Research Article

Older and Younger Adult Cochlear Implant Users: Speech Recognition in Quiet and Noise, Quality of Life, and Music Perception

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Purpose: To determine whether older cochlear implant (CI) listeners differ from younger CI listeners on measures of speech understanding, music perception, and health-related quality of life (HRQoL). In the study, the authors hypothesized that speech recognition would be more difficult for older adults, especially in noisy conditions. Performance on music perception was expected to be lower for older implanted listeners. No differences between age groups were expected on HRQoL.

Method: Twenty older (>60 years) and 20 younger (<60 years) implanted adults participated. Speech understanding was assessed using words and sentences presented in quiet, and sentences presented at +15, +10, and +5 dB

signal-to-noise ratio conditions. Music perception was tested using the University of Washington Clinical Assessment of Music, and HRQoL was measured using the Nijmegen CI survey.

Results: Speech understanding was significantly lower for the older compared with the younger group in all conditions. Older implanted adults showed lower performance on music perception compared with younger implanted adults on 1 of 3 subtests. Older adults reported lower HRQoL benefit than younger adults on 3 of 6 subdomains.

Conclusion: Data indicate that older CI listeners performed more poorly than younger CI listeners, although group differences appear to be task specific.

According to the 2010 U.S. census, more than 40 million Americans are older than 65 years; 15% more than reported in the 2000 census. Census projections indicate the number of Americans older than 65 years will increase 147% by the year 2050 (U.S. Census Bureau, 2009). Advanced age is accompanied by concomitant decreases in auditory function. Prevalence of age-related hearing loss varies across studies, though recent estimates report 63% of adults older than 70 years have some degree of hearing impairment (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011). Severe hearing loss is more common among older adults than any other age group and accounts for 18% of all cases (Davis, Wood, Healy, Webb, & Rowe, 1995). The number of older adults with severe hearing loss is important because this level of severity is, in general, the point at which patients are considered to be candidates for a

cochlear implant (CI). In short, the number of older adult CI candidates is on the rise and expected to continue.

Existing Studies of Older CI Listeners

Cochlear implantation carries minimal risk and has been proven to be a safe procedure in all age groups (Venail et al., 2008) including the older population (Budenz et al., 2011; Carlson et al., 2010; Chatelin et al., 2004; Coelho, Yeh, Kim, & Lalwani, 2009; Djalilian, King, Smith, & Levine, 2002; Eshraghi et al., 2009; Haensel, Ilgner, Chen, Thuerman, & Westhofen, 2005; Labadie, Carrasco, Gilmer, & Pillsbury, 2000; Orabi, Mawman, Al-Zoubi, Saeed, & Ramsden, 2006). These authors generally agree that older adults present with more comorbid conditions at the time of surgery, and the patient's preexisting medical conditions are more important for determining intra- or postoperative complications than age alone. The outcomes of implantation in older adults are excellent such that speech understanding is significantly improved between preoperative and postoperative test intervals (Djalilian et al., 2002; Eshraghi et al., 2009; Haensel et al., 2005; Labadie et al., 2000; Migirov,

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Taitelbaum-Swead, Drendel, Hildesheimer, & Kronenberg, 2010; Orabi et al., 2006; Pasanisi et al., 2003; Shin et al., 2000). The benefits of improved audibility and speech recognition are expected to cascade into other areas of life such as the patient's social, psychological, and overall physical health. In fact, studies unanimously demonstrate significantly higher health-related quality of life (HRQoL) scores among older CI users at postoperative compared with preoperative intervals (Djalilian et al., 2002; Noble, Tyler, Dunn, & Bhullar, 2009; Orabi, Mawman, Al-Zoubi, Saeed, & Ramsden, 2006; Park, Shipp, Chen, Nedzelski, & Lin, 2011; Poissant, Beaudoin, Huang, Brodsky, & Lee, 2008; Vermeire et al., 2005).

Age-Related Declines in Speech Understanding

Research using adults with normal or near-normal hearing have demonstrated age-related declines in speech recognition, especially for complex listening tasks, such as listening to speech in noisy or reverberant conditions (Helfer & Wilber, 1990; Larsby, Hällgren, Lyxell & Arlinger, 2005; Snell & Frisina, 2000). The underlying reason is, in part, the result of declining hearing thresholds that come with age. However, a loss of hearing sensitivity cannot fully account for the degree of difficulty experienced by older adults. The disproportionately poor speech recognition compared with auditory thresholds may, however, be explained by the nature of age-related hearing loss. The term *presbycusis*, commonly used to describe hearing loss that comes with the aging process, is associated with several physiological sources, including peripheral and central-auditory sources (e.g., Humes et al., 2012). Presbycusis might, therefore, be considered a unique form of sensorineural hearing loss in which the outcomes with hearing aids or CIs are not as high.

Age-Related Performance Differences Among Adults With CIs

The aforementioned studies indicate that age-related declines in speech recognition among adults with near-normal hearing may be because of physiological changes along the auditory system. Further, such changes may occur in isolation, or in combination, with varying levels of severity. The findings of those investigators can be used when trying to predict performance outcomes of older compared with younger implant listeners. Given the extensive research showing that older adults have more difficulty with speech understanding, especially in noisy conditions, one would predict similar patterns of performance among implant listeners.

Existing studies comparing older and younger adults with implants disagree about the presence of age-related speech-understanding performance differences. Many studies report that older and younger implanted adults do equally well on tests using single words or sentences in quiet listening conditions (Budenz et al., 2011; Haensel et al., 2005; Labadie et al., 2000; Migirov et al., 2010; Noble et al., 2009; Orabi et al., 2006; Park et al., 2011; Pasanisi et al., 2003; Poissant et al., 2008; Sterkers et al., 2004), yet others demonstrate significantly lower performance for older compared with

younger CI listeners (Chan et al., 2007; Friedland, Runge-Samuelson, Baig, & Jensen, 2010; Noble et al., 2009; Roberts, Lin, Herrmann, & Lee, 2013; Vermeire et al., 2005). Perhaps even more surprising is that studies also disagree about the presence of age-related speech-in-noise (SIN) performance differences between older and younger implanted adults. That is, some studies have demonstrated that older implanted adults perform lower on SIN than younger implanted adults (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011; Roberts et al., 2013) yet others have reported that age-related differences are absent (Budenz et al., 2011; Friedland et al., 2010; Orabi et al., 2006; Poissant et al., 2008). Adding to the complexity of aging effects on implant use are studies such as Noble et al. (2009) that suggest age-related performance differences exist in specific listener groups. Noble et al. performed a retrospective review of 38 bilateral and 38 bimodal adults. Outcome measures included the Hearing Handicap Inventory for the Elderly (HHIE; Ventry & Weinstein, 1982), the Hearing Handicap Questionnaire (HHQ; Noble, Tyler, Dunn, & Bhullar, 2008), and Speech, Spatial, and Qualities of Hearing Scale (SSQ; Gatehouse & Noble, 2004). Results showed age-related differences on the SSQ but only with the bilateral CI group and not the bimodal CI+hearing aid group.

Disagreement between studies reporting speech-understanding performance of implanted adults may be explained by methodological differences, such as the tests used to measure speech perception, presentation level of speech and/or noise, and the time intervals of testing. For example, speech materials used in previous studies included sentences spoken slowly and clearly by a single talker or words presented at high intensity levels. Perhaps strong age-related differences in implant performance emerge with more difficult materials or presentation parameters. For example, the Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994) uses a single male talker who speaks clearly and at a slow rate. It is possible that age-related speech-understanding deficits may be seen when participants are tested using materials that use multiple talkers speaking at a conversational rate.

It is also possible that age-related speech-understanding performance differences are inconsistently reported because of sampling. Roberts et al. (2013) completed a retrospective chart review of 113 patients: 46 younger (<65 years) and 67 older (≥65 years). They reported significant age-related performance differences on the consonant nucleus consonant (CNC; Peterson & Lehiste, 1952) single words tested at 65 dB SPL after at least 5 months of device use. The interval of testing is important in light of reports suggesting older adults take longer to acclimate to electrical hearing compared with younger adults (Chan et al., 2007). It is unknown whether the age-related differences reported by Roberts et al. (2013) would persist once all patients had used the device for a sufficient amount of time.

Consideration must also be given to the possibility that age-related speech-understanding performance differences are minimal or nonexistent within CI listeners. This perspective is based on the idea that age-related declines in recognizing SIN are driven more by peripheral than central

factors. In fact, Waltzman, Cohen, & Shapiro (1993) suggested age-related changes in auditory processing might be the result of physiologic changes within the cochlea, and bypassing the cochlea with a CI may reduce the clinical manifestations of auditory processing difficulties.

The aim of this study was to systematically compare older and younger CI listeners using a prospective two-cohort experimental design. Assessment materials were chosen to represent a range of difficulty from easy listening tasks (single words in quiet) to more difficult (sentences spoken by multiple talkers at conversational speed in noise). In this study we included a test of music perception to broaden our understanding of aging effects on implant performance.

Barring profound hearing deficits, music is an activity that can be continued throughout life and that has value for old and young listeners alike as an important cultural experience. Furthermore, research suggests that listening to and performing music are widely available cognitive opportunities for seniors who have differing states of health. In theory, participating in musical activities could provide mental exercise for remaining productive and independent in advancing years (Cohen, 2002; Gabrielson, 2002). Music perception among adults with CIs varies considerably, in part because of variability in musical experience, duration of deafness, and other patient- or device-related factors. Performance also varies based on the experimental task. For example, some evidence has shown that CI users perform as well as normal-hearing listeners on measures of rhythm (Gfeller & Lansing, 1991) but lower on tests of timbre recognition (Gfeller, Knutson, Woodworth, Will, & DeBus, 1998; Gfeller, Woodworth, Robin, Witt, & Knutson, 1997; Kang et al., 2009) and melody recognition (Gfeller et al., 1998).

In this study, auditory abilities of older and younger adult CI users were tested using auditory tasks that included speech understanding in quiet, speech understanding in noise, and music perception. A HRQoL scale was also administered. In this study, we posed three experimental questions and related hypotheses:

1. Do younger and older adults perform the same on speech-recognition measures in quiet and in difficult signal-to-noise ratio (SNR) conditions? It was hypothesized that speech-recognition performance in quiet would be comparable for younger and older CI adults, but speech-recognition performance in noise would be lower for older participants in the hardest SNR conditions.
2. Do younger and older adults perform equally well on music perception tasks? The music perception task had three subtests: pitch change direction, familiar melody recognition, and timbre perception. In this article we hypothesized that music perception performance for all subtests would be lower for older compared with younger implanted adults.
3. Do younger and older adults report equal benefit on a disease-specific HRQoL survey designed for CI users? It was hypothesized that HRQoL is directly

tied to self-perceived speech-recognition benefit. Older and younger adults were expected to have similar on the HRQoL survey, reflecting that both groups derive significant benefit from the CI.

Our hypotheses are based on existing research using close-to-normal hearing older adults. Specifically, we hypothesize that older implanted adults are disadvantaged by similar factors as older adults with near-normal hearing: speed of processing, decreased auditory memory, decreased central auditory processing, and general cognitive decline. We speculate that these deficits are not avoided with use of a CI system.

Materials and Method

Participants

In this study, we decided *a priori* to divide the participants into younger and older age groups. This was done to make direct comparisons to the previous research in this area. Previous studies defined “elderly” using criteria ranging from 60 to 75 years old. Although there is no universal agreement on the exact age that defines the older population, the World Health Organization (WHO; 2010) defined “older” as age 60 years and older. This definition is supported by Gates, Cooper, Kannel, and Miller (1990), who demonstrated that word recognition abilities decrease by 12% per decade after 60 years of age. A criterion of 60 years was adopted here to separate participants into a group of younger adults (<60 years old) and older adults (≥60 years old).

The Institutional Review Board at University of Texas at Austin and Mayo Clinic, Rochester, MN, reviewed and approved this study. Half of the participants were evaluated in Austin and the other half at the Mayo Clinic. A total of 42 adults consented to participate. Data from 1 participant were excluded because of a possible device failure at the time of testing. Data from another participant were excluded because only part of the study was completed. A total of 40 participants (20 older CI listeners, 20 younger CI listeners) were included in the final analyses. The older group was composed of six women and 14 men, ranging in age from 60 to 83 years, with a mean of 70.7 years. The younger group consisted of 13 women and seven men, ranging in age from 21 to 58 years, with a mean of 39.7 years. The older adults were all unilaterally implanted, likely a limitation of Medicare guidelines. Of these, seven continued to use a hearing aid on the contralateral side. The younger group included eight participants that had a contralateral CI, and four that had a contralateral hearing aid. Participants were asked to leave the contralateral hearing aid off, and that ear was plugged. Participants with a second side CI were asked to remove the CI they believed to be used by their poorer ear.

The two groups were balanced for duration of deafness and length of CI use, both of which are known to impact postoperative speech understanding among CI users (Green, Bhatt, & Mawman, 2007; UK Cochlear Implant Study Group, 2004). Duration of deafness before implantation was defined as the time between onset of severe-to-profound

hearing loss and activation of participant's CI. This timeline was determined through patient records or patient report. The average duration of deafness was 11.1 years ($SD = 5.5$ years) for the older group, and 11.3 years ($SD = 7.9$ years) for the younger group. An independent samples t test showed that duration of deafness was significantly different between the two groups, $t(38) = 0.07, p > .05$. Length of implant use was calculated as the number of years between activation and the test date. On average, the older group had 3.5 years ($SD = 3.2$ years) of implant use, and the younger group had 4.4 years ($SD = 5.1$ years) of device use. There was no significant difference of length of device use between groups, $t(38) = 0.66, p > .05$.

Materials

Speech recognition. Speech recognition was measured in quiet using CNC words and AzBio sentences (Spahr et al., 2012). The CNC word test is a standard measure of speech recognition for both clinical and research purposes. The AzBio sentence test is the preferred sentence test for assessing CI candidacy and long-term performance (Gifford, Shallop, & Peterson, 2008). The AzBio test consists of 15 lists of 20 sentences ranging in length from 6 to 10 words spoken by five talkers (two men, three women) using a conversational rate of speech. Speech recognition in noise was measured with AzBio sentences presented with four-talker babble using three SNR conditions: +15 dB, +10 dB, and +5 dB.

Music perception. Music perception was assessed using the University of Washington Clinical Assessment of Music Perception test (UW-CAMP; Kang et al., 2009). The UW-CAMP is a computerized test comprising three subtests: pitch detection discrimination, melody identification, and timbre identification. A complete description can be found in Kang et al. (2009).

Pitch change direction. In short, the pitch subtest uses a two-alternative, forced-choice adaptive procedure to determine a threshold interval for discrimination of complex pitch direction change. Complex tones were synthesized and contained both fundamental and overtone frequency cues found in real-world tones. Base frequencies for the complex tones were 262 Hz, 330 Hz, and 392 Hz. These frequencies represent the range commonly used in Western music. Pitch change threshold was calculated automatically by the program and is reported in semitones.

Melody recognition. The melody recognition task included 12 familiar melodies (e.g., "Happy Birthday to You," "Old MacDonald Had a Farm," and "Rock-a-bye Baby"). For each melody, the rhythmic pattern was removed so that the listener could not use it as a cue to recognize the tune. Listeners were first familiarized to the tunes and then asked to choose which one was played after each presentation. The program computed a percentage correct score.

Timbre recognition. Timbre is commonly referred to as the "quality" of a sound. For this subtest, eight musical instruments played the same sequence of notes at exactly the same tempo with the same loudness, thus leaving only

the quality, or timbre, of the instrument. The participant first listens to each instrument two times before starting the experimental procedure. Similar to melody recognition, the listeners are familiarized with the sound clips before the experiment starts. That is, each listener had to listen to each sound clip two times. During this task, the musical sample of each instrument is played at random until each has occurred three times. At the end of each clip, the participant must use a mouse to click on the correct icon. Again the program calculated percentage correct scores.

Quality of life. Each participant completed the Nijmegen Cochlear Implant Questionnaire health-related quality of life (HRQoL) survey (Hinderink, Krabbe, & Van Den Broek, 2000; hereafter, "the Nijmegen"). The Nijmegen is a disease-specific questionnaire developed for CI users and consists of 60 items covering three domains: physical, psychological, and social. The physical domain comprises three subdomains: self-perceived ability of basic sound processing, advanced sound processing, and speech production. The psychological domain includes one subdomain: self-esteem. The social domain includes two subdomains: activity limitations and social interactions. Each subdomain comprises 10 questions. The target items are constructed as statements with five answer categories ranging from *never* to *always* or *poor* to *good*. Alternatively, each item also contains a *not applicable* response. Responses range from 0 (*very poor*) to 4 (*very good*).

Equipment and procedures. Testing was completed in a double-walled sound booth. At the UT Austin location, speech stimuli were loaded onto a Dell Inspiron laptop computer routed through a GSI 61 audiometer. At the Mayo Clinic location, the same speech stimuli were loaded onto a Dell Desktop computer and routed through a Madsen Astera audiometer. Before the experiment began, participants were asked to confirm their CI processor was on a program for day-to-day listening and asked not to use any noise-reduction preprocessing.

Speech understanding. Speech and noise stimuli were presented through a single speaker located 1.5 m directly in front of and at ear level to the participant. Calibration of stimuli occurred during each session. Speech stimuli were presented at 60-dB sound pressure level-a (SPL-a) weighting. During speech recognition in noise testing, the multitalker babble was adjusted below the level of speech to create the SNR required for that condition. One list of AzBio sentences was administered for each SNR block. The blocks were administered in counterbalanced order (quiet, +15 dB SNR, +10 dB SNR, and +5 dB SNR). Participants were instructed to repeat as many of the words as possible and guess when necessary. The examiner recorded verbal responses and points were given for each correctly repeated word.

Music perception. Similar to the speech-understanding experiment, the music stimuli were routed from the laptop computer through the audiometer. The presentation level was calibrated each time to 60 dB SPL. Each participant was asked to set the volume on their processor while listening to recordings of sentences taken from the HINT. The purpose of this exercise was to ensure that perceived

loudness of the experimental stimuli was the same for all participants. Each subtest of the UW-CAMP includes a training interval wherein the participant is oriented to the task. The examiner stayed in the room during the training interval, then left and observed the experiment from an adjacent room.

Results

Data were analyzed using SPSS Statistics 20.0.0. Levels of significance were obtained if α reached .05 and if confidence levels were set to 95%.

Speech Recognition

The CNC percent correct scores for all participants are seen in Figure 1. The group mean was 75.6% for the younger CI listeners, and it was 62.9% for the older CI listeners. Before data analysis, however, the speech performance scores were submitted to rationalized arcsine transformations, expressed as RAU (Studebaker, 1985). Group means and *SDs* for each speech-understanding task are reported in Figure 2. A one-way analysis of variance (ANOVA) was used to test group differences using CNC word scores (RAU) in quiet as the dependent variable and age as the between-subjects factor. Results revealed significantly higher performance of younger implanted adults compared with older implanted adults, $F(1, 39) = 6.1, p < .05$.

Statistical significance in the sentence recognition data was explored using mixed-model repeated-measures ANOVA (RM-ANOVA). The level of noise (quiet, +15, +10, and +5 dB SNR) was used as a within-subject variable, and age (older and younger groups) was used as a between-subjects variable. Results revealed significant predicted main effects of noise $F(3, 108) = 17.9, p < .01$, and age, $F(1, 36) = 18.4, p < .01$, demonstrating that performance was significantly different across the noise conditions and between the two age groups. There was not a significant interaction between age and noise, $F(3, 108) =$

Figure 1. Scatterplot of all participants using age on the x-axis and consonant nucleus consonant (CNC) percentage correct score on the y-axis.

Figure 2. Average speech-understanding performance for older and younger implanted adults. Error bars indicate standard deviations. CI = cochlear implant; RAU = rationalized arcsine unit; SNR = signal-to-noise ratio.

.90, $p > .05$, demonstrating that speech-understanding performance varied across the noise conditions equally for older and younger groups. The main effect of noise was followed up with post hoc analyses. Result showed a significant decrease in performance between quiet and +15 dB SNR, $F(1, 39) = 25.5, p < .05$; between +15 dB SNR and +10 dB SNR, $F(1, 39) = 9.06, p < .05$; but not between +10 dB and +5 dB SNR, $F(1, 39) = 1.02, p < .05$.

Music recognition. The three subtests of the UW-CAMP were analyzed individually using RM-ANOVA or independent samples *t* tests.

Pitch change direction. The pitch change direction subtest yields a threshold score in semitones for three base frequencies (262 Hz, 330 Hz, and 392 Hz), as seen in Figure 3. Older CI adults had average pitch-change direction thresholds of 2.31, 2.32, and 2.53 semitones at 262 Hz, 330 Hz, and 392 Hz, respectively. The average pitch-change threshold for the younger implanted adults was 1.89, 1.39, and 1.79 semitones for the three base frequencies. Threshold data for each participant at each of the three frequencies was analyzed using a RM-ANOVA. Base frequency (262 Hz, 330 Hz, and 392 Hz) was used as the within-subjects factor, and group was used as the between-subjects factor. There was no effect of base frequency, $F(2, 76) = 0.36, p > .05$, no effect of group, $F(1, 38) = 2.47, p > .05$, and no Frequency $\times$ Group interaction, $F(2, 76) = 0.23, p > .05$.

Figure 3. Average pitch-change direction threshold in semitones for each base frequency in older and younger implanted adults. Error bars indicate standard deviations.

Melody recognition. The Melody Recognition subtest of the UW-CAMP computes a percentage correct score for each participant. Average percentage correct scores were 43% ($SD = 23.5$) for younger implanted adults and 37% ($SD = 25.8$) for older implanted adults. An independent samples t test demonstrated no significant difference between the older and younger CI groups, $t(38) = 0.38$, $p > .05$.

Timbre recognition. Percentage correct scores were also calculated for the Timbre subtest. Younger adults correctly identified the musical instruments 57.5% ($SD = 16.2$) of the time, and older adults correctly identified instruments 46% ($SD = 17.9$) of the time. An independent samples t test revealed that younger CI listeners performed significantly higher in timbre recognition between the younger CI listeners, $t(38) = 2.12$, $p < .05$.

HRQoL

The Nijmegen HRQoL survey was scored according to the authors' instructions (see Hinderink et al., 2000). Domain specific scores for each participant were calculated, and the sum of all domain scores provided an overall HRQoL score out of 20. Group averages can be found in Figure 4. Overall HRQoL was 16.5 points ($SD = 2.0$) for older implanted adults and 18.2 points ($SD = 2.6$) for younger implanted adults. The data were analyzed using one-way multivariate ANOVA (MANOVA) with domain scores as dependent variables and age group as the between-subjects factor. Statistical significance among the subdomains was reached for basic sound processing, $F(1, 39) = 9.6$, $p < .05$, speech production, $F(1, 39) = 8.3$, $p < .05$, and social interaction, $F(1, 39) = 7.7$, $p < .05$.

Pearson product-moment correlations were used to test the relationship between age, speech understanding, and HRQoL. The results can be found in Table 1. In short, age was not significantly correlated to any of the six subdomains of the Nijmegen but was correlated to each test of speech understanding, with exception of the CNC

word test. Speech understanding was correlated to some of the subdomains of the Nijmegen.

Discussion

The number of older CI candidates will continue to rise along with the aging population. Understanding aging effects on CI performance is important to patients so they may develop realistic expectations regarding postoperative performance and important for clinicians so they may correctly navigate clinical treatment options such as aural rehabilitation. Academically, the CI creates a new opportunity to explore aging effects on auditory function. Existing research comparing older and younger implanted adults is comprised of conflicting reports that demonstrate no aging affects and others that report lower performance for older adults. The aim of this study was to prospectively examine performance abilities on speech understanding, music perception, and HRQoL between older and younger CI listeners.

Speech Understanding

Performance results with implants were significantly lower for the older group compared with the younger group for all measurements of speech understanding (single words in quiet, rapidly spoken sentences presented in quiet, and in +15, +10, and +5 dB SNR conditions). A review of the speech-understanding data reveals considerable variability in performance. The variability can be seen in the SD values and also in peak performance within each group. For example, the highest CNC word score was 92% for the older group and 96% for the younger group. Despite significant group differences, there are several confounding factors. For example, the two groups differed in age but also in gender and the use of bilateral hearing. There were several more women in the older CI group and several more bilateral listeners among the younger group. We cannot rule out, therefore, that the group differences are strictly because of age, especially in light of the correlational analysis. Though age was significantly correlated to many of the outcomes, it was not uniform. For example, there was no correlation between age and the CNC words score, despite finding significant differences between groups. The group difference may have been driven by an extraneous variable not captured here.

It is worth noting that performance of both groups dropped significantly between sentence in quiet and sentence in +15 dB SNR conditions. This illuminates the idea that implant listeners are highly susceptible to background noise, even when it is a relatively high SNR. Again, age was strongly correlated to sentence understanding in quiet and noise but not CNC word understanding.

Music Perception

This study provides a first glimpse at the music perception abilities of older CI listeners compared with younger

Figure 4. Group averages for older and younger CI adults on the six subdomains of the Nijmegen health-related quality of life survey. Error bars indicate standard deviations.

Table 1. Correlation coefficients between age, speech understanding, and domains of Nijmegen health-related quality of life survey.

Variable	Age	CNC words	AzBio Quiet	AzBio +15 SNR	AzBio +10 SNR	AzBio +5 SNR
Age	1	-.242	-.496**	-.337*	-.233*	-.326*
Basic sound	-.227	.447**	.367*	.274	.270	.110
Advanced sound	.103	.284	.073	.108	.104	-.036
Speech production	-.286	.559**	.486**	.406**	.378*	.294
Self-esteem	.002	.313*	.122	.025	-.044	-.023
Activity	-.137	.166	.231	.157	.273	.228
Social interaction	-.233	.325*	.431*	.271	.250	.196

Note. CNC = consonant–nucleus–consonant; SNR = signal-to-noise ratio.

* $p < .05$. ** $p < .001$.

CI listeners. Performance results on the three subtests agree with Kang et al. (2009), who reported data from 42 CI listeners ranging in age from 35 to 81 years. Kang and colleagues reported a mean pitch-change direction threshold of 3.0 semitones, similar to our study, which found mean pitch-change direction thresholds of 3.1 for older adults and 2.7 for younger adults. The timbre recognition results of the older (46.0%) and younger (57.4%) CI users in this study are in agreement with Kang's report of 45.0%. Kang further reported average performance of 25.4% for melody recognition, which is lower than the results of our study, which found older CI listeners heard 37% correct and younger CI listeners 43% correct. Musical experience of participants was not accounted for and may explain the difference between the two studies.

Previous studies using older and younger normal- and near-normal-hearing adults suggest music perception remains intact for simple experimental tasks (Halpern, Bartlett, & Dowling, 1995). A similar pattern can be seen in our study. That is, older and younger CI listeners had similar performance scores on two subtests: (a) pitch-change direction, a short two-alternative, forced-choice procedure and (b) recognition of familiar melodies. Speculatively, the melody recognition is a more familiar task because the melodies include "Happy Birthday to You," "Twinkle, Twinkle, Little Star," and other melodies common to most people in western culture. In contrast, timbre recognition is more specific, and not all people have enough knowledge of music to identify specific instruments. Musical experience was not controlled in the current experiment, and as such the results should be interpreted with caution since age-related performance difference may be because of other variables. Further study into music perception is needed to understand the underlying principles of age-related differences.

HRQoL

Results from the HRQoL survey provide a valuable perspective on the use of CIs for older adults. Despite significant differences for speech recognition in noise between older and younger CI listeners, the two groups report equal HRQoL benefit on three of six subdomains. Previous research has demonstrated significant correlations between

HRQoL and speech recognition abilities (Damen, Beynon, Krabbe, Mulder, & Mylanus, 2007; Hirschfelder, Grabel, & Olze, 2008), but significant correlations were not found among the present data. Independent performance of HRQoL and speech understanding suggests that one cannot replace the other, and both are valuable assessments within CI programs. Results of the correlational analysis revealed significant correlations between speech understanding and four of the subdomains: basic sound processing, advanced sound processing, self-esteem, and social interaction. It is worth noting that the ANOVA results showed group differences for basic and advanced sound processing and social interaction as well as for speech understanding. The combination of findings suggests a commonality, although it is unclear if it is age or speech understanding driving the differences between groups.

Limitations

Although the study used a prospective experimental design, we acknowledge several weaknesses. For example, patient experiences such as amount of aural rehabilitation, auditory training, and musical experience were not measured or controlled. It is possible group performance was the result of one of these external forces and not age. In addition, the individuals who participated in this study chose to do so and may not reflect the general population. These participants heard about the study through a flyer or at a meeting and chose to contact the study coordinator to offer their time. Attempts were made to minimize the variability known to exist in CI research by enrolling only those participants who had been using their devices more than a year and with adult onset of severe-to-profound hearing loss.

Results of this study suggest CI outcomes are not equal for older and younger adults, at least for the tasks described in this study. The findings of this study will be useful when counseling implant candidates on the outcomes associated with implantation at advanced age. Of course, counseling prospective patients should include a candid discussion of the inherent variability of performance and that average performance is simply a statistic.

This study provides further evidence that additional research is needed to understand the implication of cochlear implantation among older adults. For example, do age-related differences exist in other areas, such as spatial hearing or

selective auditory attention? Determining which age-related deficits can be overcome with training programs is also a high priority for future investigators. Specifically, research is needed on the design and validation of intervention strategies for this population, and determining if parameters within speech-coding strategies can be adjusted to improve outcomes for older CI listeners.

Conclusions

Age-related differences between younger and older implant listeners were explored using a variety of auditory tasks and a HRQoL survey. The results of this study substantiate previous studies showing that cochlear implantation is an excellent treatment option for adults of all ages, including those older than 60 years. Benefits, as demonstrated here, include significant open-set speech recognition in quiet and, to a lesser extent, in noise. All ages of CI users demonstrated the ability to recognize components of music, and all had significant self-perceived benefit as measured on a HRQoL scale.

Findings also demonstrate lower performance outcomes for older implanted adults compared with younger implanted adults on measures of speech understanding when measured in quiet and in noise and timbre recognition. Results on HRQoL suggest that older adults achieve similar self-perceived benefit compared with younger implanted adults, such that scores were equal on three of six measured subdomains. The findings should be replicated in future studies that control for confounding variables such as musical experience, gender, and hearing configuration (unilateral–bilateral–bimodal).

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