# Computer-based Auditory Training by New Adult Cochlear Implant Recipients Is Associated With Durable Improvements in Cochlear Implant Quality of Life

James R. Dornhoffer, Christian Shannon, Kara C. Schvartz-Leyzac, Judy R. Dubno, and Theodore R. McRackan

**Objective:** The process of adapting to communicate with a cochlear implant (CI) is complex. The use of auditory training after cochlear implantation may help to facilitate improvements in postoperative speech recognition and quality-of-life outcomes in new adult CI recipients. However, the effectiveness of auditory training remains uncertain and long-term effects have not been examined in a large sample of new adult CI users. As such, the objective of this study was to examine the influence of common forms of auditory training on speech recognition and CI-related quality-of-life (CI-related QOL) outcomes at 1 year after cochlear implantation. We hypothesized that patients who reported use of computer-based auditory training (CBAT) would show improved speech and CIQOL-35 Profile scores at 1 year after activation of their implant, compared with their peers.

**Design:** This study was designed as a prospective study and was undertaken at a tertiary academic CI center. Participants included 114 adults undergoing cochlear implantation for bilateral hearing loss. Patients serially self-reported use of the following types of post-CI auditory training over their first-year postactivation: (1) face-to-face training (e.g., speech-language pathologist), (2) passive home-based training (e.g., listening to audiobooks), and (3) CBAT (e.g., self-directed software). Outcomes measures for this study included change in Consonant-Nucleus-Consonant phoneme (CNCp), CNC word (CNCw), AzBio sentences in quiet, and CIQOL-35 Profile global and domain scores from pre-CI to 12-mo post-CI.

**Results:** Of 114 patients, 94 (82.5%) used one or more auditory training resources. Of these, 19.3% used face-to-face training, 67.5% passive home-based training, and 46.5% CBAT. Of 114 patients, 73 had complete CIQOL data. At 12 mo, only CBAT use was associated with significantly greater improvements in global and all domain-specific CIQOL scores ($d$-range = 0.72–0.87), compared with those not using CBAT. Controlling for demographics and use of multiple training resources, CBAT remained the strongest positive predictor of CIQOL improvement, with significant associations with global score (ß = 12.019[4.127,19.9]) and all domain scores at 12-mo post-CI: communication (ß = 11.937 [2.456,21.318), emotional (ß = 12.293[1.827,22.759), entertainment (ß = 17.014[5.434,28.774), environment (ß = 13.771[1.814,25.727]), listening effort (ß = 12.523[2.798,22.248]), and social (ß = 18.114 [7.403,28.826]). No significant benefits were noted with use of CBAT or any other form of auditory training and speech recognition scores at 12-mo post-CI ($d$-range = –0.12–0.22).

**Conclusions:** Auditory training with CBAT was associated with improved CI-related QOL outcomes at 12-mo post-CI. Given its availability and low cost, this study provides evidence to support using CBAT to improve real-world functional abilities in new adult CI recipients.

Department of Otolaryngology—Head and Neck Surgery, Medical University of South Carolina, Charleston, South Carolina.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and text of this article on the journal's Web site (www.ear-hearing.com).

**Key words:** Auditory training, Aural rehabilitation, Cochlear implant, Computer-based auditory training.

(Ear & Hearing 2024;45;905–914)

## INTRODUCTION

Hearing with a cochlear implant (CI) differs from acoustic hearing in that patients must first learn to process and decode a degraded electrical signal from their implant. For some, this learning is acquired passively during routine use of their device, but many patients require active effort to acquire functionality with their CI (Manrique et al. 1998; Dillon et al. 2013; Dornhoffer 2019). Most patients are advised to use some form of auditory training to improve this process by exposing them to a variety of speech and environmental sounds (Henry et al. 2005; Fu & Galvin 2008; Stacey & Summerfield 2008; Humes et al. 2009; Harris et al. 2016; Reis et al. 2019). Training can be performed by several methods, and in most CI centers is primarily patient-initiated/directed. Various resources can be broadly grouped into three categories: (1) face-to-face training with an audiologist or speech-language pathologist, (2) passive home-based training such as listening to an audiobook or radio, or (3) computer-based auditory training (CBAT) with self-directed, interactive computer software.

Evidence on the effectiveness of these interventions is limited, with preliminary evidence showing benefit for face-to-face training and CBAT over passive training (Dornhoffer et al. 2022; Ma et al. 2023); however, many studies are limited due to poor ecological validity, using experimental programs with small samples of experienced implant users (Fu & Galvin 2007, 2008; Stacey & Summerfield 2008; Humes et al. 2009; Plant et al. 2015; Harris et al. 2016). Systematic analysis of this literature has been performed in CI users and in mixed populations of CI and hearing aid users (Henshaw & Ferguson 2013; Cambridge et al. 2022). Authors conclude that training generally provides benefit, but conclusions are limited by the available literature. Many studies also do not comment on patient-reported outcome measures. Speech recognition measures often correlate poorly with quality-of-life metrics and may be insensitive to some improvements in real-world functional abilities following implantation (Dorismond et al. 2023). As such, consideration of patient-reported outcome metrics is valuable for analysis of any peri-CI interventions.

A recent study on the effectiveness of commonly available resources with new implant recipients showed consistent improvements in speech recognition and CI-related quality-of-life (CI-related QOL) with CBAT (Dornhoffer et al. 2022). However, this study provided evidence only for the first 3-mo

0196/0202/2024/454-905/0 • Ear & Hearing • Copyright © 2024 Wolters Kluwer Health, Inc. All rights reserved • Printed in the U.S.A.



Copyright © 2024 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

<zdoi; 10.1097/AUD.0000000000001486>

post-CI activation. Given that some patients reach their peak performance between 6 and 12 mo, the full, persistent effects of CBAT and other interventions in this setting remain uncertain (Cusumano et al. 2017; Ma et al. 2023).

Therefore, the goal of this study was to determine the relationship between use of commonly available forms of auditory training and CI outcomes at 12-mo post-CI. We hypothesized that the use of CBAT would yield persistent speech and CI-related QOL benefits. By observing this cohort of patients over their first-year after implantation, this study may provide more detailed evidence of the effectiveness of common auditory training resources that can support recommendations to guide post-CI interventions.

## MATERIALS AND METHODS

### Patient Sample

This study was approved by our university Institutional Review Board. Data were collected prospectively from patients undergoing unilateral cochlear implantation from September 2018 to December 2020. Inclusion criteria were CI candidacy for bilateral sensorineural hearing loss and age ≥18 years. Patients undergoing revision implantation, second-sided cochlear implantation, or implantation for unilateral deafness were excluded. Patients were identified/enrolled at routine programming visits with audiology. Enrollment was voluntary and subject to oral consent at time of survey collection-detailed later.

Surgeries were performed by four attending neurotologists at an academic, tertiary referral hospital. Intraoperative device testing, postoperative programming, and pre- and post-CI speech recognition testing were performed by CI audiologists at the same center.

### Auditory Training Interventions

Upon CI activation and at routine audiology appointments, patients were provided a list of resources for passive home-based training and a list of websites to access computer-based training programs, by their audiologist. The list of resources was identical for all patients at our institution and was not modified for use in this study. Patients were also offered referrals to speech-language pathologists for face-to-face auditory training based on a perceived need or patient preference. Use of any resource was voluntary, and routine clinical practice was followed.

Face-to-face training included all speech-language pathology visits but did not include any routine auditory training performed during CI audiology appointments. Passive home-based training included reading aloud, having someone else read to the patient, or listening to audiobooks, radio, or TV. Computer-based auditory training included use of software developed by Advanced Bionics (Valencia, CA) and Cochlear Americas (Englewood, CO) as well as Listening and Communication Enhancement (LACE) (Sweetow & Sabes 2006), Angel Sound (Fu et al. 2004), and Hearoes (Brisbane, Australia).

### Data Collection

Patients completed surveys (File 1 in Supplemental Digital Content 1, http://links.lww.com/EANDH/B327) on auditory training participation through a REDCap database during routine audiology follow-ups (Harris et al. 2009). Surveys were obtained at 3-, 6-, and 12-mo post-CI. Speech recognition and patient-reported outcomes, detailed later, were also obtained at 3-, 6-, and 12-mo post-CI. Given insufficient data and significant overlap with previous 3-mo data, 6-mo data were not considered for further analysis. Pre-CI speech recognition and patient-reported outcomes were obtained at CI candidacy evaluation as part of routine clinical practice. Surveys or outcome data collected within 1 mo before or after aforementioned timepoints were included. Data on education, income, employment, and habitation were obtained through an additional survey performed at initial enrollment. Data on race (White/Non-White), age, and sex were collected as defined in institutional electronic health records to identify and control for any confounding effects.

### Outcome Measures

Outcome measures were changes in speech recognition scores (Consonant-Nucleus-Consonant phonemes [CNCp], CNC words [CNCw] (Tillman & Carhart 1966) and AzBio sentences in quiet [AzBio Quiet]) (Spahr et al. 2012) and changes in Cochlear Implant Quality of Life-35 (CIQOL-35) Profile instrument (detailed later) score from pre-CI to 3-, 6-, and 12-mo post-CI (McRackan et al. 2019, 2021). Standard practice at our center is to only measure AzBio sentences in noise outcomes when patients score ≥50% for AzBio Quiet. Thus, AzBio sentences in noise were not considered for evaluation secondary to low collection rates.

Pre-CI speech recognition was measured with hearing aids fitted to National Acoustics Laboratory–revised linear (NAL-NL2) targets (Byrne & Dillon 1986). Post-CI speech recognition testing was conducted using recorded materials presented from 0° azimuth at 60-dB sound pressure level. The implanted ear was tested independently, with the contralateral ear plugged during testing if the patient had sufficient residual hearing in the contralateral ear where cross over could be expected.

The CIQOL-35 Profile is a patient-reported outcome measure that assesses the functional abilities of adult CI recipients within 6 domains: communication (assessing communication ability in different circumstances), emotional (assessing the impact of hearing on emotional well-being), entertainment (assessing the ability to enjoy TV, radio, and music), environment (assessing the ability to distinguish and localize environmental sounds), listening effort (assessing effort and fatigue associated with receptive communication), and social (assessing the ability to interact and enjoy interaction with groups). A global score is calculated that provides a general assessment of CI-specific QOL. Scores were calculated for each domain and ranged from 0 (lowest QOL) to 100 (highest QOL) (McRackan et al. 2019, 2021).

### CI Use

Data logs for CI use were collected during routine audiologic visits. Data were collected using each implant company's proprietary data-logging software. Data presented here represent the average daily hours of use as measured at 12-mo post-CI.

Copyright © 2024 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

## Statistical Analyses

Statistical analyses were performed using SPSS version 25 (IBM Corporation, Armonk, New York). Continuous variables were summarized by mean ± standard deviation. Cohen's *d* effect sizes 95% confidence intervals (CI), denoted as "*d* [lower CI, upper CI]," were calculated where appropriate. Effect sizes were interpreted as per Cohen's conventions: ≥0.2 and <0.5 = small effect, ≥0.5 and <0.8 = medium effect, and ≥0.8 = large effect (Cohen 2013). For patient-specific factors, Fisher's exact test was used for categorical comparisons, and the Kruskal-Wallis test was used for analysis of multiple means.

Power analysis was performed in a *post hoc* fashion based on previously published data on this subject matter (Dornhoffer et al. 2022). We assumed a medium effect size (d = 0.5) and a target power of 80%. Assuming 2-sided hypothesis testing and $\alpha = 0.05$, a sample size of 31 was considered sufficient to detect significant differences between forms of aural rehabilitation and their correlation with outcome measures. As such, while auditory training was voluntary, enrollment of participants was continued until desired sample sizes were approached for different auditory training modalities.

For primary analysis of the influence of training resources on outcomes, a Wilcoxon signed-rank test was used to compare data between patients using any training resource and those using no resource. Such analysis was also performed to compare outcomes between patients using face-to-face training, passive home-based training, or CBAT compared with those patients not using that resource.

Multivariable regression was performed to identify significant independent associations of training resources with speech recognition and CIQOL-35 outcomes while controlling for confounding variables of age, sex, duration of hearing loss, and simultaneous use of multiple types of auditory training. Variance inflation factor was used to detect collinearity. Missing data for some nonoutcome covariables in the multivariable analysis were dealt with using multiple-imputation. Specifically, age was imputed for 1 patient and duration of hearing loss for 7 patients. ß values and coefficients of determination ($R^2$) are presented.

# RESULTS

## Patient Sample

A total of 114 patients were enrolled in this study. Of these, 94 (82.5%) used at least one form of training resource in the first-year post-CI. Regarding specific forms of auditory training, 22 (19.3%) of all enrolled patients used face-to-face training, 77 (67.5%) passive home-based training, and 53 (46.5%) CBAT. Considering use of multiple resources at one time, 38.6% of patients used only one category of training, 36.8% used two categories, and 7.0% used all three categories.

Patient demographics and lifestyle factors are detailed in **Table 1**. Comparisons between patients using or not using a specific category of auditory training were made regarding age, sex (male/female), race (White/non-White), duration of hearing loss (years), education (completed college, yes/no), current employment (yes/no), household income (≥ or <$50,000), and total hours of CI use and use in noise per day. No significant differences were noted in these variables (all $p > 0.05$).

**TABLE 1. Patient characteristics**

| N | 114 |
|---|---|
| **Mean age—y (SD)** | 67.7 (14.7) |
| **Mean duration of hearing loss—y (SD)** | 24.0 (16.4) |
| **Mean CI use—h/d (SD)** | 11.8 (3.1) |
| **Mean CI use in noise—h/d (SD)** | 1.63 (1.23) |
| **CI manufacturer (N, %)** | |
| Cochlear Americas | 83 (72.8) |
| Advanced bionics | 26 (22.8) |
| MED-EL | 5 (4.4) |
| **Sex (N, %)** | |
| Male | 59 (51.8) |
| Female | 55 (48.2) |
| **Race (N, %)** | |
| White | 100 (87.7) |
| Non-White | 14 (12.3) |
| **Completed college (N, %)** | |
| Yes | 52 (45.6) |
| No | 62 (54.4) |
| **Currently employed (N, %)** | |
| Yes | 27 (23.7) |
| No | 82 (71.9) |
| Chose not to reply | 5 (4.4) |
| **Household income (N, %)** | |
| ≥$50,000 per year | 44 (38.6) |
| <$50,000 per year | 35 (30.7) |
| Chose not to reply | 35 (30.7) |

*SD, standard deviation.*

Pre-CI speech testing and CIQOL scores are considered for each intervention group. Pre-CI CNCp, CNCw, AzBio Quiet, and global CIQOL-35 scores are detailed in **Table 2**. No significant difference are noted between usage groups. In addition, no significant differences are noted in any CIQOL-35 domain score between usage groups (all $p > 0.05$)

## Influence of Auditory Training on Speech Recognition

Changes in speech recognition scores for all 114 patients, broken into cohorts based on the use/nonuse of different types of auditory training are shown in **Table 3**. Overall, patients showed an average improvement in CNCp (46.9%±28.0), CNCw (42.1%±25.6), and AzBio Quiet (51.9%±30.9) scores from pre-CI to 12-mo post-CI. No significant effects from the use of any nonspecific auditory training were noted on 12-mo pre/post-CI change in speech recognition scores (*d*-range = 0.03–0.47). When considering specific types of auditory training, no significant differences were noted between users and nonusers of each type of resource, with respect to pre/post-CI change in speech recognition at 12 mo (*d*-range = –0.12–0.22).

A multivariable regression was performed as detailed earlier. After accounting for potential confounders, the use of any specific type of auditory training was not significantly associated with pre/post-CI differences in speech recognition scores, nor were there any significant associations with age, duration of hearing loss, or sex. A Kruskal-Wallis test was performed comparing speech recognition outcomes between patients utilizing one, two, or three types of training to determine any effects from use of multiple resources. No significant differences were noted between groups ($p > 0.05$) (**Table 4**).

Copyright © 2024 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

**TABLE 2. Comparisons of Pre-CI speech recognition and CIQOL-35 scores between auditory training use categories**

| | | Any Training | | Effect Size *d* | Face-to-face Training | | Effect Size *d* | Passive Home-based Training | | Effect Size *d* | Computer-based Training | | Effect Size *d* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All Patients | Yes | No | [95% CI] | Yes | No | [95% CI] | Yes | No | [95% CI] | Yes | No | [95% CI] |
| N speech recognition (%) | 114 (100) | 94 (82.5) | 20 (17.5) | | 22 (19.3) | 92 (80.7) | | 77 (67.5) | 37 (32.5) | | 53 (46.5) | 61 (53.5) | |
| CNCp % correct (SD) | 24.2 (23.8) | 23.0 (23.2) | 30.0 (26.3) | −0.30 [−0.79, 0.19] | 26.0 (22.2) | 23.8 (24.2) | 0.09 [−0.39, 0.57] | 23.1 (23.2) | 30.1 (26.3) | −0.30 [−0.79, 0.20] | 24.3 (23.8) | 24.2 (23.9) | 0.003 [−0.37, 0.38] |
| CNCw % correct (SD) | 12.3 (16.0) | 11.9 (15.4) | 14.4 (18.8) | −0.16 [−0.65, 0.34] | 12.0 (12.2) | 12.4 (16.8) | −0.022 [−0.50, 0.45] | 11.9 (15.4) | 14.4 (18.8) | −0.157 [−0.65, 0.34] | 12.8 (16.6) | 12.0 (15.5) | 0.049 [−0.32, 0.42] |
| AzBio Quiet % correct (SD) | 15.4 (20.3) | 15.6 (20.7) | 14.6 (18.7) | 0.05 [−0.44, 0.54] | 14.1 (17.9) | 15.7 (20.9) | −0.08 [−0.55, 0.39] | 15.6 (20.7) | 14.6 (18.7) | 0.049 [−0.44, 0.54] | 14.9 (21.0) | 15.9 (19.6) | −0.047 [−0.42, 0.32] |
| N CIQOL-35 (%) | 73 (100) | 63 (86.3) | 10 (13.7) | | 11 (15.1) | 62 (84.9) | | 59 (80.8) | 14 (19.2) | | 32 (42.8) | 41 (56.2) | |
| Global CIQOL score | 36.3 (8.9) | 35.9 (8.5) | 38.8 (11.2) | 0.25 [−0.42, 0.92] | 34.5 (10.8) | 36.6 (8.6) | 0.24 [−0.88, 0.40] | 35.9 (8.5) | 37.8 (10.7) | −0.21 [−0.78, 0.36] | 34.0 (8.2) | 38.0 (9.2) | 0.45 [0.98, 0.015] |

*95% CI, 95% confidence interval; CIQOL, Cochlear Implant Quality of Life, CNCp, consonant-nucleus-consonant phoneme; CNCw, consonant-nucleus-consonant word; SD, standard deviation.*

**TABLE 3. Comparisons of change in speech recognition scores from pre-CI to 12-mo post-CI between auditory training use categories**

| | | Any Training | | Effect Size *d* | Face-to-face Training | | Effect Size *d* | Passive Home-based Training | | Effect Size *d* | Computer-based Training | | Effect Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All Patients | Yes | No | [95% CI] | Yes | No | [95% CI] | Yes | No | [95% CI] | Yes | No | *d* [95% CI] |
| N (%) | 114 (100) | 94 (82.5) | 20 (17.5) | | 22 (19.3) | 92 (80.7) | | 77 (67.5) | 37 (32.5) | | 53 (46.5) | 61 (53.5) | |
| CNCp % correct (SD) | 46.9 (28.0) | 48.8 (26.9) | 37.1 (33.0) | 0.42 [−0.14, 0.97] | 44.1 (19.3) | 47.5 (29.8) | −0.12 [−0.65, 0.41] | 48.8 (28.7) | 43. 17 (27.0) | 0.22 [−0.24, 0.64] | 49.2 (27.0) | 44.3 (29.5) | 0.17 [−0.24, 0.58] |
| CNCw % correct (SD) | 42.1 (25.6) | 43.3 (25.5) | 36.3 (26.6) | 0.27 [−0.28, 0.82] | 42.4 (26.9) | 40.8 (20.5) | 0.06 [−0.47, 0.59] | 42.2 (26.0) | 41.9 (25.4) | 0.01 [−0.43, 0.45] | 44.7 (27.0) | 39.1 (24.1) | 0.22 [−0.19, 0.63] |
| AzBio Quiet % correct (SD) | 51.8 (30.9) | 51.9 (32.4) | 50.9 (23.9) | 0.03 [−0.54, 0.60] | 50.3 (26.3) | 52.1 (32.4) | −0.06 [−0.57, 0.46] | 51.8 (33.9) | 51.7 (25.0) | 0.004 [−0.43, 0.44] | 53.6 (31.9) | 49.7 (30.5) | 0.12 [−0.29, 0.54] |

*95% CI, 95% confidence interval; CNCp, consonant-nucleus-consonant phoneme; CNCw, consonant-nucleus-consonant word; SD, standard deviation.*

Copyright © 2024 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

**TABLE 4. Multivariable regression of factors associated with change in speech recognition scores from pre-CI to 12-mo post-CI**

| | CNCp Score (%) | | CNCw score (%) | | AzBio Quiet score (%) | |
|---|---|---|---|---|---|---|
| | Model F = 0.750, $p$ = 0.661, $R^2$ = 0.053 | | Model F = 1.199, $p$ = 0.315, $R^2$ = 0.083 | | Model F = 1.602, $p$ = 0.158, $R^2$ = 0.108 | |
| | ß (95% Confidence Interval) | VIF | ß (95% Confidence Interval) | VIF | ß (95% Confidence Interval) | VIF |
| **Age at implantation (years)** | –0.152 [–0.607, 0.303] | 1.148 | –0.345 [–0.751, 0.062] | 1.148 | –0.481 [–0.970, 0.008] | 1.118 |
| **Duration of hearing loss (years)** | –0.115 [–0.518, 0.288] | 1.044 | –0.220 [–0.580, 0.140] | 1.044 | –0.227 [–0.658, 0.401] | 1.059 |
| **Female sex** | 7.404 [–5.628, 20.426] | 1.142 | 3.226 [–8.425, 14.877] | 1.142 | 9.365 [–4.447, 23.176] | 1.118 |
| **Face-to-face auditory training** | –7.782 [–23.536, 7.971] | 1.056 | –6.241 [–20.325, 7.843] | 1.056 | –7.830 [–24.274, 8.615] | 1.051 |
| **Passive home-based auditory training** | 3.056 [–10.223, 16.335] | 1.042 | –3.051 [–14.922, 8.821] | 1.042 | –6.051 [–20.352, 8.250] | 1.035 |
| **Computer-based auditory training** | 5.485 [–7.013, 17.984] | 1.046 | 6.324 [–4.850, 17.499] | 1.046 | 5.517 [–8.084, 19.117] | 1.072 |

*CNCp, consonant-nucleus-consonant phoneme; CNCw, consonant-nucleus-consonant word; CIQOL, Cochlear Implant Quality of Life; VIF, variance inflation factor.*
*Bolded text denotes a significant association.*

### Influence of Auditory Training on CIQOL-35 Profile Scores

CIQOL-35 outcomes were available for 73 of 114 patients, **Table 5**. Overall, patients showed an average increase from pre- to 12-mo post-CI in global CIQOL scores of 13.1 ± 16.3 and an increase in scores for all CIQOL domains for the same period (average change in domain score ranged from 14.5 ± 22.6 for the Social domain to 19.9 ± 24.6 for the Environment domain). Use of any nonspecific auditory training was not significantly associated with greater improvements in CIQOL-35 domain scores or global score at 12 mo, compared with those who used no resource. In contrast, the use of CBAT, specifically, was associated with significant, medium-to-large, beneficial effects for all CIQOL-35 Profile domains ($d$-range = 0.72–0.87), **Figure 1**, **Table 5**. Use of face-to-face and passive home-based training showed no significant association with change in CIQOL scores.

After accounting for potential confounders in our multivariable analysis (results detailed in **Table 6**), CBAT use was an independent predictor of change in global scores (ß = 12.019 [4.127, 19.9]) as well as all domain scores from pre-CI to 12-mo post-CI, (ß range = 11.937–21.318). Interestingly, greater duration of hearing loss was associated with a significantly greater change (ß = 0.318 [0.027, 0.609]) in the communication domain from pre-CI to 12-mo post-CI; however, the effect was small. No other significant associations were noted. As with speech recognition, to evaluate the effect of simultaneous use of multiple resource categories, a Kruskal-Wallis test was performed comparing CIQOL scores between patients utilizing one, two, or three types of training resources. No significant differences were noted between these groups (all $p > 0.05$).

### Influence of CBAT From 3-mo to 12-mo Post-CI

We previously published data on a similar, overlapping, adult cohort examining the effects of auditory training on CI outcomes at 3-mo post-CI (Citation masked to maintain anonymity during peer-review). In this previous analysis, we noted that 24 patients using CBAT showed significantly greater improvement in both speech recognition (AzBio: 49.8% ± 29.7 vs. 16.3% ± 29.7) and CIQOL scores (CIQOL-35 Global: 11.9 ± 6.3 vs. 3.7 ± 6.8) from pre-CI to 3-mo post-CI, as compared to 48 patients who did not use CBAT (citation masked to maintain anonymity during peer-review). However, the current data show that by 12-mo post-CI, patients who did and did not use CBAT had similar improvements in speech recognition (AzBio: 53.6% ± 31.9 vs. 49.7% ± 30.5) from pre-CI to 12-mo post-CI; but in contrast, patients who used CBAT had greater improvement in CIQOL scores (CIQOL-35 Global: 20.6 ± 16.8 vs. 7.3 ± 13.4) by 12 mo. Considering both analyses, it appears that benefits from CBAT on CIQOL score persisted from 3- to 12-mo post-CI, even if benefits regarding speech recognition did not (**Figures 2** and **3**).

## DISCUSSION

Auditory training is often recommended to new CI recipients to improve or hasten their acquisition of speech recognition skills, with a majority of surveyed audiologists considering it an essential part of CI aural rehabilitation (Reis et al. 2019). Despite this endorsement, there is limited evidence of the real-world effectiveness of such interventions (Fu & Galvin 2007; Plant et al. 2015; Harris et al. 2016). In this study, we have observed a cohort of new adult CI recipients from before cochlear implantation to 12-mo postimplantation and have shown CBAT to have persistent beneficial associations with greater improvements in CIQOL scores from pre-CI to 12-mo post-CI than patients who did not use CBAT.

Evidence of the effectiveness of auditory training in adult CI recipients is scarce. Cambridge et al. (2022) reviewed the effectiveness of auditory training in CI users, and Henshaw and Ferguson (2013) reviewed the literature on auditory training in a mixed population of CI and non-CI patients. In addition, independent review revealed a small number of additional studies examining auditory training in CI patients (Barlow et al. 2016; Bernstein et al. 2021; Fu et al. 2004; Gagne et al. 1991; Green et al. 2019; Ihler et al. 2017; Ingvalson et al. 2013; Miller et al. 2008; Moberly et al. 2018; Oba et al. 2011; G. Stacey et al. 2010; Tyler et al. 2010; Plant et al. 2015; Schumann et al. 2015; Reis et al. 2021; Völter et al. 2021). These studies generally show beneficial effects of auditory training, with a trend toward a benefit in speech recognition using face-to-face interaction and CBAT over passive learning. However, these studies are limited in quality, sample size, and heterogeneity. The literature is also limited in ecological validity as the studies mostly examined experimental computer programs or therapies utilized by CI recipients with experience in excess of 12 mo, under strict observation (Gagne et al. 1991; Fu et al. 2004; Miller et al. 2008; Stacey et al. 2010; Tyler et al. 2010;

Copyright © 2024 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

**TABLE 5. Comparison of change in CIQOL-35 scores from pre-CI to 12-mo post-CI between auditory training categories**

| | All Patients | Any Training | | Effect Size *d* [95% CI] | Face-to-face Training | | Effect Size *d* [95% CI] | Passive Home-based Training | | Effect Size *d* [95% CI] | Computer-based Training | | Effect Size *d* [95% CI] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Yes | No | | Yes | No | | Yes | No | | Yes | No | |
| N (%) | 73 (100) | 63 (86.3) | 10 (13.7) | | 11 (15.1) | 62 (84.9) | | 59 (80.8) | 14 (19.2) | | 32 (42.8) | 41 (56.2) | |
| Change in CIQOL Score (SD) | | | | | | | | | | | | | |
| *Global* | 13.1 (16.3) | 13.7 (16.7) | 9.5 (14.0) | 0.25 [–0.42, 0.92] | 14.8 (12.2) | 12.8 (17.0) | 0.12 [–0.53, 0.76] | 13.0 (17.0) | 13.6 (13.6) | –0.03 [–0.62, 0.55] | **20.6 (16.8)** | **7.3 (13.4)** | **0.87 [0.39, 1.36]** |
| *Communication* | 15.3 (19.7) | 16.3 (19.6) | 9.4 (20.0) | 0.34 [–0.33, 1.01] | 15.5 (18.9) | 15.3 (20.0) | 0.01 [–0.63, 0.65] | 15.6 (20.0) | 14.0 (18.9) | 0.08 [–0.50, 0.66] | **23.5 (19.3)** | **8.9 (17.7)** | **0.79 [0.31, 1.26]** |
| *Emotional* | 14.7 (20.9) | 16.4 (21.1) | 3.80 (16.7) | 0.61 [–0.07, 1.28] | 20.8 (18.3) | 13.6 (21.3) | 0.34 [–0.31, 0.98] | 16.0 (21.5) | 9.4 (17.7) | 0.31 [–0.27, 0.90] | **23.4 (22.4)** | **8.0 (17.0)** | **0.78 [0.30, 1.26]** |
| *Entertainment* | 19.2 (23.7) | 20.1 (23.3) | 13.3 (26.7) | 0.28 [–0.39, 0.95] | 16.0 (24.8) | 19.8 (23.7) | –0.16 [–0.80. 0.48] | 18.4 (23.1) | 22.5 (26.9) | –0.17 [–0.75, 0.41] | **29.2 (23.9)** | **11.4 (20.7)** | **0.79 [0.31, 1.27]** |
| *Environmental* | 19.9 (24.6) | 20.3 (25.6) | 16.8 (18.1) | 0.14 [–0.34, 0.95] | 19.6 (26.1) | 19.9 (24.6) | –0.01 [–0.65, 0.63] | 19.2 (25.7) | 22.5 (20.2) | –0.13 [–0.72, 0.45] | **29.4 (25.8)** | **12.4 (21.2)** | **0.72 [0.24, 1.20]** |
| *Listening Effort* | 15.5 (19.5) | 16.7 (18.9) | 7.6 (21.9) | 0.47 [–0.20, 1.14] | 14.1 (17.6) | 15.7 (19.9) | –0.08 [–0.73, 0.56] | 16.6 (19.6) | 10.9 (19.1) | 0.24 [–0.30, 0.87] | **23.3 (19.4)** | **9.4 (17.4)** | **0.75 [0.28, 1.23]** |
| *Social* | 14.5 (22.6) | 14.6 (23.5) | 13.5 (17.0) | 0.05 [–0.34, 0.72] | 21.7 (18.0) | 13.2 (23.3) | 0.37 [–0.27, 1.02] | 14.0 (23.8) | 16.3 (17.2) | –0.10 [–0.68, 0.48] | **24.7 (24.7)** | **6.5 (17.4)** | **0.86 [0.38, 1.34]** |

*95% CI, 95% confidence interval; CIQOL, Cochlear Implant Quality of Life; SD, standard deviation.*
*Bold text shows significant effect sizes.*

Oba et al. 2011; Ingvalson et al. 2013; Schumann et al. 2015; Barlow et al. 2016; Ihler et al. 2017; Green et al. 2019). As such, the results may not be applicable to the average new implant recipient in an outpatient setting. These studies also generally fail to comment on outcomes beyond speech recognition, with only a small number of studies examining patient-reported outcome measures; however, when reported, there was generally an improvement in QOL with auditory training as compared to no training (Moberly et al. 2018; Bernstein et al. 2021; Reis et al. 2021; Völter et al. 2021). The present study aimed to address the limitations of the prior research by providing a real-world perspective on auditory training via examination of commonly available resources used in an outpatient setting and by examining functional abilities beyond speech recognition in the form of the CIQOL-35 Profile scores. This study also provides a holistic perspective on outcomes from pre- to post-CI and the influence that training can have on such outcomes.

We previously published on a similar cohort, using the same methodology, examining the effects of auditory training on adult CI outcomes at 3-mo post-CI (citation masked to maintain anonymity during peer-review). As with the present study, CBAT use was associated with significantly greater improvements in CIQOL from pre-CI than patients who did not use CBAT; however, at the 3-mo timepoint, CBAT use was also associated with significantly greater improvement in speech recognition scores than for patients who did not use CBAT. In the present study, we do not see any significant association between CBAT use and improvement in speech recognition scores from pre-CI to 12-mo post-CI. As such, while benefits related to CBAT use on CIQOL scores are persistent at 12-mo post-CI, benefits related to speech recognition scores are lessened, as speech recognition scores for CBAT nonusers "catch up," **Figures 2 and 3**. Reasons for this cannot be fully explained from the present study although we might consider some possible explanations.

One is that CBAT use allows for early reacquisition of speech recognition skills, as evidenced by the large improvement in speech recognition scores at 3-mo post-CI seen in the prior study (citation masked to maintain anonymity during peer-review). Over time, the CBAT nonusers passively acquire similar levels of performance. However, the early acquisition of skills seen in the CBAT users may build habits and proficiencies not assessed by routine speech recognition measures that, nevertheless, yield improvements in functional abilities as shown by improved CIQOL scores at 12 mo. Another possibility is that the speech recognition measures used in this study may fail to capture meaningful changes in functional ability in these patients. Fu & Galvin (2007) showed, in a study on CI recipients undergoing experimental reprogramming of their implant, that passive acquisition was sufficient to reacquire baseline scores for some but not all tests of speech recognition, with passive learners failing to reacquire skills in tests requiring high levels of bottom-up processing (e.g., low levels of contextual information). In addition, McRackan et al. (2018) showed that speech recognition scores generally showed low correlation with general and CI-specific measures of quality of life. Thus, we must consider that routine speech recognition measures used in our study may be inadequate to show certain differences in speech recognition skills, or that routine speech recognition

Copyright © 2024 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

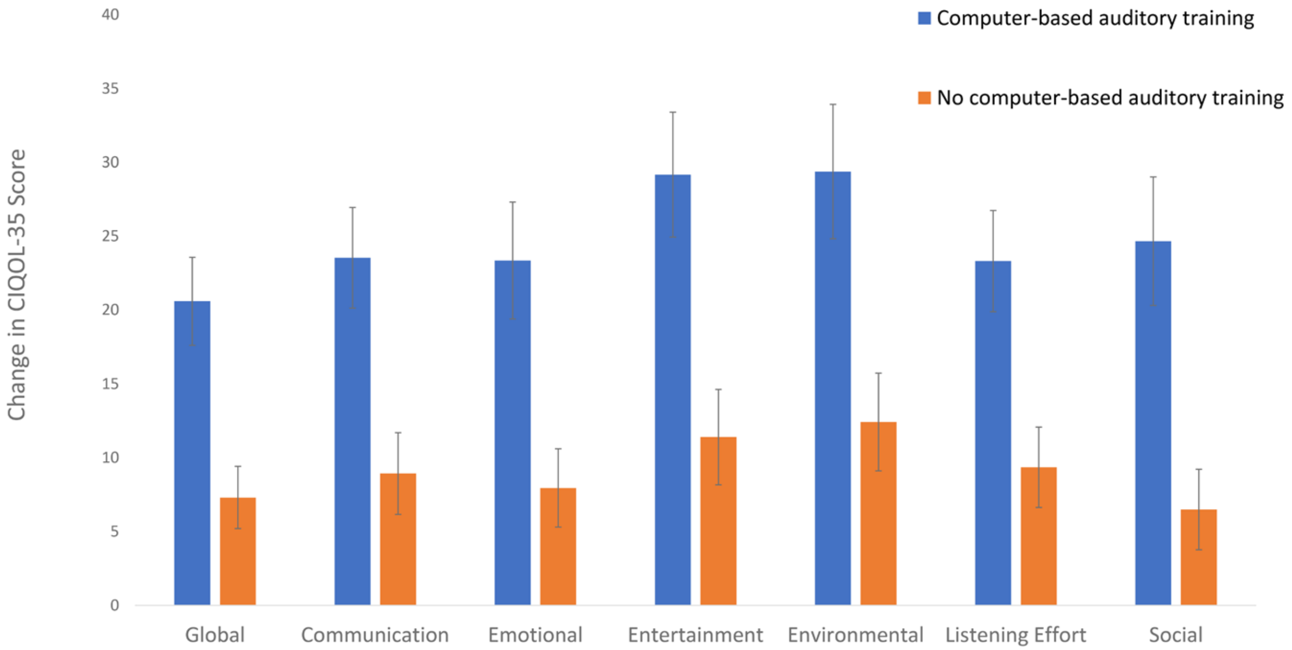


Fig. 1. Change in CIQOL-35 domain and global scores from pre-CI to 12-mo post-CI for users and nonusers of computer-based auditory training. Error bars represent ±1 standard error.

testing typically used to assess CI success may be insufficiently sensitive to improvements in real-world functional abilities after implantation.

Our prior study on 3-mo outcomes and auditory training also noted that the use of face-to-face training was significantly associated with greater improvement in emotional and social CIQOL domain scores than no face-to-face training after controlling for confounding factors. In the present study, we saw a trend toward improvement in these domains, but the relationships were not significant at 12-mo post-CI. It is possible that the present study was underpowered to analyze the effect of face-to-face training. Analysis of face-to-face training may also suffer from selection bias, detailed more later. As such, it is difficult to make conclusions regarding face-to-face training and CIQOL here.

This study has several limitations. The first is the limitation of the survey format and potential lack of reliable patient self-report. To preserve the natural history study design, no auditing or time-tracking of training was used, because this may influence usage. As such, the accuracy of patient report is uncertain and specifics of time spent on each resource inexact. This may limit the conclusions that can be drawn from the study. In addition, this study suffered from selection bias. Auditory training was voluntary, and confounding factors may have influenced the use of specific resources. For example, while most resources in this study are free or affordable, face-to-face training often has costs, both financially, and it in time and travel. Financial and access barriers may prevent some patients from pursuing this training, unless specific circumstances necessitate it, such as slower than expected progress (Rossi-Katz & Arehart 2011). This study also had limited power for analysis of CIQOL data, with pre- and post-CI CIQOL-35 score available for only 73 of 114 patients, as the CIQOL instrument was under development at the initiation of the present study. Finally, unmeasurable patient factors such as motivation may play a large role in outcomes and confound results, particularly considering quality-of-life scores, as a motivated patient may be simultaneously more likely to use training, such as CBAT, and to report better CIQOL scores. That said, previous analysis did not show any link between various patient factors, including pre-CI CIQOL, scores and use of CBAT in new, adult CI recipients (Dornhoffer et al. 2023).

## CONCLUSIONS

Auditory training with self-directed computer software was associated with a greater improvement in CIQOL global and domain scores from pre-CI to 12-mo post-CI after controlling for demographics and use of multiple training resources simultaneously. This is despite no significant association with greater improvement in speech recognition at this same time-period. Future randomized, controlled, and carefully tracked studies are necessary to confirm these relationships and determine dose-dependent effects. However, given the low risk and low cost of these interventions, this study provides evidence to support the use of CBAT to improve functional abilities of new adult CI users.

## ACKNOWLEDGMENTS

All authors contributed equally to this work. J.R.D. and T.R.M. developed the research strategy. J.R.D., C.S., and K.C.S. collected data. J.R.D., C.S., K.C.S., J.R.D., and T.R.M. reviewed and analysized. J.R.D. wrote the main article. All authors discussed the results and implications and commented on the article at all stages. All authors contributed to a review and editing of the final article.

This research was partially supported by funding from a grant from National Institutes of Health Number K23 DC016911, and a grant from the American Cochlear Implant Alliance.

The authors have no conflicts of interest to disclose.

Copyright © 2024 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

**TABLE 6. Multivariable regression of factors associated with change in CIQOL-35 scores from pre-CI to 12-mo post-CI**

| | Global Score | | Communication Domain | | Emotional Domain | | Entertainment Domain | | Environmental Domain | | Listening Effort Domain | | Social Domain | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Model F = 3.133, $p = 0.009$, $R^2 = 0.230$ | | Model F = 3.243, $p = 0.008$, $R^2 = 0.236$ | | Model F = 2.209, $p = 0.054$, $R^2 = 0.174$ | | Model F = 2.239, $p = 0.051$, $R^2 = 0.176$ | | Model F = 2.590, $p = 0.026$, $R^2 = 0.198$ | | Model F = 2.345, $p = 0.042$, $R^2 = 0.183$ | | Model F = 3.488, $p = 0.005$, $R^2 = 0.249$ | |
| | **ß (95% Confidence Interval)** | **VIF** | **ß (95% Confidence Interval)** | **VIF** | **ß (95% Confidence Interval)** | **VIF** | **ß (95% Confidence Interval)** | **VIF** | **ß (95% Confidence Interval)** | **VIF** | **ß (95% Confidence Interval)** | **VIF** | **ß (95% Confidence Interval)** | **VIF** |
| **Age at implantation (years)** | −0.220 [−0.485, 0.045] | 1.18 | −0.239 [−0.557, 0.079] | 1.18 | −0.210 [−0.562, 0.141] | 1.18 | −0.223 [−0.625, 0.159] | 1.159 | −0.236 [−0.638, 0.165] | 1.18 | −0.186 [−0.513, 0.140] | 1.159 | −0.351 [−0.711, 0.008] | 1.18 |
| **Duration of hearing loss (years)** | 0.134 [−0.108, 0.376] | 1.081 | **0.318 [0.027, 0.663]** | 1.081 | 0.158 [−0.164, 0.479] | 1.081 | −0.002 [−0.360, 0.356] | 1.0017 | 0.269 [−0.098, 0.636] | 1.081 | 0.124 [−0.174, 0.423] | 1.017 | −0.147 [−0.476, 0.182] | 1.02 |
| **Female sex** | 3.559 [−4.019, 11.138] | 1.083 | 3.559 [−4.876, 13.334] | 1.083 | 0.196 [−9.854, 10.246] | 1.083 | 5.995 [−5.211, 17.201] | 1.08 | 10.192 [−1.289, 21.674] | 1.083 | 4.715 [−4.624, 14.054] | 1.08 | 4.661 [−5.625, 14.947] | 1.056 |
| **Face-to-face auditory training** | −2.000 [−12.650, 8.650] | 1.137 | −4.545 [−17.340, 8.249] | 1.137 | 2.310 [−11.813, 16.433] | 1.137 | −8.196 [−23.944, 7.552] | 1.136 | −4.937 [−21.072, 11.198] | 1.137 | −7.191 [−20.315, 5.933] | 1.136 | 2.905 [−11.549, 17.360] | 1.079 |
| **Passive home-based auditory Training** | −2.073 [−12.308, 8.163] | 1.127 | 1.021 [−11.276, 13.318] | 1.127 | 5.073 [−8.501, 18.647] | 1.127 | −3.699 [−18.835, 11.436] | 1.124 | −0.790 [−16.298, 14.717] | 1.127 | 4.685 [−7.928, 17.299] | 1.124 | −6.319 [−20.212, 7.574] | 1.102 |
| **Computer-based Auditory training** | **12.019 [4.127, 19.911]** | 1.155 | **11.937 [2.456, 21.318]** | 1.155 | **12.293 [1.927, 22.759]** | 1.155 | **17.014 [5.434, 28.774]** | 1.156 | **13.771 [1.814, 25.727]** | 1.155 | **12.523 [2.798, 22.248]** | 1.156 | **18.114 [7.403, 28.826]** | 1.082 |

*CNCp, consonant-nucleus-consonant phoneme; CNCw, consonant-nucleus-consonant word; CIQOL, Cochlear Implant Quality of Life; VIF, variance inflation factor*
*Bolded text denotes a significant association*

Copyright © 2024 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

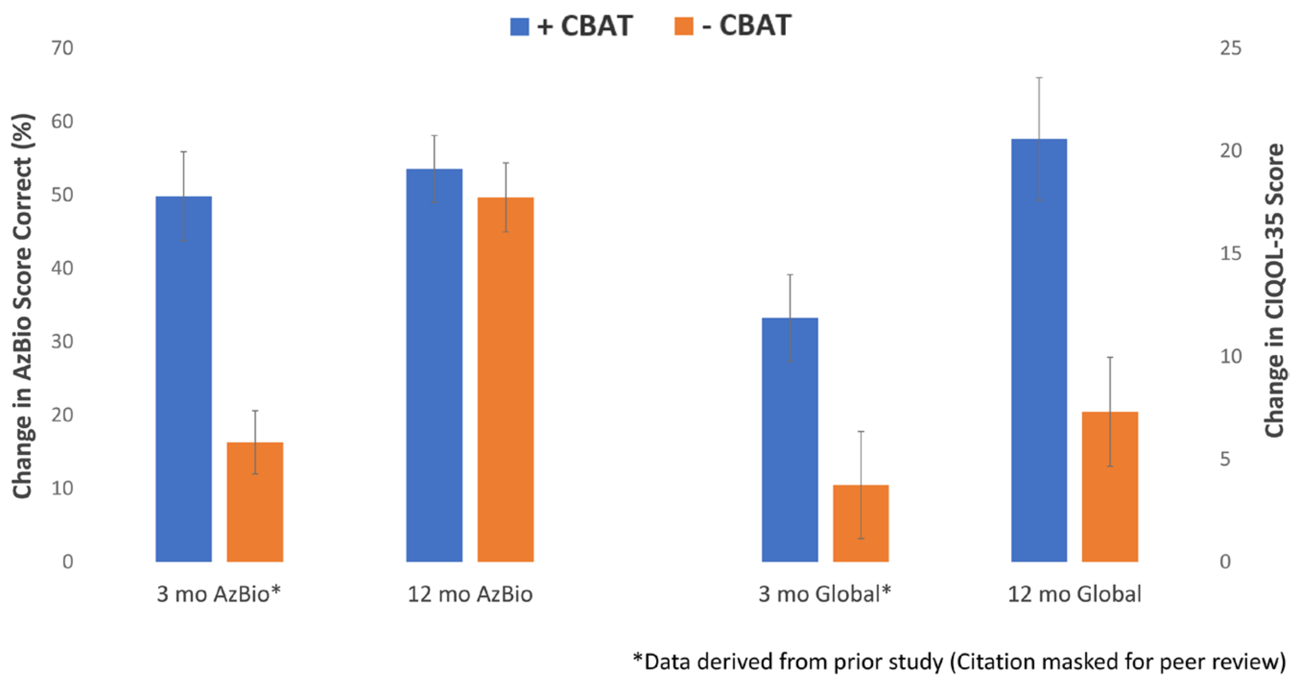


Fig. 2. Change in AzBio and CIQOL global scores for CBAT users and nonusers from pre-CI to 3 mo and pre-CI to 12 mo post-CI. Error bars represent ±1 standard error.

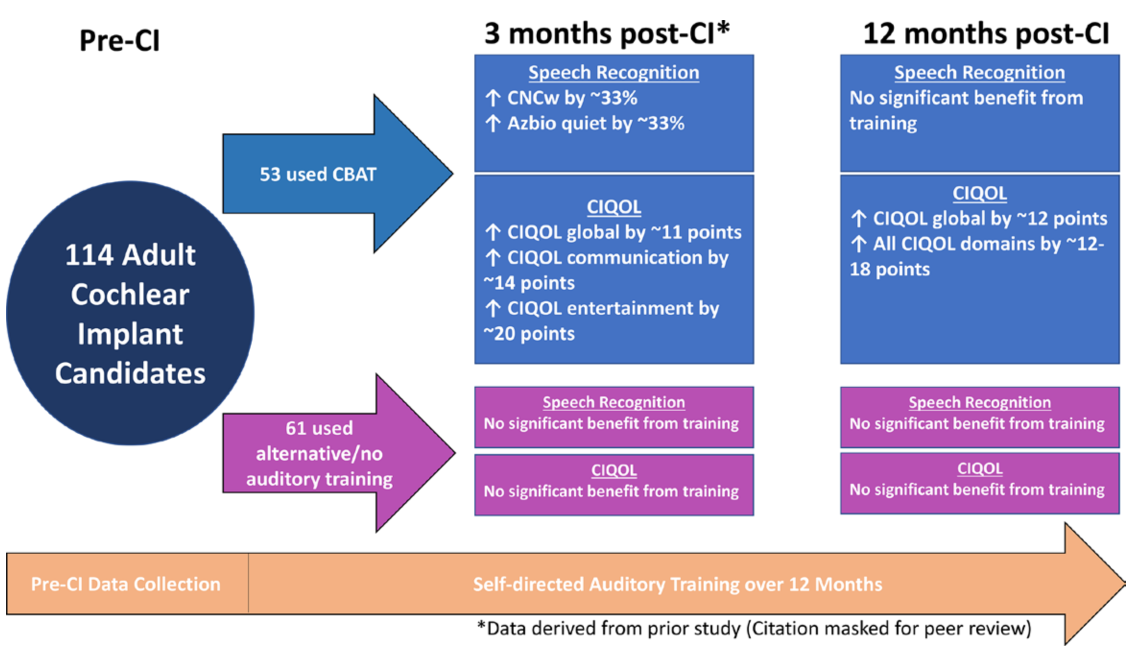


Fig. 3. Benefit derived from computer-based auditory training for speech recognition and CIQOL outcomes at 3- and 12-mo post-CI as compared to pre-CI scores.

Address for correspondence: Theodore R. McRackan, Department of Otolaryngology—Head and Neck Surgery, Medical University of South Carolina, 135 Rutledge Ave, MSC 550, Charleston, SC 29425. Email: mcrackan@musc.edu.

Received August 26, 2023; accepted January 5, 2024; published online ahead of print February 14, 2024

## REFERENCES

Barlow, N., Purdy, S. C., Sharma, M., Giles, E., Narne, V. (2016). The effect of short-term auditory training on speech in noise perception and cortical auditory evoked potentials in adults with cochlear implants. *Semin Hear*, *37*, 84–98.

Bernstein, C. M., Brewer, D. M., Bakke, M. H., Olson, A. D., Machmer, E. J., Spitzer, J. B., Schauer, P. C., Sydlowski, S. A., Levitt, H. (2021). Maximizing cochlear implant outcomes with short-term aural rehabilitation. *J Am Acad Audiol*, *32*, 144–156.

Byrne, D., & Dillon, H. (1986). The National Acoustic Laboratories' (NAL) new procedure for selecting the gain and frequency response of a hearing aid. *Ear Hear*, *7*, 257–265.

Cambridge, G., Taylor, T., Arnott, W., Wilson, W. J. (2022). Auditory training for adults with cochlear implants: A systematic review. *Int J Audiol*, *61*, 896–904.

Copyright © 2024 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Routledge.
Cusumano, C., Friedmann, D. R., Fang, Y., Wang, B., Roland, J. T., Jr., Waltzman, S. B. (2017). Performance plateau in prelingually and postlingually deafened adult cochlear implant recipients. *Otol Neurotol*, *38*, 334–338.
Dillon, M. T., Buss, E., Adunka, M. C., King, E. R., Pillsbury, H. C., 3rd, Adunka, O. F., Buchman, C. A. (2013). Long-term speech perception in elderly cochlear implant users. *JAMA Otolaryngol Head Neck Surg*, *139*, 279–283.
Dorismond, C., Patro, A., Holder, J. T., Perkins, E. L. (2023). Correlation between quality of life and speech recognition outcomes following cochlear implantation. *Otol Neurotol*, *44*, 1015–1020.
Dornhoffer, J. (2019). An otologist's experience as a cochlear implant patient-the power of neuroplasticity. *JAMA Otolaryngol Head Neck Surg*, *145*, 401–402.
Dornhoffer, J. R., Reddy, P., Ma, C., Schvartz-Leyzac, K. C., Dubno, J. R., McRackan, T. R. (2022). Use of auditory training and its influence on early cochlear implant outcomes in adults. *Otol Neurotol*, *43*, e165–e173.
Dornhoffer, J. R., Kinkhabwala, C. M., Chidarala, S., Ma, C., Schvartz-Leyzac, K. C., Meyer, T. A., Sterba, K. R., Dubno, J. R., McRackan, T. R. (2023). Patient-related factors do not predict use of computer-based auditory training by new adult cochlear implant recipients. *Otol Neurotol*, *44*, e81–e87.
Fu, Q.-J., & Galvin, J. J. (2007). Perceptual learning and auditory training in cochlear implant recipients. *Trends Amplif*, *11*, 193–205.
Fu, Q.-J., & Galvin, J. J., III. (2008). Maximizing cochlear implant patients' performance with advanced speech training procedures. *Hear Res*, *242*, 198–208.
Fu, Q. J., Galvin, J., Wang, X., Nogaki, G. (2004). Effects of auditory training on adult cochlear implant patients: a preliminary report. *Cochlear Implants Int*, *5*, 84–90.
Gagne, J. P., Parnes, L. S., LaRocque, M., Hassan, R., Vidas, S. (1991). Effectiveness of an intensive speech perception training program for adult cochlear implant recipients. *Ann Otol Rhinol Laryngol*, *100*, 700–707.
Green, T., Faulkner, A., Rosen, S. (2019). Computer-based connected-text training of speech-in-noise perception for cochlear implant users. *Trends Hear*, *23*, 2331216519843878.
Harris, P. A., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., Conde, J. G. (2009). Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*, *42*, 377–381.
Harris, M. S., Capretta, N. R., Henning, S. C., Feeney, L., Pitt, M. A., Moberly, A. C. (2016). Postoperative rehabilitation strategies used by adults with cochlear implants: a pilot study. *Laryngoscope Investig Otolaryngol*, *1*, 42–48.
Henry, B., Pedley, K., & Fu, Q. J. (2005). *Adult cochlear implant home-based auditory training manual—prelingual or long duration hearing loss*. https://www.cochlear.com/7d6f67c8-0aeb-4a03-9dda-148c9f4cec12/en_rehab_ci_adult_homebasedauditory_trainingmanual_postlingual_n585130_585133_iss2_jul15_935kb.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE-7d6f67c8-0aeb-4a03-9dda-148c9f4cec12-k.9my1Z
Henshaw, H., & Ferguson, M. A. (2013). Efficacy of individual computer-based auditory training for people with hearing loss: a systematic review of the evidence. *PLoS One*, *8*, e62836.
Humes, L. E., Burk, M. H., Strauser, L. E., Kinney, D. L. (2009). Development and efficacy of a frequent-word auditory training protocol for older adults with impaired hearing. *Ear Hear*, *30*, 613–627.
Ihler, F., Blum, J., Steinmetz, G., Weiss, B. G., Zirn, S., Canis, M. (2017). Development of a home-based auditory training to improve speech recognition on the telephone for patients with cochlear implants: a randomised trial. *Clin Otolaryngol*, *42*, 1303–1310.
Ingvalson, E. M., Lee, B., Fiebig, P., Wong, P. C. (2013). The effects of short-term computerized speech-in-noise training on postlingually deafened adult cochlear implant recipients. *J Speech Lang Hear Res*, *56*, 81–88.
Ma, C., Fried, J., Nguyen, S. A., Schvartz-Leyzac, K. C., Camposeo, E. L., Meyer, T. A., Dubno, J. R., McRackan, T. R. (2023). Longitudinal speech recognition changes after cochlear implant: systematic review and meta-analysis. *Laryngoscope*, *133*, 1014–1024.
Manrique, M. J., Espinosa, J. M., Huarte, A., Molina, M., Garcia-Tapia, R., Artieda, J. (1998). [Cochlear implants in post-lingual persons: results during the first five years of the clinical course]. *Acta Otorrinolaringol Esp*, *49*, 19–24. (Implantes cocleares en personas postlinguales: resultados durante los primeros cinco anos de evolucion.)
McRackan, T. R., Bauschard, M., Hatch, J. L., Franko-Tobin, E., Droghini, H. R., Nguyen, S. A., Dubno, J. R. (2018). Meta-analysis of quality-of-life improvement after cochlear implantation and associations with speech recognition abilities. *Laryngoscope*, *128*, 982–990.
McRackan, T. R., Hand, B. N., Velozo, C. A., Dubno, J. R.; Cochlear Implant Quality of Life Development Consortium. (2019). Cochlear Implant Quality of Life (CIQOL): Development of a Profile Instrument (CIQOL-35 Profile) and a Global Measure (CIQOL-10 Global). *J Speech Lang Hear Res*, *62*, 3554–3563.
McRackan, T. R., Hand, B. N., Velozo, C. A., Dubno, J. R.; Cochlear Implant Quality of Life Consortium. (2021). Validity and reliability of the Cochlear Implant Quality of Life (CIQOL)-35 Profile and CIQOL-10 Global Instruments in comparison to legacy instruments. *Ear Hear*, *42*, 896–908.
Miller, J. D., Watson, C. S., Kistler, D. J., Wightman, F. L., Preminger, J. E. (2008). Preliminary evaluation of the speech perception assessment and training system (SPATS) with hearing-aid and cochlear-implant users. *Proc Meet Acoust*, *2*, 1–9.
Moberly, A. C., Vasil, K., Baxter, J., Ray, C. (2018). What to do when cochlear implant users plateau in performance: a pilot study of clinician-guided aural rehabilitation. *Otol Neurotol*, *39*, e794–e802.
Oba, S. I., Fu, Q. J., Galvin, J. J., III (2011). Digit training in noise can improve cochlear implant users' speech understanding in noise. *Ear Hear*, *32*, 573–581.
Plant, G., Bernstein, C. M., Levitt, H. (2015). Optimizing performance in adult cochlear implant users through clinician directed auditory training. *Semin Hear*, *36*, 296–310.
Reis, M., Boisvert, I., Beedell, E., Mumford, V. (2019). Auditory training for adult cochlear implant users: a survey and cost analysis study. *Ear Hear*, *40*, 1445–1456.
Reis, M., McMahon, C. M., Távora-Vieira, D., Humburg, P., Boisvert, I. (2021). Effectiveness of computer-based auditory training for adult cochlear implant users: a randomized crossover study. *Trends Hear*, *25*, 23312165211025938.
Rossi-Katz, J., & Arehart, K. H. (2011). Survey of audiologic service provision to older adults with cochlear implants. *Am J Audiol*, *20*, 84–89.
Schumann, A., Serman, M., Gefeller, O., Hoppe, U. (2015). Computer-based auditory phoneme discrimination training improves speech recognition in noise in experienced adult cochlear implant listeners. *Int J Audiol*, *54*, 190–198.
Spahr, A. J., Dorman, M. F., Litvak, L. M., Van Wie, S., Gifford, R. H., Loizou, P. C., Loiselle, L. M., Oakes, T., Cook, S. (2012). Development and validation of the AzBio sentence lists. *Ear Hear*, *33*, 112–117.
Stacey, P. C., & Summerfield, A. Q. (2008). Comparison of word-, sentence-, and phoneme-based training strategies in improving the perception of spectrally distorted speech. *J Speech Lang Hear Res*, *51*, 526–538.
Stacey, P. C., Raine, C. H., O'Donoghue, G. M., Tapper, L., Twomey, T., Summerfield, A. Q. (2010). Effectiveness of computer-based auditory training for adult users of cochlear implants. *Int J Audiol*, *49*, 347–356.
Sweetow, R. W., & Sabes, J. H. (2006). The need for and development of an adaptive Listening and Communication Enhancement (LACE) Program. *J Am Acad Audiol*, *17*, 538–558.
Tillman, T. W., & Carhart, R. (1966). An expanded test for speech discrimination utilizing CNC monosyllabic words. Northwestern University Auditory Test No. 6. SAM-TR-66-55. *Tech Rep SAM-TR*, 1–12.
Tyler, R. S., Witt, S. A., Dunn, C. C., Wang, W. (2010). Initial development of a spatially separated speech-in-noise and localization training program. *J Am Acad Audiol*, *21*, 390–403.
Völter, C., Stöckmann, C., Schirmer, C., Dazert, S. (2021). Tablet-based telerehabilitation versus conventional face-to-face rehabilitation after cochlear implantation: Prospective Intervention Pilot Study. *JMIR Rehabil Assist Technol*, *8*, e20405.

Copyright © 2024 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.