AMERICAN ACADEMY OF OTOLARYNGOLOGY–HEAD AND NECK SURGERY FOUNDATION

Original Research

OTO Open
2021, 5(3) 1–7
© The Authors 2021
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/2473974X21031471
http://oto-open.org
SAGE

Perceptions of Sound Quality and Enjoyment After Cochlear Implantation

Sarah Y. Bessen, MPH[1], James E. Saunders, MD[2], Eric A. Eisen, MD[2], and Isabelle L. Magro, MD[3]

Abstract

Objectives. To characterize the quality and enjoyment of sound by cochlear implant (CI) recipients and identify predictors of these outcomes after cochlear implantation.

Study Design. Cross-sectional study.

Setting. A tertiary care hospital.

Methods. Surveys based on the Hearing Implant Sound Quality Index were sent to all patients who received a CI at a tertiary care hospital from 2000 to 2019. Survey questions prompted CI recipients to characterize enjoyment and quality of voices, music, and various sounds.

Results. Of the 339 surveys, 60 (17.7%) were returned with complete data. CI recipients had a mean ± SD age of 62.5 ± 17.4 years with a mean 8.0 ± 6.1 years since CI surgery. Older current age and age at implantation significantly predicted lower current sound quality ($P < .05$) and sound enjoyment ($P < .05$), as well as worsening of sound quality ($P < .05$) and sound enjoyment ($P < .05$) over time. Greater length of implantation was associated with higher reported quality and enjoyment ($r = 0.4$, $P < .001$; $r = 0.4$, $P < .05$), as well as improvement of sound quality ($r = 0.3$, $P < .05$) but not sound enjoyment over time.

Conclusion. Recipients who had CIs for a longer period had improved quality of sound perception, suggesting a degree of adaptation. However, CI recipients with implantation at an older age reported poorer sound quality and enjoyment as well as worsening sound quality and enjoyment over time, indicating that age-related changes influence outcomes of cochlear implantation.

Keywords

cochlear implants, sound quality, sound enjoyment, patient-reported outcomes

Received May 2, 2021; accepted June 14, 2021.

Cochlear implantation is a mainstay in the treatment of patients with severe to profound hearing loss. Over 5% of the world's population has disabling hearing loss, including nearly one-third of people aged >65 years.[1] At present, >400,000 people across the world have a cochlear implant (CI).[2] This figure is expected to rise on account of expanded CI candidacy, earlier implantation, increased binaural implantation, and a growing aging population.

At present, cochlear implantation candidacy and outcomes are determined by using objective measures of hearing and comprehension, such as sound field thresholds and speech recognition scores. However, these measures do not consider subjective aspects of the auditory input, such as sound quality (ie, the ability to distinguish different sounds) or enjoyment (ie, subjective pleasantness of sound). Subjective rating scales—for example, the Hearing Implant Sound Quality Index ($HISQUI_{19}$)—have been developed to characterize sound perception in CI recipients, but these primarily focus on the quality of sound. Studies have found that CI recipients generally demonstrate significantly poorer accuracy and appraisal as compared with those with normal hearing[3-9] and as a group report ''moderate'' sound quality on average.[10]

Several studies have demonstrated that speech recognition outcomes following cochlear implantation can be predicted by various patient factors, including length of implantation, preoperative hearing levels, duration of deafness, and age of implantation.[11] However, few studies have assessed the predictors of sound quality and enjoyment. Mertens et al[10] found that sound quality was negatively correlated with age at testing and pure tone average. Gfeller et al reported that music perception was negatively correlated with age at testing but positively correlated with musical training, months of CI use, and cognitive factors.[12] Furthermore, studies have shown that objective measures of hearing and comprehension do not correlate with

[1]Dartmouth Geisel School of Medicine, Hanover, New Hampshire, USA
[2]Dartmouth-Hitchcock Medical Center, Lebanon, New Hampshire, USA
[3]Caruso Department of Otolaryngology–Head and Neck Surgery, Keck School of Medicine of the University of Southern California, Los Angeles, California, USA

This article was presented at the 2020 AAO-HNSF Virtual Annual Meeting & OTO Experience; September 13, 2020.

Corresponding Author:
Isabelle L. Magro, MD, LAC+USC Medical Center, 1200 N State Street, Los Angeles, CA 90033, USA.
Email: Isabelle.Magro@med.usc.edu

This Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (http://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).

the quality or enjoyment of sound, which emphasizes the importance of studying these factors separately.[3,12,13]

Overall, there is a paucity of data surrounding self-reported perceptions of sound quality and enjoyment following cochlear implantation, and even less is known about evolution of the auditory experience. A further understanding of the subjective perception of sound in CI recipients is needed to predict outcomes in CI candidates and provide better counseling to patients. In the current study, we aimed to characterize the quality and enjoyment of sound by CI recipients and identify predictors of sound quality and enjoyment over time soon after implantation and over the duration of implantation. We also aimed to identify specific patient demographic and health factors that predict sound perception.

Materials and Methods

Survey Administration and Data Collection

All adult patients who had undergone cochlear implantation at a tertiary medical center between 2000 and 2019 were eligible to participate in the study. A list of eligible patients was generated by searching the medical records for patients assigned *CPT* codes related to CI implantation, diagnostic analysis, or reprogramming of a CI (69930, 92601, 96602, 92604; *Current Procedural Terminology*). This study received approval under the Dartmouth College Institutional Review Board.

Eligible patients were mailed a survey with 5 sections: patient characteristics, participant hearing status, experiences related to quality of sound, experiences related to enjoyment of sound, and adjective descriptors of sound experience (Appendix 1, available online). The first 2 sections included basic demographics (age, sex, education, musical background), as well as information regarding hearing status and otologic history (side of implantation, bilateral vs unilateral implantation, age of hearing loss, age at implantation, duration of deafness, and duration of implantation). The third and fourth sections included questions related to perceptions of sound quality and enjoyment, which were developed and modified per the $HISQUI_{19}$, a previously validated questionnaire for subjective sound quality assessment.[14] The $HISQUI_{19}$ was modified to add questions related to self-reported sound enjoyment, which were modeled after the validated sound quality questions. The assessment was additionally modified to assess the change in perception over time by asking participants to indicate their current impressions of sound quality and enjoyment and to recall their impressions immediately after implantation. Sound enjoyment questions asked participants to rate their experiences related to enjoyment of music, voices, and various sounds through visual analog scales, with the descriptors ''enjoyable/pleasant'' and ''unenjoyable/unpleasant'' at each extreme. Sound quality questions asked participants to rate their experiences related to quality of music, voices, and various other sounds through visual analog scales, with ''normal/as it should'' and ''abnormal'' as anchors; questions also included their ability to distinguish or recognize sounds (eg, distinguish male vs female voice, recognize familiar or unfamiliar voices, distinguish 1 vs multiple instruments being played simultaneously), with ''yes'' and ''no'' on each end of the scale.

In the final sections, we aimed to characterize and classify experiences of hearing in patients with cochlear implantation by providing various descriptors. Participants were asked to select all applicable descriptions. Participants were asked to answer each question for 2 periods: soon after cochlear implantation and at the time of completing the survey.

Data Analysis

Primary outcomes included sound quality and enjoyment scores soon after cochlear implantation, mean quality and enjoyment scores at the time of completing the survey, and the change in quality and enjoyment scores over time. The mean scores related to the enjoyment of music, voices, and various sounds were compared with each other at each time point. The mean scores related to the quality of music, voices, and various sounds were also compared with each other at each time point. There were no statistically significant differences in either the sound enjoyment scores or the sound quality scores at each time point. Therefore, the combined averages of all quality- and enjoyment-related questions were used to generate sound quality and enjoyment scores for each time point. These scores were considered for the remainder of the analysis. Change in quality and enjoyment was determined by calculating the difference in sound quality or enjoyment scores between the time points (immediately after implantation vs current time point). Independent predictor variables included factors related to patient demographics, hearing status, and otologic history.

All statistical analyses were performed with SPSS Statistics version 25 (IBM Corp). Shapiro-Wilk and Welch tests were used to assess for normality of the data and homogeneity of variances, respectively. Mean difference in sound quality and enjoyment scores over time were analyzed with paired *t* tests or a nonparametric alternative. Bivariate analyses were performed with analysis of variance and Pearson's correlations or nonparametric alternatives. Significant associations identified during bivariate analyses were then included in multivariate regression models, and multicollinearity was assessed through variance inflation factors. A 2-sided $\alpha < 0.05$ was considered statistically significant.

Results

Survey Sample

A total of 339 surveys were mailed to eligible participants. The response rate was 17.7% (N = 60). Of the 279 remaining surveys, 29 (8.6%) were deemed incomplete responses, while 250 (73.7%) either elected not to participate or did not respond. Participant characteristics are described in **Table 1**. A power analysis indicated that this sample size of 60 participants achieves 80% power to detect a correlation of 0.35 between our predictor variables and sound quality and enjoyment scores, based on a 2-sided hypothesis test with a significance level of 5%.

Table 1. Participant Characteristics.

	No. (%)
Sex	
Male	29 (50.8)
Female	30 (49.2)
Side of implant	
Left	22 (36.7)
Right	18 (30.0)
Bilateral implantation	20 (33.33)
Education	
Less than high school or equivalent	19 (31.7)
High school or equivalent	23 (38.3)
College	19 (31.7)
Graduate degree or greater	3 (5.0)
Formal musical training	
None	41 (68.3)
Some	12 (20)
Several years	7 (11.7)
	Mean (SD)
Age, y	62.51 (17.43)
Age of hearing loss, y	25.13 (21.7)
Congenital hearing loss	0 (0)
Acquired hearing loss	29.07 (20.7)
Age at implantation, y	54.7 (20.8)
Duration of deafness prior to implantation, y	29.1 (15.7)
Duration of implantation, y	8.0 (6.1)

Sound Quality vs Sound Enjoyment Over Time

A Wilcoxon signed rank test showed that sound quality scores were not statistically significantly different between the current time point and soon after implantation ($P = .76$), but sound enjoyment scores were significantly higher for the current time as compared with to the soon-after-implantation point ($P < .001$).

Predictors of Sound Quality

In bivariate analyses, older current age and age at implantation were significantly associated with lower current quality scores ($r = -0.376$, $P < .001$; $r = -0.401$, $P < .001$; **Figure 1**) and worsening quality scores ($r = -0.306$, $P < .05$; $r = -0.315$, $P < .05$; **Figure 2**) between the current time point and soon after implantation. Greater length of implantation was significantly associated with higher current quality scores ($r = 0.375$, $P < .001$; **Figure 3**) and improved quality of sound ($r = 0.321$, $P < .05$) between the current time point and soon after implantation. The relationships between sound quality outcomes and the independent variables current age, age at implantation, and length of implantation were each linear. Older age of hearing loss onset was also significantly associated with worse current quality scores. No factors were significantly associated with quality scores at the soon-after-implantation time point (**Table 2**).

Predictors of Sound Enjoyment

In the bivariate analyses, older current age and age at implantation were significantly associated with lower current enjoyment scores ($r = -0.372$, $P < .001$; $r = -0.420$, $P < .001$; **Figure 4**) and worsening enjoyment scores ($r = -0.280$, $P < .05$; $r = -0.297$, $P < .05$; **Figure 5**) between the current time point and soon after implantation. Greater length of implantation was significantly associated with higher enjoyment scores ($r = 0.351$, $P < .05$; **Figure 3**). Older age of hearing loss was also significantly associated with worse current enjoyment scores. The relationships between sound enjoyment outcomes and the independent variables current age, age at implantation, length of implantation, and age of hearing loss were each linear. No factors were significantly associated with enjoyment scores at the soon-after-implantation time point (**Table 2**).

Adjective Descriptions of Sound

Among the 60 participants, the most commonly experienced sound descriptions were ''echoey'' (n = 30, 50%), ''tinny'' (n = 28, 47%), and sharp (n = 19, 32%). However, 21 (35%) indicated resolution of these sound experiences over time (**Table 3**).

Discussion

The current study examines sound perception as it relates to sound quality and enjoyment in CI recipients. We found that older age, age at implantation, and age of hearing loss were associated with lower self-reported quality and enjoyment scores at the time of survey completion. These age-related associations are consistent with previous studies in the literature.[10,12] Mertens et al surveyed 65 adult CI recipients with the $HISQUI_{19}$ sound quality questionnaire and noted that CI recipients overall reported moderate sound quality and that these sound quality scores were moderately correlated with age.[10] Gfeller et al later studied music perception and enjoyment in adult CI recipients using a variety of tests. Their study identified music listening background, residual hearing, cognitive factors, speech recognition, and bilateral implantation as significant predictors of music perception overall, though these findings were not consistently significant across the various measures of music perception.[12] In their study, age at the time of testing was associated only with measures of melody recognition but did not significantly predict other measures of music perception. In general, the impacts of age and temporal factors on perceptions of sound quality and enjoyment, such as age at hearing loss or preimplantation duration of deafness, are not well characterized in the literature to date.

This study is the first to evaluate the change in patient perception of sound quality and enjoyment after cochlear implantation. Overall, patient-reported sound enjoyment scores significantly improved over time. Sound quality scores also improved over time, but this trend did not reach statistical significance. Furthermore, nearly one-third of CI recipients indicated resolution of sound characteristics such as ''tinny,'' ''echoey,'' and ''sharp'' over time, suggesting that their perception of sound may normalize. However, older patients and

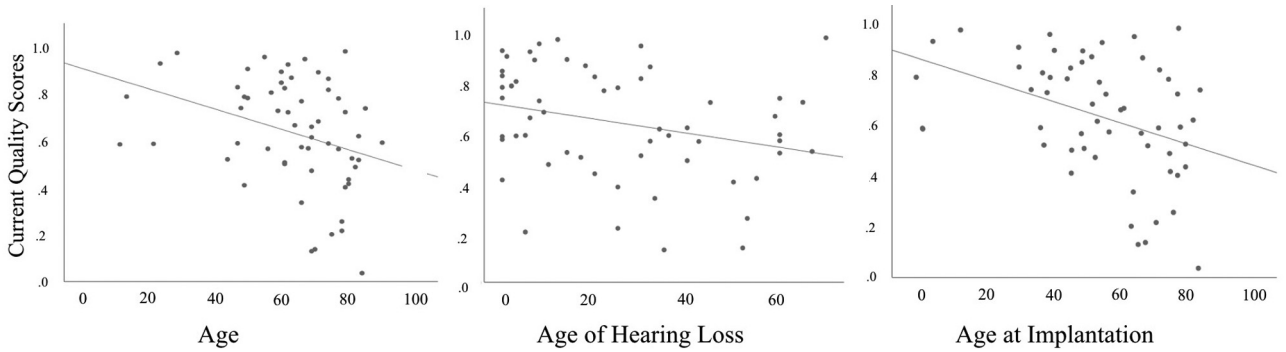

Figure 1. Self-reported sound quality scores by age-related factors. Age, age of hearing loss, and age at implantation significantly predicted worse sound enjoyment scores.

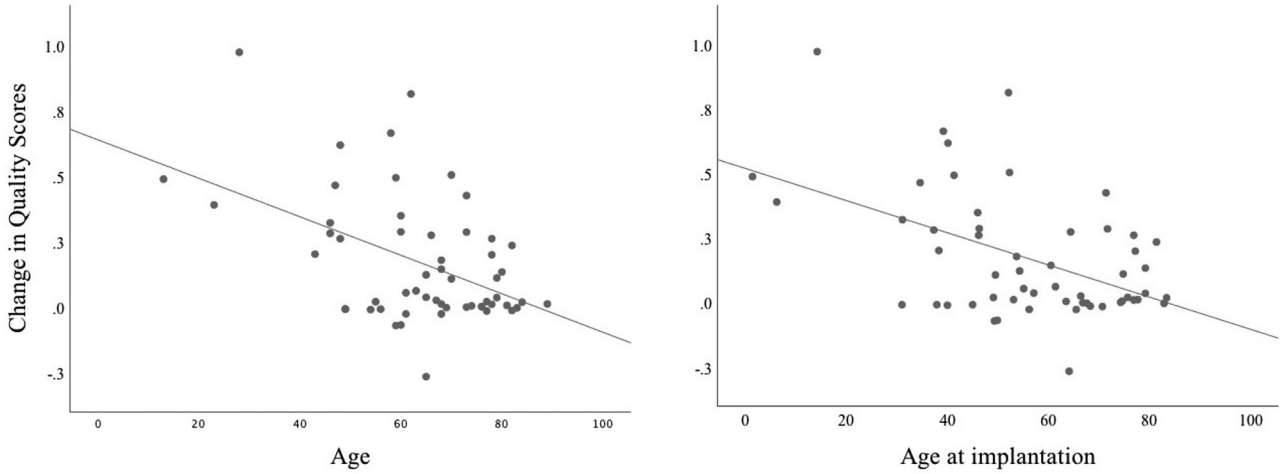

Figure 2. Change in sound quality scores over time by age-related factors. Age and age at implantation significantly predicted worsening sound quality over time when comparing sound quality scores soon after implantation with the current time point.

Table 2. Correlation Coefficients for the Associations of Patient Demographics and Hearing Status to Sound Quality and Enjoyment.

Variable	Quality after implantation	Current quality	Change in quality	Enjoyment after implantation	Current enjoyment	Change in enjoyment
Age	−0.021	**–0.376**[a]	**–0.306**[b]	–0.126	**–0.372**[a]	**–0.280**[b]
Sex	0.68	0.182	0.322	0.631	0.829	0.28
Musical background	0.074	0.493	0.067	0.466	0.409	0.276
Side of implantation	0.954	0.704	0.388	0.953	0.936	0.981
Bilateral implantation	0.813	0.404	0.441	0.635	0.72	0.719
Age of hearing loss	0.019	**–0.309**[b]	–0.23	–0.074	**–0.279**[b]	–0.215
Age of implantation	–0.002	**–0.401**[a]	**–0.315**[b]	–0.141	**–0.420**[a]	**–0.297**[b]
Preimplantation duration of deafness	0.058	–0.008	–0.086	0.087	–0.1	–0.119
Length of implantation	–0.025	**0.375**[a]	**0.321**[b]	0.038	**0.351**[b]	0.259

[a] $P < .01$.
[b] $P < .05$.

those who underwent implantation at older ages reported an overall worsening of sound quality and enjoyment over time. Given the multitude of factors that affect cochlear implantation, as well as this study's observed linear association between (1) current age and age at implantation and (2) sound quality and enjoyment outcomes, we were not able to detect a distinct age when outcomes appear to exponentially worsen. Therefore, a cutoff age when cochlear implantation becomes

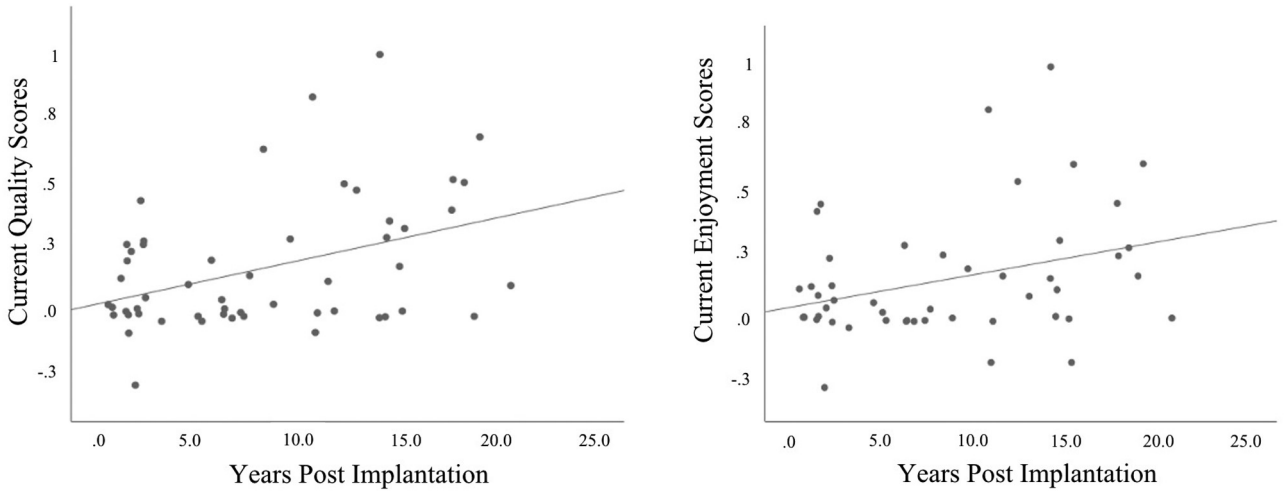

Figure 3. Impact of length of implantation on sound quality and enjoyment. Length of implantation significantly predicted higher self-reported sound quality and enjoyment.

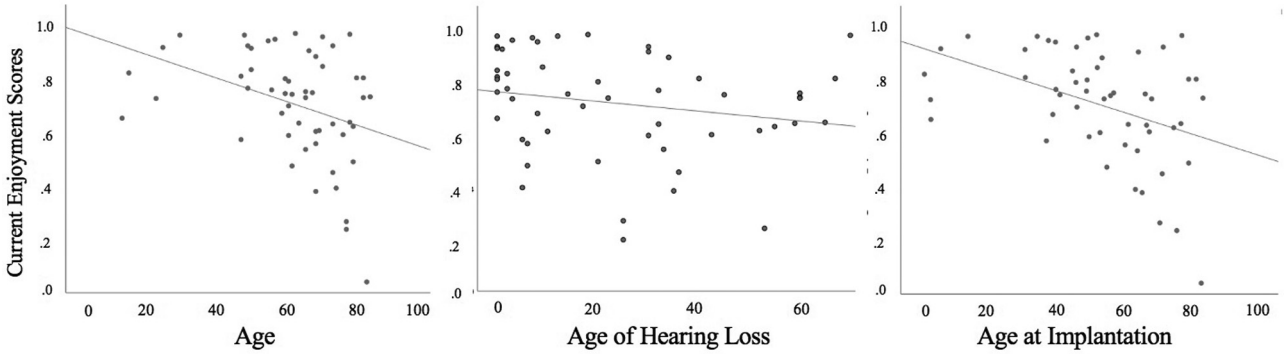

Figure 4. Self-reported sound enjoyment by age-related factors. Age, age of hearing loss, and age at implantation significantly predicted worse sound enjoyment scores.

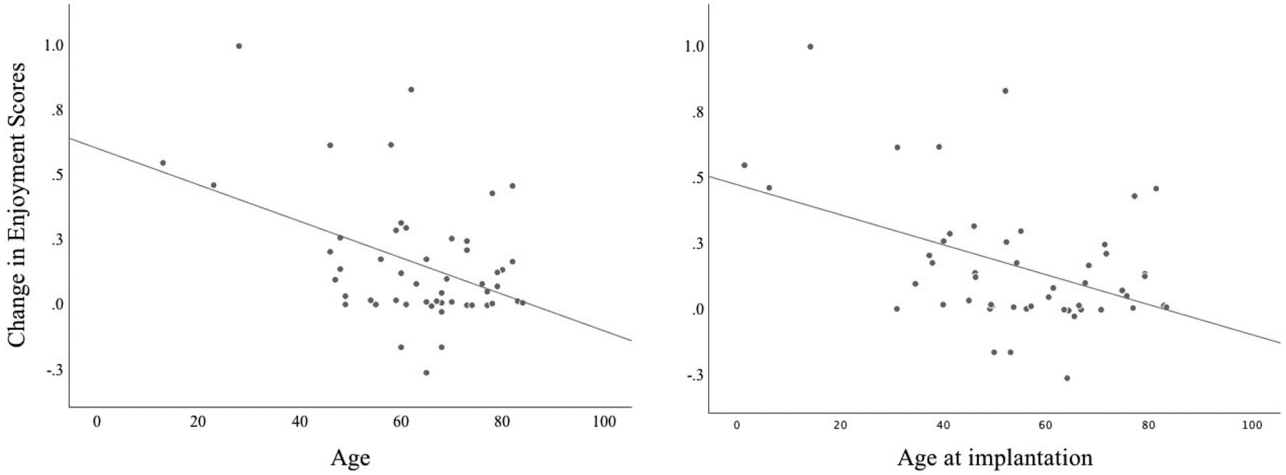

Figure 5. Change in sound enjoyment scores over time by age-related factors. Age and age at implantation significantly predicted worsening sound enjoyment over time when comparing sound enjoyment scores soon after implantation with the current time point.

less appropriate. However, greater length of implantation may confer a benefit to self-reported sound quality and enjoyment scores. Our findings suggest that greater length of implantation was associated with higher current quality and enjoyment scores, as well as improvement of sound quality over time but not sound enjoyment. Of note, younger

Table 3. Adjective Descriptors of Sound Experience.

Sound description	No. (%)
High-frequency distortion or bias	
Tinny	28 (47)
Sharp	19 (32)
Cartoonish	12 (20)
"Mickey Mouse"	10 (17)
"Munchkin" in *Wizard of Oz*	9 (15)
Helium	5 (8)
Screechy	5 (8)
Artificial or robotic	
Synthesizer	10 (17)
Robotic	7 (12)
Static	6 (10)
"Darth Vader"	1 (2)
Other	
Echoey	30 (50)
Monotone	9 (15)
None	5 (8)
Resolution of all descriptors	21 (35)

participants in our cohort were more likely to have a greater length of implantation. Taken together, our data support the premise that patients who undergo implantation at a younger age and have longer duration of implant use may have more favorable outcomes as they grow older, as compared with those who undergo implantation at a later age.

These age-related and temporal effects suggest a degree of adaptation and may be correlated to changes in cognitive function and central auditory processing over time. Prior studies have demonstrated that higher-order auditory centers are capable of functional reorganization and neuroplasticity in pediatric and adult populations.[15-17] However, this neuroplasticity has predominantly been studied in pediatric and young adult populations. Rouger et al found that 97 CI users (mean age, 56 years) had superior abilities to integrate visual inputs with speech signals, suggesting improved reorganization of the cortical networks involved in speech recognition to allow input from visual areas.[18] Such reorganization has been shown on imaging studies of CI recipients. Lee et al studied 8 CI recipients before and after cochlear implantation and noted that patients who had hypometabolic areas in the auditory cortex prior to implantation recovered to normal levels after cochlear implantation. This was consistent with improvements in speech perception performance.[19] Our findings on older participants (mean age, 63 years) suggest that age of implantation and length of implantation may affect CI recipients' ability to adapt after implantation. Future studies should aim to explore the relationship between self-reported outcomes and cognitive testing in patients with CIs.

Bilateral cochlear implantation has been suggested to provide better sound enjoyment and quality.[20,21] Some studies have found that bilateral implantation improved functional outcomes, such as sound localization and speech perception in noise, as well as subjective quality outcomes when compared with patients with unilateral implantation. Our findings did not reveal a significant association of bilateral implantation with sound quality or enjoyment across any time point. However, our study may not be adequately powered to detect this difference, with only 20 (33.3%) participants having bilateral CIs. Last, prior studies have demonstrated significant differences in speech perception outcomes depending on side of implantation in older adults due to asymmetry of speech processing in central auditory pathways.[20,21] However, our findings did not show a statistically significant association between CI laterality and sound perception.

We hypothesized that musical training would influence self-reported sound quality and enjoyment, but our study findings do not support any significant association. This association has been examined in previous studies, but a firm association between musical training and sound perception is not clear. Gfeller et al found that music listening experience prior to implantation was associated with improved song recognition as well as higher enjoyability of music,[12] though other studies have not supported this association.[9,22]

There are limitations to the current study. Our findings were subject to recall bias, as the survey asked participants to remember their perception of sound quality and enjoyment prior to implantation, which occurred an average of 8 years prior to the study. The study also evaluated only postoperative assessments of sound perceptions and did not investigate preoperative perception of sound. In addition, there was a relatively low response rate and thus potential for nonresponse bias. Several surveys were not included in the final analysis because they contained inappropriate responses to some of the questions, particularly for the visual analog portions. These were likely due to misunderstanding the instructions and a lack of familiarity with visual analog scales. Last, high levels of multicollinearity among age-related factors precluded a multivariate analysis of these variables and their impact on sound quality and enjoyment. Nevertheless, our research is one of few studies to explore self-reported sound perceptions over time in this population and, therefore, may offer important insight into these subjective outcomes.

Subjective measures such as sound quality and enjoyment should be more routinely used to supplement functional outcome measurements to provide a more comprehensive understanding of the impact of cochlear implantation on the total experience of hearing. A better understanding of the overall experience of sound over time may play an important role in managing patient expectations regarding overall auditory capabilities following cochlear implantation and facilitate more informed decision making in this patient population. Future studies should focus on the prospective evaluation of sound quality and enjoyment pre- and postoperatively, as well as the investigation of cognitive measures as a predictor for these outcomes.

Conclusion

Older CI recipients and those who underwent implantation at an older age reported poorer sound quality and enjoyment as

well as a worsening sound quality and enjoyment over time, indicating that age-related changes influence outcomes of cochlear implantation. However, CI recipients with a longer duration of CI experience had higher quality of sound perception, suggesting a degree of adaptation.

Author Contributions

Sarah Y. Bessen, data collection, data analysis and interpretation, manuscript writing and revision; **James E. Saunders**, study design, data analysis and interpretation, manuscript revision; **Eric A. Eisen**, study design, data analysis and interpretation; **Isabelle L. Magro**, study design, data analysis and interpretation, manuscript writing and revision.

Disclosures

Competing interests: None.

Sponsorships: None.

Funding source: None.

Supplemental Material

Additional supporting information is available at http://journals.sagepub.com/doi/suppl/10.1177/2473974X211031471

References

1. World Health Organisation. *Deafness and Hearing Loss Factsheet*. World Health Organisation; 2017.
2. Zeng F-G, Yang S-M, Gao Z. Cochlear implantation. *Hearing Journal*. 2015;68(7):8-9. doi:10.1097/01.hj.0000469514.54428.eb
3. Dorman MF, Natale SC, Butts AM, Zeitler DM, Carlson ML. The sound quality of cochlear implants: studies with single-sided deaf patients. *Otol Neurotol*. 2017;38(8):e268-e273.
4. Gfeller K, Turner C, Mehr M, et al. Recognition of familiar melodies by adult cochlear implant recipients and normal-hearing adults. *Cochlear Implants Int*. 2002;3(1):29-53.
5. Gfeller K, Olszewski C, Rychener M, et al. Recognition of ''real-world'' musical excerpts by cochlear implant recipients and normal-hearing adults. *Ear Hear*. 2005;26(3):237-250.
6. Schulz E. Music perception with the MED-EL implants. In: Hochmair-Desoyer IJ, Hochmair ES, eds. *Advances in Cochlear Implants*. Manz; 1994:326-332.
7. Gfeller K, Knutson JF, Woodworth G, Witt S, DeBus B. Timbral recognition and appraisal by adult cochlear implant users and normal-hearing adults. *J Am Acad Audiol*. 1998;9(1):1-19.
8. Gfeller K, Witt S, Stordahl J, Mehr M, Woodworth G. The effects of training on melody recognition and appraisal by adult cochlear implant recipients. *J Acad Rehabil Audiol*. 2000;33:115-138.
9. Fujita S, Ito J. Ability of nucleus cochlear implantees to recognize music. *Ann Otol Rhinol Laryngol*. 1999;108(7, pt 1):634-640.
10. Mertens G, Kleine Punte A, De Bodt M, Van de Heyning P. Sound quality in adult cochlear implant recipients using the HISQUI19. *Acta Otolaryngol*. 2015;135(11):1138-1145.
11. Limb CJ, Francis HW, Niparko JK. Cochlear implantation: results, outcomes, rehabilitation, and education. In: Flint PW, Haughey BH, Lund V, et al, eds. *Cummings Otolaryngology: Head and Neck Surgery*. 6th ed. Elsevier Saunders; 2015:2455-2471.
12. Gfeller K, Oleson J, Knutson JF, Breheny P, Driscoll V, Olszewski C. Multivariate predictors of music perception and appraisal by adult cochlear implant users. *J Am Acad Audiol*. 2008;19(2):120-134.
13. Wright R, Uchanski RM. Music perception and appraisal: cochlear implant users and simulated cochlear implant listening. *J Am Acad Audiol*. 2012;23(5):350-365.
14. Amann E, Anderson I. Development and validation of a questionnaire for hearing implant users to self-assess their auditory abilities in everyday communication situations: the Hearing Implant Sound Quality Index (HISQUI19). *Acta Otolaryngol*. 2014;134(9):915-923.
15. Ramsden RT. Cochlear implants and brain stem implants. *Br Med Bull*. 2002;63:183-193.
16. Cordes M, Wszolek ZK. Deafness and cerebral plasticity. *J Nucl Med*. 2003;44(9):1440-1442.
17. Fallon JB, Irvine DRF, Shepherd RK. Cochlear implants and brain plasticity. *Hear Res*. 2008;238(1-2):110-117.
18. Rouger J, Lagleyre S, Fraysse B, Deneve S, Deguine O, Barone P. Evidence that cochlear-implanted deaf patients are better multisensory integrators. *Proc Natl Acad Sci U S A*. 2007;104(17):7295-7300.
19. Kang KW, Lee JS, Kim SK, et al. Comparison of F-18-FDG PET findings before and after cochlear implantation in deaf pateints. *J Nucl Med*. 2000;41:215.
20. Morris LG, Mallur PS, Roland JT Jr, Waltzman SB, Lalwani AK. Implication of central asymmetry in speech processing on selecting the ear for cochlear implantation. *Otol Neurotol*. 2007;28(1):25-30.
21. Budenz CL, Cosetti MK, Coelho DH, et al. The effects of cochlear implantation on speech perception in older adults. *J Am Geriatr Soc*. 2011;59(3):446-453.
22. Looi V, Wong Y, Loo JHY. The effects of training on music perception and appreciation for cochlear implant recipients. *Advances in Otolaryngology*. 2016;2016. doi:10.1155/2016/6286514.