Original Study

Use of Auditory Training and Its Influence on Early Cochlear Implant Outcomes in Adults

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Objective: Assess associations between postcochlear implant (CI) auditory training and early outcomes related to speech recognition and CI quality of life (CIQOL).
Study Design: Longitudinal, prospective cohort.
Setting: Tertiary academic center.
Patients: Seventy-two adults undergoing cochlear implantation for bilateral severe-to-profound hearing loss.
Interventions: Self-reported use of three categories of auditory training post-CI activation: (1) face-to-face training (e.g., speech pathologist), (2) passive home-based training (e.g., listening to audiobooks), and (3) computer-based training (e.g., interactive software).
Main Outcome Measures: 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 3-month post-CI.
Results: Of 72 patients, 52 (72.2%) used an auditory training resource. Of all patients, 18.4% used face-to-face training, 58.3% passive home-based training, and 33.3% computer-based training. At 3 months post-CI, use of any training was associated with greater improvement in speech recognition (d-range = 0.57–0.85) and global and domain-specific CIQOL scores, except entertainment (d-range = −0.33 to 0.77). Use of computer-based training demonstrated the greatest effect, with larger improvements in speech recognition (CNCp: $d = 0.69$[0.03,1.35]; CNCw: $d = 0.80$[0.14,1.46]; AzBio: $d = 1.11$[0.44,1.77]) and global and all domain-specific CIQOL scores (d-range = 0.05–1.35). Controlling for age, sex, household income, and use of multiple training resources, computer-based training remained the strongest positive predictor of speech recognition and CIQOL improvement, with significant associations with CNCp (ß = 33.07[1,43,64.719]), AzBio (ß = 33.03[5.71,60.35]), and CIQOL-global (ß = 10.92[1.15,20.70]) score improvement.
Conclusions: Our findings provide preliminary evidence-based recommendations for use of specific auditory training resources for new adult CI recipients. Auditory training, especially self-directed computer software, resulted in improved speech recognition and CIQOL outcomes after 3 months and are widely available for CI users.

Key Words: Auditory training—Cochlear implant—Cochlear implantation—Listening activities—Outcome measures—Patient reported—Quality of life—Speech recognition.

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Approximately two million adults in the United States have severe-to-profound bilateral sensorineural hearing loss (1). Cochlear implantation has become the standard of care for these patients, and those with lesser degrees of hearing loss, with studies showing consistent improvement in speech recognition and quality of life (QOL) (2–6). Such successes have spurred broadening of cochlear implant (CI) candidacy criteria, and the global economic impact of cochlear implantation is expected to exceed 2.5 billion USD in the near future (7–9). Despite innovation and technological advances, postoperative measured and self-reported communication ability remains limited for a substantial portion of CI users (10–13).

Hearing with a CI is a unique experience compared to normal acoustic hearing. While patients often show dramatic increases in speech recognition and QOL, deficits remain, with mean word recognition ability in quiet at 60 to 70% with substantial unexplained variability among CI recipients (10,12,14). A large portion of this deficit and variability may be related to patients having to learn to process electrical stimulation and hear with the implant. For some, this process comes passively during daily life, but for others it may require more intentional practice or rehabilitation. For many adults, this learning process can be protracted, with peak CI speech recognition ability reached 1 to 2 years after implantation (15–17).

Other than changes in programming by audiologists, there are few evidence-based interventions available to improve CI outcomes. Post-CI auditory training may

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improve or hasten the learning process (18–24). In general, auditory training can be divided into two general categories: (1) home-based training, designed to be self-directed by the CI user and (2) face-to-face training sessions typically led by a speech-language pathologist with an individual or a group. The home-based training includes passive training that is, listening to recorded speech, and computer-based training, which employs interactive software developed by CI companies and other third parties. Auditory training is felt to be beneficial and is considered necessary by a majority of surveyed audiologists (24), but there is scarce evidence to guide protocols and no standardization for use in the adult CI populaton (18,20,25). This is in contrast to the pediatric population where structured auditory training is a mainstay of post-CI care (26).

Research on the effectiveness of auditory training in adult CI users generally shows a trend toward benefit with use of face-to-face or computer-based training (18–22,27,28). However current studies are limited in their scope and ecological validity. All are limited by small sample size and strict laboratory control, and those examining computer-based training utilized experimental software not available to the average CI user. Thus, effectiveness of commonly available forms of auditory training in real-world settings remains unknown (18–22,27,28). That is, no study has assessed the effectiveness of auditory training resources as they would be used in a routine CI practice. Also, no published study has assessed their effectiveness in the immediate post-CI period. As a result, most audiologists and physicians base their recommendations on anecdotal experience of specific patient benefit (18–20,27).

A formal evaluation of the effectiveness of commonly used auditory training in an outpatient setting is of great importance to fill this knowledge gap. Therefore, this study was conducted to determine the relationship between commonly available auditory training and outcomes related to speech recognition and CI quality of life (CIQOL). The goal of the study was to provide preliminary evidence to guide recommendations for post-CI auditory training to optimize CI outcomes.

MATERIALS AND METHODS

Patient Sample and Data Collection

This study was approved by our university Institutional Review Board. Data were collected prospectively from patients undergoing unilateral cochlear implantation from September 2018 to July 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.

Surgeries were performed by one of four attending neurotologists at an academic, tertiary referral hospital. All intraoperative device testing, postoperative programming, and speech recognition testing were performed by three CI audiologists at the same center.

Patients meeting inclusion criteria were identified when they presented for routine programming visits with audiology. At their 3-month post-CI appointment patients were provided a survey on auditory training participation and common demographic factors. This was completed by the patient and recorded in a REDCap database (29). Audiological and patient-reported outcomes, detailed below, were obtained preimplantation and at audiology appointments 3 months post-CI.

Auditory Training Interventions

Upon CI activation, patients were provided a list of at-home auditory training resources and websites to access computer-based training programs. Adhering to standard of care, the list of recommended resources was identical for all patients at our institution and was not modified for this study. At every clinic visit, patients were encouraged to use the auditory training resources as much as possible.

Passive training in the list of at-home auditory training resources included reading aloud, having someone else read to the patient, following an audiobook, listening to the radio, or listening to the TV. Computer-based training in the list included use of software developed by Advanced Bionics (Valencia, CA) and Cochlear Americas (Englewood, CO), and Listening and Communication Enhancement (LACE) (30) and Angel Sound (31).

Referrals were offered to speech-language pathologists for auditory-verbal therapy (termed face-to-face auditory training) based on clinician and patient preference. For this study, face-to-face training included all speech-language pathology visits but not any routine auditory training performed during CI audiology appointments.

Outcome Measures and Speech Recognition Testing

Outcome measures were changes in speech recognition scores (Consonant-Nucleus-Consonant phonemes (CNCp), CNC words (CNCw), and AzBio sentences in quiet (AzBio Quiet)) and changes in QOL from preimplantation to 3 months post-CI. QOL was assessed by the Cochlear Implant Quality of Life-35 (CIQOL-35) Profile instrument, a CI-specific patient-reported outcome measure (see later sections) (32,33).

Preimplantation speech recognition was measured with hearing aids (personal or stock) fitted to National Acoustics Laboratory—revised linear (NAL-NL2) targets (34). Post-CI speech recognition testing was conducted using recorded materials presented from 0° azimuth at 60 dB sound pressure level (SPL). Ears were tested independently. Test materials included CNC monosyllabic words (35) and AzBio sentences (36). Patients scoring >50% on AzBio Quiet were tested at +10 dB signal-in-noise ratio (SNR). There were insufficient data for AzBio sentences in noise for analyses. Speech recognition testing was collected for the implanted ear pre-CI, and 3 months post-CI.

The CIQOL-35 is a patient-reported outcome measure that assesses the functional abilities of adult CI recipients within six 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; environmental, 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. An additional global score is calculated providing a general assessment of CI-specific QOL. Scores were calculated for each domain and ranged from 0 (poorest QOL) to 100 (highest QOL) (32,33).

Statistical Analysis

Statistical analyses were performed using SPSS version 25 (IBM Corporation, Armonk, New York). Continuous variables were summarized by mean (standard deviation; SD). 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 follows per Cohen's conventions: 0.2 to 0.49 = small effect, 0.5 to 0.79 = medium effect, and $\geq$0.8 = large effect (37). Categorical comparisons were undertaken using a Fisher's exact test. A Kruskal–Wallis test was employed for analysis of multiple means.

For primary analysis, 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 computer-based training, passive home-based training, and/or face-to-face training compared to those patients not using that resource.

Multivariate regression was performed to identify significant independent associations of training resources with speech recognition and CIQOL outcomes while controlling for confounding variables of age, duration of hearing loss, household income, and simultaneous use of multiple types of auditory training. Variance inflation factor (VIF) was used to detect collinearity. Missing variables were dealt with using mean-imputation. ß values and coefficients of determination (R^2) are presented.

RESULTS

Patients

A total of 72 patients were involved in this study. Of these, 52 (72.2%) used one or more training resources. Specifically, 18.1% used face-to-face training, 58.3% passive home-based training, and 33.3% computer-based training. Of all patients, 28 (38.8%) patients used only one category of training, 21 (29.2%) used two categories, and 3 (4.2%) used all three categories. Patient characteristics are detailed in Table 1. Comparisons were made regarding age, sex, race (White/Nonwhite), education (completed college, yes/no), current employment (yes/no), and household income ($\geq$ or <\$50,000) between patients using or not using a specific training resource, and no significant differences were noted (all $p > 0.05$). Patients using any form of auditory training ($d = -0.67[-1.19, -0.14]$) and those using passive home-based training ($d = 0.71[-1.19, -0.23]$) had significantly shorter durations of hearing loss compared to patients not using those resources with medium effects for each comparison. No significant differences in duration of hearing loss were noted for patients using face-to-face or computer-based auditory training.

Overall Outcomes

The patient sample showed an average improvement in CNCp (32.30% ± 24.25), CNCw (28.56% ± 27.71), and AzBio Quiet (30.20% ± 33.76) scores from pre-CI to 3 months post-CI (Table 2). Patients showed an average increase in all global CIQOL and all CIQOL domains in the same period. Average change in score ranged from 6.90 ± 7.75 to 13.23 ± 13.05 (Table 3).

TABLE 1. *Patient characteristics*

	All Patients
N	72
Mean age in years (SD)	68.62 (15.91)
Mean duration of hearing loss in years (SD)	23.97 (13.16)
Sex (N, %)	
Male	39 (54.2)
Female	33 (45.8)
Race (N, %)	
White	63 (87.5)
Nonwhite	9 (12.5)
Completed college (N, %)	
Yes	37 (51.4)
No	35 (48.6)
Currently employed (N, %)	
Yes	20 (27.8)
No	52 (72.2)
Household income (N, %)	
≥\$50,000 per year	31 (43.1)
<\$50,000 per year	22 (30.6)
Chose not to reply	19 (26.3)

Influence of Auditory Training on Speech Recognition Changes

Outcomes for the study sample were detailed and subdivided into groups based on the use of different forms of auditory training (Table 2). Patients using any auditory training had an improvement in CNCp (38.68 ± 33.25), CNCw (33.17% ± 28.05), and AzBio Quiet (37.60% ± 31.80) at 3 months as compared to pre-CI. The use of any form of training had a medium effect on CNCp ($d = 0.72[-0.02,1.46]$) and CNCw scores ($d = 0.63[-0.10,1.36]$) and a large effect on AzBio Quiet scores ($d = 0.85[0.14,1.57]$) (Table 2).

When comparing use and nonuse of each category of training, use of computer-based training was associated with significantly greater improvement in CNCp, CNCw, and AzBio Quiet scores at 3 months, with a medium effect on CNCp ($d = 0.69[0.03, 1.35]$), and a large effect on CNCw ($d = 0.80[0.14, 1.46]$), and AzBio Quiet scores ($d = 1.11[0.44, 1.77]$). Use of face-to-face training or passive home-based training was not associated with any significant benefit with only several small positive effects and no significant associations (*d*-range = 0.06–0.37).

To account for cofounders a multivariable regression was performed. Variables included age, sex, household income, and use of face-to-face, passive home-based, and/or computer-based training resources. Results are detailed in Table 4. Notable effects are summarized in Figure 1. After accounting for potential confounders, the use of computer-based auditory training was an independent predictor for improvement in CNCp (ß = 33.07[1,43, 64.719]) and AzBio Quiet scores at 3 months (ß = 33.03[5.71, 60.35]). This means that use of computer-based auditory training was associated with an average greater increase of 33% in CNCp and AzBio percent correct at 3 months. No significant association

TABLE 2. *Comparison of change in speech recognition scores from preimplantation to 3-month post-CI between auditory training usage categories*

		Any Training			Face-to-Face Training			Passive Home-Based Training			Computer-Based Training		
	All Patients	Yes	No	Effect Size *d* [95% CI]	Yes	No	Effect Size *d* [95% CI]	Yes	No	Effect Size *d* [95% CI]	Yes	No	Effect. Size *d* [95% CI]
N (%)	72 (100)	52 (72.2)	20 (27.8)		13 (18.1)	59 (81.9)		42 (58.3)	30 (41.7)		24 (33.3)	48 (66.7)	
CNCp % correct (SD)	32.30 (24.25)	38.68 (33.25)	14.40 (32.02)	0.72 [−0.02, 1.46]	37.14 (32.81)	31.29 (35.00)	0.17 [−0.65, 0.99]	34.40 (31.27)	29.94 (38.07)	0.13 [−0.51, 0.76]	**45.01** **(34.44)**	**22.00** **(31.20)**	**0.69** **[0.03,1.35]**
CNCw % correct (SD)	28.56 (27.71)	33.17 (28.05)	15.20 (27.65)	0.63 [−0.10, 1.36]	32.29 (31.53)	27.75 (28.53)	0.15 [−0.67, 0.97]	29.43 (24.41)	27.56 (33.75)	0.06 [−0.56, 069]	**40.94** **(26.49)**	**19.00** **(27.14)**	**0.80** **[0.14,1.46]**
AzBio Quiet % correct (SD)	30.20 (33.76)	**37.60** **(31.80)**	**10.01** **(31.80)**	**0.85** **[0.14 1.57]**	41.00 (27.89)	27.97 (34.78)	0.37 [−0.44, 1.20]	31.18 (30.02)	29.05 (38.45)	0.06 [−0.55, 0.68]	**49.82** **(29.66)**	**16.29** **(29.72)**	**1.11** **[0.44, 1.77]**

Bold text shows significant effect sizes.
CNCp indicates consonant-nucleus-consonant phoneme; CNCw, consonant-nucleus-consonant word.

TABLE 3. *Comparison of change in CIQOL-35 scores from preimplantation to 3-month post-CI between auditory training usage categories*

		Any Training			Face-to-Face Training			Passive Home-Based Training			Computer-Based Training		
	All Patients	Yes	No	Effect Size *d* [95% CI]	Yes	No	Effect Size *d* [95% CI]	Yes	No	Effect Size *d* [95% CI]	Yes	No	Effect Size *d* [95% CI]
N (%)	26 (100)	24 (92.3)	2 (7.7)		7 (26.9)	19 (73.1)		21 (80.8)	5 (19.2)		9 (34.6)	17 (65.4)	
Change in CIQOL score (SD)													
Global	6.90 (7.57)	7.63 (7.79)	1.57 (2.23)	0.77 [−0.70, 2.23]	8.80 (5.67)	6.84 (8.37)	0.24 [−0.75, 1.23]	6.79 (7.81)	8.79 (7.58)	−0.25 [−1.32, 0.83]	**11.87** **(6.32)**	**3.74** **(6.80)**	**1.19** **[0.31, 2.07]**
Communication	6.13 (9.96)	6.91 (10.29)	−2.32 (1.27)	0.89 [−0.58, 2.36]	7.61 (11.93)	6.40 (9.88)	0.11 [−0.88, 1.10]	5.25 (9.54)	10.59 (13.64)	−0.51 [−1.59, 0.58]	**12.31** **(10.65)**	**1.74** **(7.39)**	**1.15** **[0.28, 2.03]**
Emotional	11.71 (15.29)	11.90 (16.05)	9.85 (13.93)	0.12 [−1.32, 1.57]	21.71 (6.74)	8.79 (16.74)	0.81 [−0.21, 1.83]	11.54 (16.67)	12.66 (10.49)	−0.07 [−1.14, 1.01]	16.83 (16.68)	8.08 (14.30)	0.55 [−0.27, 1.38]
Entertainment	13.23 (13.05)	12.93 (13.21)	17.53 (19.63)	−0.33 [−1.78, 1.12]	11.88 (17.36)	14.05 (12.89)	−0.15 [−1.14. 0.84]	11.38 (13.05)	22.98 (11.58)	−0.87 [−1.97, 0.23]	17.26 (12.80)	10.49 (13.43)	0.50 [−0.33, 1.32]
Environmental	10.41 (15.97)	10.99 (16.67)	9.21 (13.02)	0.10 [−1.34, 1.55]	7.47 (20.52)	12.00 (15.77)	−0.26 [−1.25, 0.73]	8.47 (15.28)	22.70 (17.30)	−0.88 [−1.98, 0.22]	**19.60** **(13.03)**	**4.58** **(15.61)**	**0.99** **[0.13, 1.85]**
Listening Effort	6.90 (11.67)	7.84 (12.15)	−1.11 (1.92)	0.64 [−0.82, 2.10]	6.18 (12.78)	7.43 (12.26)	−0.10 [−1.09, 0.89]	5.89 (10.90)	13.66 (15.83)	−0.64 [−1.73, 0.45]	**15.18** **(11.87)**	**1.47** **(8.07)**	**1.35** **[0.45, 2.25]**
Social	7.24 (15.13)	7.98 (16.01)	2.69 (3.80)	0.33 [−1.12, 1.78]	17.89 (11.44)	4.02 (15.40)	0.91 [−0.12, 1.93]	8.23 (16.55)	4.05 (7.85)	0.26 [−0.82. 1.33]	8.02 (15.34)	7.19 (16.00)	0.05 [−0.76, 0.86]

Bold text shows significant effect sizes.
CIQOL indicates Cochlear implant quality of life.

was noted between use of computer-based auditory training and change in CNCw (ß = 23.202[−5.40, 51.80]) scores. No significant association was noted between 3-month speech recognition outcomes and age, sex, household income, or use of any other category of auditory training. To parse out effects from simultaneous use of multiple resources, a Kruskal−Wallis test was performed on speech recognition outcomes between patients utilizing one, two, or three types of training. No significant differences were noted between groups.

Influence of Auditory Training on CIQOL

CIQOL outcomes are detailed in Table 3. Compared to those who did not use auditory training, patients who utilized any form of training showed a positive effect on improvement in all CIQOL-35 domain scores except for the entertainment domain (*d*-range = −0.33 to 1.89, Table 3). As with speech recognition, the most consistent increases in CIQOL scores were seen with computer-based auditory training (*d*-range = 0.05−1.35). Significant, large effect sizes were observed for change in the global (*d* = 1.19[0.31, 2.07]), communication (*d* = 1.15[0.28, 2.03], environmental (*d* = 0.99[0.13, 1.85), and listening effort domains (*d* = 1.35[0.45, 2.25]). Use of face-to-face and passive home-based training showed no significant association with change in CIQOL scores.

Multivariable analysis was performed in the same manner previously mentioned for speech recognition (results detailed in Table 4 and summarized in Fig. 1). After accounting for potential confounders, computer-based auditory training was an independent predictor for improvement in global (ß = 10.92[1.15, 20.70]), communication (ß = 13.867[2.43, 25.31), and entertainment (ß = 19.50[4.08, 34.92]) domains at 3 months. This means that the use of computer-based auditory training was associated with an average greater increase of 11.68 to 20.39 in CIQOL scores for these domains at 3 months. No other significant associations were noted between computer-based training and other CIQOL domains. However, we found that the use of face-to-face training (ß = 19.80[5.14,34.47]) and female sex (ß = 20.01[6.76,33.26]) were predictors of greater improvement in social domain scores at 3 months. No other significant associations were noted between 3-month CIQOL outcomes and age, sex, household income, or use of auditory training. To evaluate the effect of simultaneous use of multiple resource categories, a Kruskal−Wallis test was performed on CIQOL scores between patients utilizing one, two, or three types of training resources. No significant differences were noted between groups.

DISCUSSION

Learning to hear with a CI can be equated to learning a new language (17). To help this process, auditory training is often recommended to new CI recipients by audiologists and otologists (21), but there is scarce literature on the general or specific effectiveness of this training and a

TABLE 4. *Multivariable regression of factors associated with change in speech recognition and CIQOL-35 scores from preimplantation to 3-month post-CI*

	CNCp score (%)		CNCw score (%)		AzBio Quiet Score (%)		Global CIQOL-35 Score	
	Model $F = 1.265$, $p = 0.321$, $R^2 = 0.330$		Model $F = 0.830$ $p = 0.576$, $R^2 = 0.244$		Model $F = 1.732$, $p = 0.158$, $R^2 = 0.377$		Model $F = 2.697$, $p = 0.075$, $R^2 = 0.411$	
	ß (95% Confidence Interval)	VIF	ß (95% Confidence Interval)	VIF	ß (95% Confidence Interval)	VIF	ß (95% Confidence Interval)	VIF
Age at implantation (yesrs)	−0.410 [−1.508, 0.688]	1.442	−0.297 [−1.290, 0.695]	1.442	−0.540 [−1.523, 0.442]	1.368	−0.014 [−0.328, 0.472]	2.120
Duration of hearing Loss (years)	−0.686 [−1.736, 0.363]	1.149	−0.252 [−1.200, 0.697]	1.149	−0.560 [−1.507, 0.386]	1.118	0.171 [−0.292, 0.634]	1.803
Female sex	15.572 [−16.353, 47.497]	1.380	1.595 [−27.261, 30.451]	1.380	4.686 [−22.499, 31.870]	1.268	5.207 [−3.832, 9.649]	1.741
Household income ≥$50,000	−18.778 [−48.814, 11.257]	1.229	−18.806 [−45.954, 8.342]	1.229	−17.412 [−43.518, 8.694]	1.163	0.486 [−8.678, 9.649]	1.768
Face-to-face auditory training	17.743 [−26.183, 61.669]	1.073	14.862 [−24.842, 54.565]	1.073	14.728 [−25.871, 55.327]	1.082	2.571 [−7.431, 12.572]	1.185
Passive home-based auditory training	4.943 [−23.246, 33.131]	1.057	0.092 [−25.386, 25.571]	1.057	2.410 [−22.583, 27.404]	1.050	−1.515 [−13.788, 10.758]	1.268
computer-based auditory training	**33.074 [1.429, 64.719]**	**1.356**	23.202 [−5.401, 51.804]	1.356	**33.029 [5.711, 60.346]**	**1.254**	**10.922 [1.145, 20.699]**	**2.012**

Bolded text denotes a significant association.
CNCp indicates consonant-nucleus-consonant phoneme; CNCw, consonant-nucleus-consonant word; CIQOL, Cochlear implant quality of life; VIF, variance inflation factor.

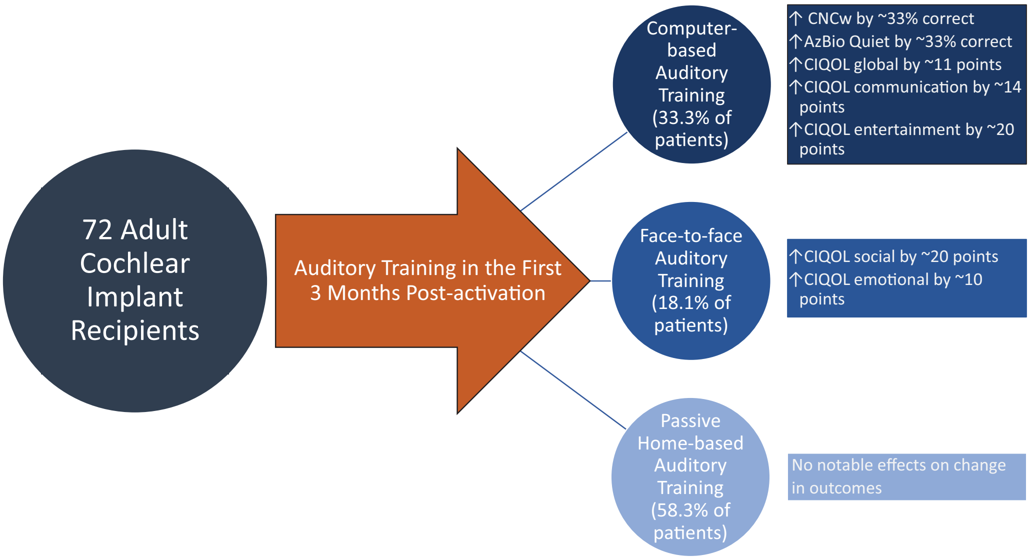

FIG. 1. Summary of significant effects of auditory training in early adult cochlear implant recipients as found by multivariable regression. Patients could utilize more than one type of resource and may be represented in more than one group.

lack of any evidence-based consensus recommendations. In this observational study, we have examined the effectiveness of commonly available forms of auditory training in real-world settings. We have shown training to be generally effective, with computer-based auditory training having the most consistent association with early (3-months postactivation) speech recognition and CIQOL score improvements.

Comparing these results to the literature, we found limited information on the effectiveness of auditory training in CI users. Sweetow et al. (25) performed a systematic review on the efficacy of auditory training for non-CI patients with hearing loss, and Henshaw et al. (38) reviewed the literature on auditory training in CI and non-CI patients. Both reviews were limited by number, quality, and heterogeneity of publications; however, both support auditory training as a possible intervention for hearing-impaired patients to improve speech recognition. A review of CI-specific literature revealed a limited number of individual studies (28,31,39–48). These generally showed benefit in speech recognition; however, they were limited by sample size and ecological validity. The largest study enrolled only 15 patients, most patients were experienced implant users (>12 months post-CI), and those studies examining computer-based auditory training utilized a custom computer program, often under laboratory or remote monitoring. (31,39–48) As such, published evidence may not be generalizable to many CI users. By reporting on the effectiveness of commonly available post-CI auditory training resources on early post-CI speech and patient-reported outcome measures, our study provides novel data to help guide specific auditory training recommendations for new CI recipients. Moreover, these self-directed auditory training resources are widely available at no cost for CI users (except LACE) in contrast to clinician-directed auditory training, whose availability, cost, and coverage can vary based on CI center.

Use of computer software for auditory training has features that streamline the learning process, such as automated testing/scoring, customized training, matched visual and auditory cues, and real-time corrective feedback (25,30). Immediate corrective feedback is particularly important as it allows a user to actively correct errors in speech and sound discrimination and focus on areas of weakness. Henshaw et al. (38) performed a review of auditory training for patient with hearing loss (including hearing aid and CI users) and noted that feedback during training is a common feature in modern computer-based auditory training that appears to maximize training effects. This may offer some explanation for the benefits seen in this study; however, any explanation must be guarded as the majority of such data in the literature is not from CI-specific patients, and there is significant heterogeneity among computer-based auditory training platforms.

The general benefit seen with the use of any form of auditory training is likely secondary to increased exposure to environmental and speech stimuli. Schvartz-Leyzac et al. (49) and Holder et al. (50) have each shown, using data logging, that hours per day of wearing a CI processer was strongly positively correlated with speech recognition outcomes. Schvartz-Leyzac et al. (49) also showed that hours spent listening to speech in quiet was weakly, positively correlated with sentence recognition, whereas hours spent in quiet was negatively correlated with word and sentence recognition. Thus, increased exposure to speech of any sort may result in a more rapid and effective learning experience. The results of this study showed that computer-based auditory training offers strong benefit, with large positive effect sizes for both speech recognition and

CIQOL-35 scores. This relationship remained true even after controlling for demographics and concomitant use of multiple resources.

Regarding CIQOL-35 scores, use of computer-based auditory training was associated with improvement in global and some, but not all, domain scores. Domains that were significantly affected by auditory training were communication, environment, and listening effort. In general, these domains reflect a patient's ability to understand speech and environmental stimuli and ease in doing so (33). Computer-based auditory training focuses on recognition and interpretation of a variety of speech and environmental sounds, with and without noise. Therefore, we would anticipate a large effect on these domains, which reflect a patient's perceived proficiency in areas trained directly by computer-based resources. On the other hand, the emotional, entertainment, and social domain scores remained the same with computer-based auditory training. The emotional and social domains assess the burden of hearing loss on patients' emotional well-being and social interactions (33). Although auditory training may address causes of adverse emotional and social habits, they are not directly addressed, and training may not significantly affect these domains in the early post-CI period. In contrast, face-to-face training, although focused on speech recognition ability, may provide direct social interactions and emotional support. This benefit is reflected in the significant effect of face-to-face training on the CIQOL-35 social domain scores, as shown in the multivariable regression. Finally, the entertainment domain deals with enjoyment of TV, radio, and particularly music (33). Most computer-based auditory training resources have options for music training, but we lack data on the degree to which these options were utilized.

The current study was underpowered to answer several questions. First, the dose-dependent nature of the auditory training was not assessed, namely the extent to which hours or frequency of computer-based auditory training was associated with outcomes. The effects of schedule on auditory training for hearing aid users have shown to be relatively independent of outcomes, but the same may not hold true for CI recipients (51). Second, we were unable to directly compare the effectiveness of each computer-based auditory training format. Although the training activities for each program are similar, there may be subtle differences that impact outcomes. Third, patterns of usage as they relate to patient demographics, lifestyles, and expectations were not assessed. Given the apparent benefit of auditory training in this study, identifying patients who are likely to participate in training will be of help in guiding effective patient counselling. We will examine these questions in future studies.

The primary limitation of this study is the potential unreliability in patient self-report. To preserve ecological validity, we chose to avoid any active recordings or time-tracking, which may influence usage patterns. Therefore, patient responses may not perfectly reflect their true usage, nor can we make meaningful observations on the amount of time spent on each type of training. Moreover, home- and computer-based auditory training resources were not used in a controlled setting, which introduces variability in the presentation levels and listening environments (e.g., background noise) where these were completed. Although this represents a potential confounding factor, it does allow this form of auditory training to be carried out in the real-world setting where it was intended to be used.

The sample size limited our analysis of face-to-face auditory training. Although some beneficial effects were seen from face-to-face training, particular in CIQOL social domain scores, the number of patients who reported using these resources was small. This may be due to financial and access barriers in getting to therapy appointments, making this resource less available than home-based training (52). In addition, patients may have been referred to a speech-language pathologist after either self-identifying or being identified by a clinician as making slower than expected progress. This introduces a potential bias for this cohort and may explain the lack of substantial benefit from face-to-face training. Therefore, it is difficult to make any conclusions on the effectiveness of face-to-face auditory training based in the current study.

Sample size also limited our evaluation of the effect of auditory training on CIQOL. Given that the CIQOL-35 Profile was only recently validated (33), there were fewer patients with CIQOL scores available for analysis compared to speech recognition scores. As a result, analysis of the effect of auditory training on CIQOL global and domain score is limited. With continued collection of CIQOL data, we anticipate future studies will better assess this relationship.

Finally, this study only examined early CI outcomes. CI recipients are anticipated to continue to improve for as long as 2 years post-CI (15,16). As such, with adequate sample size for analysis at only 3 months, the current study is unable to comment on long-term outcomes (16). With this in mind, future studies will aim for a longitudinal assessment of CI users over at least the first year post-CI.

CONCLUSIONS

The use of auditory training in real-world settings was found to be associated with improved speech recognition and CIQOL outcomes at 3 months post-CI. Specifically, the use of computer-based auditory training was noted to have the most consistent beneficial effect as compared to face-to-face and passive home-based training, after controlling for age, sex, household income, and use of multiple training resources simultaneously. Randomized, controlled studies with longer follow up are necessary to confirm these findings and better assess the impact of face-to-face resources; however, our findings provide preliminary evidence-based recommendations for specific auditory training for new adult CI recipients.

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