results

Demographic, Social and Medical Characteristics

A cohort of 219 consecutively implanted adults met criteria for inclusion in this study. The racial and ethnic contribution of the cohort was 89.0% Caucasian, 7.8% African American and 1.4% Asian; 56% were female (Table I). The mean (SD) age at CI was 67.1 y (11.1), with 130 subjects aged 65 y or older. Previous hearing aid history was available for 160 subjects who on average (SD) used conventional amplification 37.9% (25.5) of their lives prior to CI surgery. A full insertion was achieved in 217 cases. Post-operative complications occurred in 18 cases (8.3%) of which 12 had transient or prolonged dizziness, 2 had wound complications, 2 had transient facial paresis, 1 had pneumonia and 1 had pseudo-membranous colitis. Eight (4%) patients were admitted following surgery; 208 were discharged to home on the day of surgery. Two patients had received bilateral CIs at the time of the study.

A review of candidacy evaluations including the psychological evaluation, medical history and intake questionnaire are shown in Table I. Forty-four (20%) patients had a diagnosis of depression, 118 patients had an absence of depression, and depression status was unknown for 57 patients. One hundred fifty-two (69.5%) subjects had no significant health problems (CCI=0), 36 (16.4%) had a CCI of one, 21 (9.6%) had a CCI of two and 10 (4.5%) had a CCI of three or higher. The CACI scores had a mean (SD) of 2.7 (1.6). Seventy-one (32.4%) subjects had some college or higher education, and 44 (20.1%) had a high school diploma, a GED or less education (Table I). Thirty-four (15.5%) individuals lived alone, 153 (70%) lived with a spouse, domestic partner or other family member and 12 (5.5%) lived in an assisted-living facility. There was no family support or involvement for 16 (7.3%) subjects. Neither the occurrence of peri-operative complications nor the need to be admitted after surgery were found to be related to the age at CI, morbidity score, residential status, education level or family involvement (statistics not shown).

Nine subjects experienced the onset of hearing loss in the pre- or peri-lingual period; 205 had post-lingual onset of hearing loss, which occurred during adulthood in most cases. At the time of CI, the mean (SD) PTA of both ears was 92.4 (15.5) dB SPL. The mean (SD) proportion of life spent wearing at least one hearing aid averaged was 37.8% (26) (Table I). The mean (SD) proportion of life spent with hearing loss was 48.9% (28.4).

Post-Operative Speech Perception Trends

Baseline speech perception (SP) was measured within several weeks before CI surgery (time C0), and mean (SD) post-activation intervals for visits C1, C2 and C3 were 3.4 (0.9), 6.5 (0.6) and 11.9 (1.2) months, respectively. Following CI surgery, mean SP scores changed over time, with an initial sharp increase and then a leveling off of gains from C1 to C3, as demonstrated for CNC-P scores in Figure 1. Having two or more missing evaluations was

associated, on average, with a score decrement of 6.3% relative to one or no missing evaluations ($p < 0.05$). There were similar findings for CNC-W and HINT sentences.

Overall Gains at 1 year

A step-wise regression analysis for overall SP gains at 1 year (C0 to C3 or C2, if C3 is not available) revealed an inverse relationship to co-morbidity indices: including CCI for HINT (model I, Table II) and CACI for all three outcome measures (model II, Table II). Compared to residents in assisted-living facilities, subjects with unknown residence status (L4 in Table II) were more likely to experience larger overall SP gains at one year for all outcome measures in both models. Relative to subjects with a high school diploma or less education, those with a college education (E1 in Table II) or unknown status (E2 in Table II) were more likely to have larger overall gains at 1 year. Missing two or more evaluations was associated with smaller overall gains in CNC-W scores at 1 year. Speech perception scores at C0 had a large inverse effect on overall SP gains (C0 to C2/C3).

Early versus Late Speech Perception Gains

Age at CI had no effect on the size of early, late or overall performance gains (Table II). Hearing history influenced 3-month SP gains relative to baseline; psychosocial and medical history were more important determinants of later functional gains (Table II). Up to 48% of variability in early gains (C0 to C1) of HINT was explained by scores at C0 and the proportion of life spent with a hearing aid (Table II). There was, on average, a 2 to 3% decrement in early SP gain for every 10% increase in the proportion of life with a hearing aid. There was an inverse relationship between SP gains from C0 to C1 and baseline scores (SP at C0), possibly related to ceiling effects.

Medical co-morbidity status, particularly CACI (model II, Table II), had a significant inverse relationship with later performance growth from time C2 to C3, but had limited or no influence on early SP gains (C0 to C1). Relative to residence in assisted-living facilities other residential categories were associated with larger late gains (C2 to C3) in CNC-P and CNC-W scores (Table II), but had no demonstrable effect on early gains. Similarly, a diagnosis of depression relative to no depression, was also associated with larger late gains, but had no effect on early performance gain.

Larger CNC-W gains during the C2 to C3 time interval were associated with college or higher education (E1) compared to individuals with high school or less education (model I, Table II); unknown education status (E2) had an opposite effect on later SP gains, however (Table II) to that observed for overall gains (see Table II).

Predictors of Gaps in Evaluations

Speech perception results were not available for all time points in many patients (Table III). CNC-P, CNC-W and HINT in quiet were administered concurrently at the same clinical encounter in over half the patients. Single tests and a variety of instrument combinations were used in other patients. Outcome data for each instrument were not available at all time points in 3 to 4% of subjects. In some cases other SP tests were used, particularly at time C0 to evaluate CI candidacy.

Subjects lacking evaluation outcomes for CNC-P, CNC-W and HINT at time C1 reported longer periods of hearing loss (data not shown) compared to those with outcomes (Table IV). A similar relationship was found for proportion of life with a hearing aid although only for HINT in quiet. Although no systematic differences were identified between subjects with and without available evaluation outcomes at the intermediate time point (C2), several were found at the latest time point (C3). Subjects without CNC-P and CNC-W data at time C3 were more likely to be female and to have less family involvement as assessed and documented by the implant audiologist. There were four times as many subjects without scores for CNC-P, CNC-W and HINT in quiet tests at time C3 residing in assisted-living facilities. There was also a larger likelihood for subjects without known residential status to have gaps in SP data. The lack of CNC-P and CNC-W scores at time C3 was also associated with higher co-morbidity indices on CCI and CACI scales (Table IV).

Discussion

This study demonstrates progressive gains in SP in a heterogeneous cohort of middle age to older adults following CI surgery. Whereas initial gains were quite rapid, on-going improvement was slower but still significant in its contribution to overall performance. A novel finding in this study was the demonstration of a differential effect of hearing history, general health, psychosocial and socioeconomic factors on early versus later phases of SP growth within the first year following CI surgery (Figure 2). The proportion of life spent using a hearing aid was a determinant of early SP gains within the first 3 months after CI surgery. Incremental gains over the second 6 months of the first year and cumulative gains over the first year, by comparison, were more dependent on education level, residential status, general health status and the history of depression. The unavailability of SP data from two or more evaluations was also associated with significantly lower SP performance, and provided additional insights into risk factors for poor outcome that are possibly linked to levels of engagement in the rehabilitation process. Alternatively, less time may have been available during appointments for testing due to the need for additional counseling and programming. The pattern mixture model is a well-established method in biostatistics²¹ used to assess missingness and its impact on outcomes, an approach that should be applied more routinely in clinical studies of CI outcomes

Age at CI surgery did not have a demonstrable influence on either SP results or the occurrence of missing data. Unlike Chan et al¹⁴ who report slower early gains in SP performance by older adults compared to younger adults, this study did not identify any demonstrable effect of age at CI on the magnitude of SP growth. This discrepancy may result from the small sample size which limited the ability to correct for confounding effects such as length of deafness. This study furthermore supports the findings of several others¹², that CI surgery is safe and well tolerated as an outpatient procedure across the full age range including the elderly, even when moderate to severe co-morbidities are present.

Although likely an underestimate of the duration of hearing deprivation, the proportion of life with a hearing aid was more consistently reported in the medical record than the duration of deafness, which is subject to variable interpretation. Patients without available SP evaluations at time C1 were more likely to have longer duration of hearing loss and

larger proportion of life spent using hearing aids (Table IV). The effect of hearing deprivation on early SP performance with a CI may therefore be worse than reported using available measured results alone.

These results have policy implications at a time when Centers for Medicare & Medicaid Services rules restrict coverage of CI surgery to older adults with more severe levels of hearing loss than is currently allowed by the Food and Drug Administration²². The findings in this study suggest that the resulting prolongation of ineffectual amplification may reduce the benefit of a CI when finally acquired. Associated disabilities in other functional and health domains^{3–8} may also result in mounting challenges to the aging experience. Our findings therefore support policies that encourage early access to hearing technologies and rehabilitation services that provide the best chance for improved communication.

Later gains in SP were influenced by risk factors that may be relevant to the level of engagement in post-operative CI services. For the first time to our knowledge, poor general health status (CCI and CACI) was shown to have a negative impact on SP performance after CI surgery (Table II). Missing SP data at time C3 was associated with unfavorable co-morbidity indices, suggesting that health concerns may reduce the sustainability of engagement with rehabilitation services and practice that support ongoing improvement. Although the risk of peri-operative morbidity was low in this cohort of older adults, counseling during the candidacy process should include discussion of the added uncertainty of achieving desired improvements in SP in the setting of poor general health.

The apparent benefit of a depression diagnosis on late SP gains is more likely to reflect the advantages of previous or on-going treatment on sustained engagement in the rehabilitation process. Depression is reportedly improved following CI intervention²³; however, undiagnosed and untreated depression may impede sustained effort, motivation and optimism required to realize continued late benefits. These findings suggest that untreated occult depression influences sustained improvement in performance with the CI and should be explored during the candidacy process.

Residential status is likely to be a marker of patient independence as well as the availability of others in the home for social interaction, moral support and logistical assistance. Indeed, there were smaller late gains in SP for the assisted living group compared to all other resident groups (Table II) independent of health status and age. Subjects with missing evaluations at later time points were more likely to be residents in assisted living facilities (Table IV). A possible explanation for both observations includes reduced participation in programming, rehabilitation services or practice due to logistical considerations, progressive fragility or cognitive decline.

We found that less education was associated on average with poorer overall SP gains at 1 year after CI surgery (Table II). Yet unlike health and residential status, education status was not found to be a risk factor for missing data. It is therefore unlikely that lack of engagement in post-CI services by less educated individuals would explain smaller SP gains. Alternative explanations worthy of investigation include the effects of cumulative noise-related injury and more prolonged periods of sound deprivation due to delayed intervention, both of which

may be associated with lower education and socioeconomic status²⁴. Contradictory findings within the C2–C3 interval may result from the small sample size. Given the larger samples for the C0 to C2 or C3 analysis, however, there is greater confidence in the findings that lower-education is associated with a high risk of smaller cumulative gains.

Instrument ceiling effect was a limitation in this study. The magnitude of early SP gains for example had a strong inverse relationship with baseline scores, which may result from the fact that the former was derived from the latter. The inclusion of this factor may therefore serve to adjust for this confounder resulting in the revelation of other predictors in the logistic model. We do not know how generalizable the results are to the larger population of older CI candidates. The relatively small dataset available to analyze C2 to C3 change, for example, may not be representative of the original patient cohort, and the general CI population. These uncertainties should not however diminish this study's potential value as a first approximation of audiological, general health and psychosocial influences of rehabilitation outcome with the CI in older adults.

Although this study focuses on communication capacity in the form of SP, it identified important links to psychosocial dimensions of life that have relevance to functional performance and ultimately, quality of life. Continual gains in CI performance is desirable for all patients, but particularly those who must overcome the associated challenges of aging including declines in health status⁴, cognitive function²⁵ and role function⁵. Our ability to enhance sustained gains in communication capacity and performance will likely yield improvements in general function and quality-of-life outcomes and realize greater cost-effectiveness of the CI intervention. A conceptual model is helpful in plotting the interactions between biological, individual and environmental factors, to produce an array of functional and quality-of-life outcomes¹². An understanding of these relationships can help to identify candidates' greatest risks for suboptimal progression and possible strategies for mitigating them. Auditory rehabilitation services for example may help patients who are disadvantaged by less robust social networks and at risk for early cognitive decline^{25,26}. They could also benefit from provision of these services and device programming at convenient locations in-person or remotely by computer. Social enrichment programs and the opportunity to practice new communication skills could further aid these efforts. As shown in a conceptual model of patient outcomes adapted for hearing loss by Clark et al¹² from Wilson and Cleary¹⁶, findings from this study highlight a possible feedback effect of functional status on sustained SP gains with the cochlear prosthesis (Figure 3). This effect is further mediated by individual and environmental characteristics that were directly investigated in this study, including health, depression, education level and residence status. A more refined understanding of these relationships at the population level may inform the future evolution of clinical services and public policies that optimize functional outcomes and cost effectiveness of cochlear implantation in older adults.

Conclusions

Cochlear implantation is a safe and effective intervention for severe to profound sensorineural hearing loss in adults of all ages. Age at implantation is not a clinically significant predictor of SP gains with a cochlear implant, but delayed intervention reflected

by proportion of life spent with a hearing aid has a significant negative impact on early performance gains. Speech perception gains in the latter half of the first year after CI surgery were negatively influenced by factors that may limit engagement in the rehabilitation process, including poor general health, residence in an assisted living facility and lower socioeconomic status reflected by education level. These trends strongly support early CI intervention to limit disadvantages imposed by hearing deprivation, advancing age and possible downstream effects on cognitive function, general health and quality of life.

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Figure 1.

Mean CNC-P scores change over time with a sharp increase at visit C1 (3m post-activation) followed by a leveling off at visit C2 (6m post-activation) and C3 (12m post-activation). The linear mixed model shows a strong effect of visit with a plateau effect over time. The absence of evaluations at two or more post-operative time points has a significantly negative effect on outcome. CNC-P Consonant Nucleus Consonant Phoneme test.

Figure 2.

Summary of patient characteristics shown in this study to influence speech perception gains. C0 pre-operative baseline; C1 first post-activation time point (approximately 3m); C2 second post-activation time point (approximately 6 m); C3 third post-activation time point (approximately 12m); SP speech perception; propLifeHA proportion of life spent using hearing aids

Figure 3.

An adaptation of Wilson and Cleary's conceptual model of patient outcomes¹⁶ showing a continuum of the consequences of hearing loss and the intervening variables that mediate cochlear implant (CI) outcomes. Relationships identified in this study are indicated in italics, and include a proposed feedback of functional status (broken line with arrow) and its sustained influence on speech perception with the cochlear prosthesis

Table I

Characteristics of the study cohort

		N (%)
Gender	Male	96 (44)
	Female	123 (56)
Race	African American	17 (7.8)
	Asian	3 (1.4)
	White	195 (89)
	Other	4 (1.8)
Age at CI (y)	45–55	35 (16)
	56–65	54 (24.6)
	66–75	67 (30.6)
	76–85	51 (23.3)
	86–95	12 (5.5)
Proportion of life using hearing aids (PropLifeHA)	0–0.2	47 (21.5)
	0.2–0.4	50 (22.8)
	0.4–0.6	29 (13.2)
	0.6–0.8	18 (8.2)
	0.8–1.0	16 (7.3)
	Unknown	59 (27)
Charlson Comorbidity Index (CCI)	0–1	152 (69.4)
	1–2	36 (16.4)
	2–3	21 (9.6)
	3–4	9 (4.1)
	4–5	1 (0.5)
Combined Age & Cormorbidity index (CACI)	0–2	46 (21)
	2–4	111 (51.7)
	4–6	52 (23.7)
	6–8	9 (4.1)
	8–10	1 (0.5)
Depression	Yes	44 (20.1)
	No	118 (53.9)
	Unknown	57 (26.0)
Education	High school diploma or less	44 (20.1)
	Some College or higher	71 (32.4)
	Unknown	104 (47.5)
Residential status	Living at home with other(s)	153 (69.9)
	Living at home alone	34 (15.5)

		N (%)
	Assisted living facility	12 (5.5)
	Unknown	20 (9.1)

Table II

Stepwise Regression Models for Early and Later Gains following Cochlear Implantation

	Overall Gains (C0 to C2 or C3) ^a				Early Gains (C0 to C1)				Late Gains (C2 to C3)			
	CNC-P	CNC-W	HINT		CNC-P	CNC-W	HINT		CNC-P	CNC-W	HINT	
Model I^b												
N	63	64	77		49	51	68		34	34	52	
R ²	0.55	0.25	0.57		0.46	0.24	0.40		0.31	0.36	0	
Age at CI (y)	-	-	-		-	-	-		-	-	-	
CCI	-	-	-9.11 ^{†††}		-	-	-		-	-	-	
Mean PTA (dB)	-	-	-		-	-	-		-	-	-	
SP at C0 (%)	-0.79 ^{†††}	-0.69 ^{†††}	-0.88 ^{†††}		-0.69 ^{†††}	-0.55 ^{††}	-0.78 ^{†††}		-	-	-	
PropLifeHA (per 0.1)	-	-	-		-2.16 ^{††}	-2.62 ^{†††}	-		-	1.71 [†]	-	
Education ^c	E1: 17.0 ^{††} E2: 12.5 [†]	-	E1: 12.8 ^{††}		E1: 7.9 [†]	-	-		E2: -10.8 [†]	E1: 13.8 ^{††}	-	
Depression ^d	-	-	-		-	-	-		D1: 8.0 ^{†††}	D1: 7.4 [†]	-	
ResStatus ^e	L4: 11.3 [†]	L4: 15.1 ^{††}	L4: 22.4 ^{†††}		-	-	-		L3: 15.4 ^{†††} L4: 14.4 ^{†††} L2: 7.6 [†]	L3: 11.8 ^{††} L4: 9.4 [†]	-	
Missing >1 ^f	-	-17.2 ^{††}	-		-	-	-		-	-	-	
Model II^b												
N	63	64	77		49	51	68		34	34	52	
R ²	0.57	0.28	0.61		0.46	0.24	0.48		0.51	0.37	0	
CACI	-2.6 [†]	-2.8 ^{††}	-6.45 ^{†††}		-	-	-6.1 ^{†††}		-3.8 ^{††}	-3.7 ^{††}	-	
Mean PTA (dB)	-	-	-		-	-	-		-	-	-	
SP at C0 (%)	-0.8 ^{†††}	-0.72 ^{†††}	-1.00 ^{†††}		-0.69 ^{†††}	-0.55 ^{††}	-0.86 ^{†††}		-	-	-	
PropLifeHA (per 0.1)	-	-	-		-2.16 ^{††}	-2.62 ^{†††}	-2.40 ^{††}		1.26 ^{††}	-	-	
Education ^c	E1: 15.6 ^{††} E2: 11.3 [†]	-	E1: 21.8 ^{†††} E2: 16.39 ^{††}		E1: 7.9 [†]	-	-		E2: -14.5 ^{†††}	E2: -13.4 ^{††}	-	

	Overall Gains (C0 to C2 or C3) ^a			Early Gains (C0 to C1)			Late Gains (C2 to C3)		
	CNC-P	CNC-W	HINT	CNC-P	CNC-W	HINT	CNC-P	CNC-W	HINT
Depression ^d	-	-	-	-	-	-	-	D1: 9.89 ^{††}	-
ResStatus ^e	L4: 13.0 ^{††}	L4: 16.0 ^{††}	L4: 23.8 ^{†††}	-	-	-	L2: -7.0 [†]	L3: 8.3 ^{††}	-
Missing > 1 ^f	-	-16.1 ^{††}	-	-	-	-	-	-	-

C0 pre-operative baseline; C1 first post-activation time point (approximately 3m); C2 second post-activation time point (approximately 6 m); C3 third post-activation time point (approximately 12m); CCI Charlson Comorbidity index; CACI Combined Age and Comorbidity Index ; CNC Consonant Nucleus Consonant phoneme (P) and word (W) tests; HINT Hearing in Noise Test; PTA pure tone average; SP speech perception; PropLifeHA proportion of life spent using hearing aids; ResStatus residential status

^aEvaluation results from C2 were used if none were available from C3

^bStepwise Model I contains age at CI and CCI as independent variables, whereas Model II replaces these factors with a combined age and comorbidity index. Criteria for inclusion in the final model were a p-value for entry of 0.1 or less and a p-value for removal of 0.2 or more.

^cEducation: Reference variable – High school education or less; E1 college education or higher; E2 education unknown

^dDepression: Reference variable – no depression; D1 depression present

^eResidential status (ResStatus): Reference variable –Assisted Living; L2 Living alone; L3 Not living alone; L4 Unknown living arrangements

^fMissingness (Missing>1): Outcome data missing at 2 or more time points relative to data missing at 1 or no time points

[†] p<0.1;

^{††} p<0.05;

^{†††} p<0.005

Table III

Number (percent) of evaluations with available outcome data at each time point

	CNC-P	CNC-W	HINT
C0	136 (62.1)	140 (63.9)	155 (70.8)
C1	128 (58.4)	131 (59.8)	143 (65.3)
C2	137 (62.6)	139 (63.5)	143 (65.3)
C3	133 (60.7)	133 (60.7)	137 (62.6)
Any time point	211 (96.3)	211 (96.3)	213 (97.3)

C0 pre-operative baseline; C1 first post-activation time point (approximately 3m); C2 second post-activation time point (approximately 6 m); C3 third post-activation time point (approximately 12m); CNC Consonant Nucleus Consonant phoneme (P) and word (W) tests; HINT Hearing in Noise Test

Table IV

Distinguishing characteristics of patients with available versus unavailable evaluation outcomes

	Evaluation outcomes available	Evaluation outcomes unavailable	p-value
C1 evaluation			
Length of Hearing Loss (y)	Mean (SD)	Mean (SD)	
CNC-P	37.25 (20.30)	48.11 (25.30)	.0488
CNC-W	37.20 (20.92)	48.85 (24.68)	.0388
HINT	35.65 (21.86)	51.77 (21.27)	.0034
PropLifeHA	Mean (SD)	Mean (SD)	
HINT	0.34(.23)	0.48(.28)	.0016
C3 evaluation			
Gender	Male (%)	Male (%)	
CNC-P	63.91	44.19	.0041
CNC-W	64.66	43.02	.0016
Family involvement	No/Yes/Unknown (%)	No/Yes/Unknown (%)	
CNC-P	3.76/93.23/3.01	12.79/83.72/3.49	.0408
CNC-W	3.76/93.23/3.01	12.79/83.72/3.49	.0408
Residential Status	AL/ILA/ILNA/Unknown (%)	AL/ILA/ILNA/Unknown (%)	
CNC-P	2.26/15.04/78.20/4.51	10.47/16.28/56.98/16.28	.0005
CNC-W	2.26/15.79/77.44/4.51	10.47/15.12/58.14/16.28	.0007
HINT	2.92/16.06/76.64/4.38	9.76/14.63/69.86/17.07	.0012
Co-morbidities			
CCI	0/1/>1 (%)	0/1/>1 (%)	
CNC-P	74.44/11.28/14.29	61.63/24.42/13.95	.0347
CNC-W	75.19/10.53/14.29	60.47/25.28/13.95	.0121
CACI	0-1/2-3/>3(%)	0-1/2-3/>3(%)	
CNC-W	24.06/51.13/24.81	16.28/50.00/33.72	.0541

C1 first post-activation time point (approximately 3m); C2 second post-activation time point (approximately 6 m); C3 third post-activation time point (approximately 12m); PropLifeHA proportion of life spent using hearing aids; AL assisted living, ILA individual living alone, ILNA individual not living alone; CCI Charlson Comorbidity index; CACI Combined Age and Comorbidity Index; CNC Consonant Nucleus Consonant phoneme (P) and word (W) tests; HINT Hearing in Noise Test