When to Start Computer-Based Auditory Training After Cochlear Implantation: Effects on Quality of Life and Speech Recognition

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Objective: Computer-based auditory training (CBAT) has been shown to improve outcomes in adult cochlear implant (CI) users. This study evaluates in new CI users whether starting CBAT within 3 months of activation or later impacts CI outcomes.
Study Design: Prospective natural experiment.
Setting: Tertiary academic medical center.
Patients: Sixty-five new adult CI users.
Interventions: CBAT use over the first-year postactivation.
Main Outcome Measures: Speech recognition scores and CIQOL-35 Profile score improvements between CI recipients who started CBAT resources early (<3 mo) and late (3–12 mo) postactivation.
Results: A total of 43 CI recipients started using CBAT within 3 months postactivation (early) and 22 after 3 months (late). Patients who used CBAT within 3 months postactivation showed significantly greater improvement in consonant-nucleus-consonant words (CNCw) (48.3 ± 24.2% vs 27.8 ± 24.9%; $d = 0.84$), AzBio Sentences in quiet (55.1 ± 28.0% vs 35.7 ± 36.5%; $d = 0.62$), and CIQOL-35 listening domain scores (18.2 ± 16.3 vs 6.9 ± 12.9, $d = 0.73$ [0.023, 1.43]), at 3 months postactivation, compared to those who had not yet initiated CBAT. However, by 12 months postactivation, after which all CI recipients had started CBAT, there were no differences observed between patients who started CBAT early or late in speech recognition scores (CNCw: $d = 0.26$ [−0.35, 0.88]; AzBio: $d = 0.37$ [−0.23, 0.97]) or in any CIQOL global or domain score (d-range = 0.014–0.47).
Conclusions: Auditory training with self-directed computer software (CBAT) may yield speech recognition and quality-of-life benefits for new adult CI recipients. While early users showed greater improvement in outcomes at 3 months postactivation than users who started later, both groups achieved similar benefits by 12 months postactivation.
Key Words: Auditory training—Cochlear implant—Computer-based auditory training—Rehabilitation.

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INTRODUCTION

While cochlear implants (CIs) have consistently demonstrated success as an intervention for moderate-to-profound sensorineural hearing loss, individual variability in outcomes persists (1–5). This may be related to difference in patients' abilities to learn to hear and listen with their CI (6,7). New implant recipients must learn to decode an electrical stimulus from the CI, and this process may take several months or even up to a year or more (5,8). Auditory training has been shown to potentially augment this learning process (5,9,10). A recent longitudinal study on commonly available forms of auditory training demonstrated that computer-based auditory training (CBAT) programs appear to offer unique benefits for new adult CI recipients (11). A recent meta-analysis also demonstrates benefit in studies that primarily examined CBAT use in various patient populations (9).

While data support the use of CBAT programs, evidence is lacking regarding the most appropriate starting time for these interventions. Patients show their most rapid improvement of speech recognition skills in the first several months postactivation (5,8), so, presumably, an intervention during this period of rapid adaptation may yield the most benefit. Unfortunately, most research on CI-related auditory training has examined its effect in experienced CI users, often in patients with years of CI experience (9,10). Only a small number of studies examined auditory training with at least some new implant recipients (11–14). While outcomes in such studies are favorable, there is no comparison between new and experienced implant users, or there are insufficient data to make such comparisons. As such, there is a limited understanding of the ideal starting time of auditory training in new CI recipients.

The goal of this study was to assess differences in speech recognition and quality-of-life benefits in new adult CI recipients with early (<3 mo) or late (3–12 mo) starting times of CBAT use. It was hypothesized that early use of CBAT

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would yield improved speech recognition and/or quality-of-life outcomes compared to late users. Such findings would provide preliminary evidence for specific postimplantation CI care algorithms or schedules.

MATERIALS AND METHODS

Patient Population

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 at preimplantation and routine programming appointments, and enrollment was strictly voluntary. CI surgeries were performed by four attending neurotologists at an academic, tertiary referral hospital. Postoperative programming and pre-and post-CI speech recognition testing were performed by CI audiologists at the same center. At routine audiology appointments, patients were provided a list of home-based CI auditory training exercises, as well as a list of websites to access computer-based training programs. Patients were also offered referrals to speech-language pathologists for face-to-face auditory training based on a perceived need or patient preference. The list of resources was identical for all patients at our institution and was not modified for use in this study. Use of any resource was voluntary. At regular time periods, detailed below, patients reported their use or nonuse of any or all such resources.

Patients who endorsed use of at least one CBAT program were included in this study. Programs used included software developed by Advanced Bionics (Valencia, CA) and Cochlear Americas (Englewood, CO), as well as Listening and Communication Enhancement (LACE),15 Angel Sound,16 and Hearoes (Brisbane, Australia). For purposes of this study, any patient who initiated CBAT use before 3 months postactivation was considered an "early" user, while those starting CBAT, any period after that was considered a "late" user. Differences in outcomes between CBAT users and non-users have been presented in previous manuscripts (17). However, graphical representation of CI recipients who never used CBAT in the first year postactivation is provided for context.

Data Collection

Patients completed surveys on auditory training participation through a REDCap database during routine audiology follow-ups (18). Surveys were obtained at 3, 6, and 12 months post-CI. Speech recognition and patient-reported outcomes, detailed below, were also obtained over this same period. Pre-CI speech recognition and patient-reported outcomes were obtained at CI candidacy evaluation. Surveys or outcome data collected within 1 month before or after aforementioned time points were included. Data on education (completed college, yes/no), household income (≥ or <$50,000 annually), current employment (yes/no), and habitation were obtained through an additional survey performed at initial enrollment. Data on race (collapsed to White/racial minority due to sample size), age, sex (male/female), and duration of hearing loss (years) were collected, as defined in institutional electronic health records, to identify and control for any confounding effects. The CI manufacturer and data logs for CI use (total hours and use in noise per day) were also collected during routine audiologic visits using each implant company's data-logging software. Data presented here represent average daily hours of use, measured at 12 months post-CI. Comparisons were then made between patients starting CBAT early or late regarding these demographic and CI factors.

Outcome Measures

Outcome measures were changes in speech recognition scores (consonant-nucleus-consonant words [CNCw] and AzBio sentences in quiet [AzBio Quiet]) (19,20 and changes in Cochlear Implant Quality of Life-35 (CIQOL-35) Profile instrument scores (detailed below) from pre-CI to 3 and 12 months post-CI (21).

Pre-CI speech recognition was measured with hearing aids fitted to National Acoustics Laboratory—revised linear (NAL-NL2) targets (22). Post-CI speech recognition testing was conducted using recorded materials presented from 0° azimuth at 60-dB sound pressure level (SPL). The implanted ear was tested independently, with the contralateral ear plugged during testing if the patient had sufficient residual hearing in the contralateral ear expected to contribute to speech recognition scores (i.e., any audiometric threshold better than the presentation level used for administration of speech stimuli).

The CIQOL-35 Profile is a validated, patient-reported outcome measure that assesses the functional abilities of adult CI recipients. A global score is calculated, as well as a score for 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), 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). Scores range from 0 (lowest QOL) to 100 (highest QOL) (21).

Statistical Analyses

Statistical analyses were performed using SPSS version 25 (IBM Corporation, Armonk, NY). Continuous variables were summarized by mean ± standard deviation (SD). Cohen *d* effect sizes 95% confidence intervals (CI), denoted as "*d* [lower CI, upper CI]," were calculated where appropriate. Effect sizes were interpreted per Cohen conventions as follows: ≥0.2 and <0.5 = small effect, ≥0.5 and <0.8 = medium effect, and ≥0.8 = large effect (23). 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.

For analysis of the influence of timing of training resources on outcomes, a Wilcoxon signed-rank test was used

TABLE 1. *Patient characteristics*

	All Patients	Early CBAT	Late CBAT	Effect Size *d* [95% CI]
N	65	43	22	
Mean age (SD), y	64.4 (15.7)	62.3 (14.9)	68.5 (16.6)	−0.24 [−0.76, 0.27]
Mean duration of hearing loss (SD), y	26.1 (14.6)	26.8 (14.2)	24.6 (11.5)	0.16 [−0.35, 0.68]
Mean CI use (SD), h/d	12.0 (2.7)	12.3 (2.5)	10.9 (2.9)	0.52 [−0.09, 1.13]
Mean CI use in noise (SD), h/d	1.9 (1.2)	2.1 (1.3)	1.5 (1.0)	0.49 [−0.27, 1.25]
	All Patients	**Early CBAT**	**Late CBAT**	**Odds Ratio [95% CI]; *p***
CI manufacturer (N, %)				NA; 0.22
Cochlear Americas	45 (69.2)	31 (72.1)	14 (63.6)	
Advanced Bionics	17 (26.2)	9 (20.9)	8 (36.4)	
MED-EL	3 (4.6)	3 (7.0	0 (0)	
Sex (N, %)				0.72 [0.26, 2.02]; 0.53
Male	36 (55.4)	25 (58.1)	11 (50)	
Female	29 (44.6)	18 (41.9)	11 (50)	
Race (N, %)				
White	59 (90.8)	39 (90.7)	20 (90.9)	1.03 [0.17, 6.09]; 0.98
Racial minority	6 (9.2)	4 (9.3)	2 (9.1)	
Completed college (N, %)				
Yes	34 (52.3)	20 (46.5)	14 (63.6)	0.50 [0.17, 1.42]; 0.19
No	31 (47.7)	23 (53.5)	8 (36.4)	
Currently employed (N, %)				0.97 [0.30, 0.06]; 0.78
Yes	18 (27.7)	12 (27.9)	6 (27.3)	
No	43 (66.2)	29 (67.4)	14 (63.6)	
Chose not to reply	4 (6.1)	2 (4.7)	2 (9.1)	
Household income (N, %)				0.93 [0.28, 3.11]; 0.49
≥$50,000 per year	26 (40)	18 (41.9)	8 (36.4)	
<$50,000 per year	24 (36.9)	17 (39.5)	7 (31.8)	
Chose not to reply	15 (23.1)	8 (18.6)	7 (31.8)	

95% CI indicates 95% confidence interval; SD, standard deviation.

to compare data between patients using CBAT early or late after CI activation. Comparisons were made between early and late CBAT users at 3 months, when the later users had not yet started CBAT use, and at 12 months postactivation, at which point all patients had initiated CBAT use. Due to the CIQOL-35 Profile being validated after initiation of the study, CIQOL data were available for 43 of 65 patients.

RESULTS

Patient Sample

A total of 65 patients were enrolled in this study. Of these, 43 (66.2%) started using CBAT early (<3 mo) after activation, and 22 (33.8%) started using CBAT late (3–12 mo) after activation. Patient demographics and lifestyle factors are detailed in Table 1. No significant differences were noted between early and late CBAT users in any of the variables examined (*d* or *odds ratio* crosses the point of equivalence for all variables).

Influence of CBAT Start Time on Speech Recognition

Improvement in speech recognition scores for both patient cohorts is shown in Table 2. Progression of speech recognition scores over the first-year postactivation is detailed for each group in Fig. 1. A cohort of CBAT nonusers, from previous study, is provided graphically for comparison (17).

TABLE 2. *Improvement in speech recognition scores from pre-CI: comparing early and late CBAT users*

		Time of CBAT Use		
	All Patients	Early	Late	Effect Size *d* [95% CI]
N (%)	65 (100)	43 (66.2)	22 (33.8)	
3 mo postactivation[a]				
CNCw % correct (SD)	41.1 (26.1)	**48.3 (24.2)**	**27.2 (24.4)**	**0.84 [0.22, 1.45]**
AzBio Quiet % correct (SD)	48.0 (32.4)	**55.1 (28.0)**	**35.7 (36.5)**	**0.62 [0.04, 1.19]**
12 mo postactivation[a]				
CNCw % correct (SD)	44.1 (28.3)	47.3 (27.4)	40.6 (29.6)	0.26 [−0.35, 0.88]
AzBio Quiet % correct (SD)	54.9 (33.1)	59.7 (29.8)	47.4 (37.3)	0.37 [−0.23, 0.97]

[a]At 3 months, late CBAT users will have had no training; by 12 months, all late CBAT users will have had training.
95% CI indicates 95% confidence interval; CNCw, consonant-nucleus-consonant word; SD, standard deviation.
Bold text shows significant effect sizes.

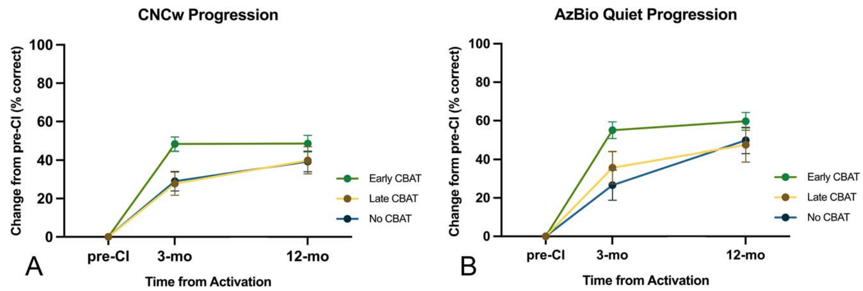

FIG. 1. Comparing progression of (*A*) CNC word scores and (*B*) AzBio sentences in quiet scores over the first year postactivation in early and late CBAT users. Brackets represent standard error. The No CBAT group is representative of a prior analysis (17).

At 3 months postactivation, patients who initiated CBAT use early had greater improvement, from pre-CI, in CNCw (48.3 ± 24.2% vs 27.2 ± 24.4%; $d = 0.84$) and AzBio scores (55.1 ± 28.0% vs 35.7 ± 36.5%; $d = 0.62$), compared to those who had not yet initiated CBAT use (late group), with significant, medium-to-large beneficial effects. However, by 12 months postactivation, there was no significant difference between early and late CBAT users for CNCw ($d = 0.26$ [−0.35, 0.88]) or AzBio scores ($d = 0.37$ [−0.23, 0.97]).

Influence of CBAT Start Time on CIQOL Outcomes

Comparisons of the improvement in CIQOL-35 Profile scores from pre-CI between patients who started CBAT early and late are shown in Table 3. This is also shown in Fig. 2 with a cohort of CBAT nonusers, from prior study, provided for graphic comparison (17). At 3 months postactivation, early CBAT use was associated with significantly greater improvement in listening effort domain scores (18.2 ± 16.3 vs 6.9 ± 12.9, $d = 0.73$ [0.023, 1.43]), with a medium beneficial effect, compared with those who had not yet initiated CBAT training. Early CBAT use also had neutral or beneficial effects for all other domains this time compared to late use (d = 0.07–0.63); however, the remaining associations are not significant. As with speech recognition scores, differences in CIQOL scores were greatest at 3 months and narrowed as the late cohort started using CBAT resources (d = 0.07–0.73 vs 0.014–0.47, at 3 and 12 months, respectively). Fig. 2 details this relationship as a line graph of global scores and scores for the communication and listening effort domains over the first year after activation.

DISCUSSION

Auditory training with CBAT has been associated with improved speech recognition and quality-of-life outcomes in adult CI recipients (9); however, the optimal timing for this intervention is unknown, with most studies including experienced CI users. The greatest improvement of speech recognition skills occurs in the first 3 to 6 months after activation, with marginal gain up to 2 years after implantation

TABLE 3. *Improvement in CIQOL-35 scores from pre-CI: comparing early and late CBAT users*

		Time of CBAT Use		
	All Patients	Early	Late	Effect Size d [95% CI]
N (%)	43 (100)	27 (62.8)	16 (37.2)	
3 mo postactivation[a]				
Change in CIQOL Score (SD)				
Global	14.0 (12.8)	15.9 (13.5)	10.7 (10.9)	0.46 [−0.19, 1.10]
Communication	15.1 (15.4)	18.1 (16.6)	8.1 (10.3)	0.63 [−0.03, 1.32]
Emotional	18.2 (18.0)	23.1 (19.0)	14.7 (18.1)	0.50 [−0.14, 1.11]
Entertainment	20.0 (18.7)	23.1 (19.4)	12.3 (16.1)	0.58 [−0.09, 1.24]
Environmental	19.3 (18.2)	20.1 (21.5)	17.8 (11.3)	0.07 [−0.59, 0.72]
Listening effort	14.7 (16.3)	**18.2 (16.3)**	**6.9 (12.9)**	**0.73 [0.02, 1.43]**
Social	14.9 (23.3)	16.3 (24.4)	12.3 (21.5)	0.17 [−0.47, 0.81]
12 mo postactivation[a]				
Change in CIQOL Score (SD)				
Global	20.9 (16.7)	22.3 (18.8)	18.5 (12.7)	0.22 [−0.46, 0.90]
Communication	21.5 (18.3)	23.0 (19.8)	18.5 (15.4)	0.24 [−0.49, 0.97]
Emotional	22.8 (22.0)	23.0 (24.6)	22.6 (17.8)	0.014 [−0.65, 0.68]
Entertainment	28.6 (19.5)	30.4 (19.5)	26.0 (19.4)	0.39 [−0.33, 1.09]
Environmental	28.8 (19.3)	27.9 (24.4)	23.9 (26.6)	0.121 [−0.58, 0.82]
Listening effort	20.2 (19.4)	22.9 (21.9)	14.3 (14.1)	0.47 [−0.30, 1.23]
Social	23.5 (26.6)	24.3 (26.4)	22.1 (28.2)	0.081 [−0.60, 0.76]

[a]At 3 months, late CBAT users will have had no training; by 12 months, all late CBAT users will have had training.
95% CI indicates 95% confidence interval; CIQOL, Cochlear Implant Quality of Life; SD, standard deviation.
Bold text shows significant effect sizes.

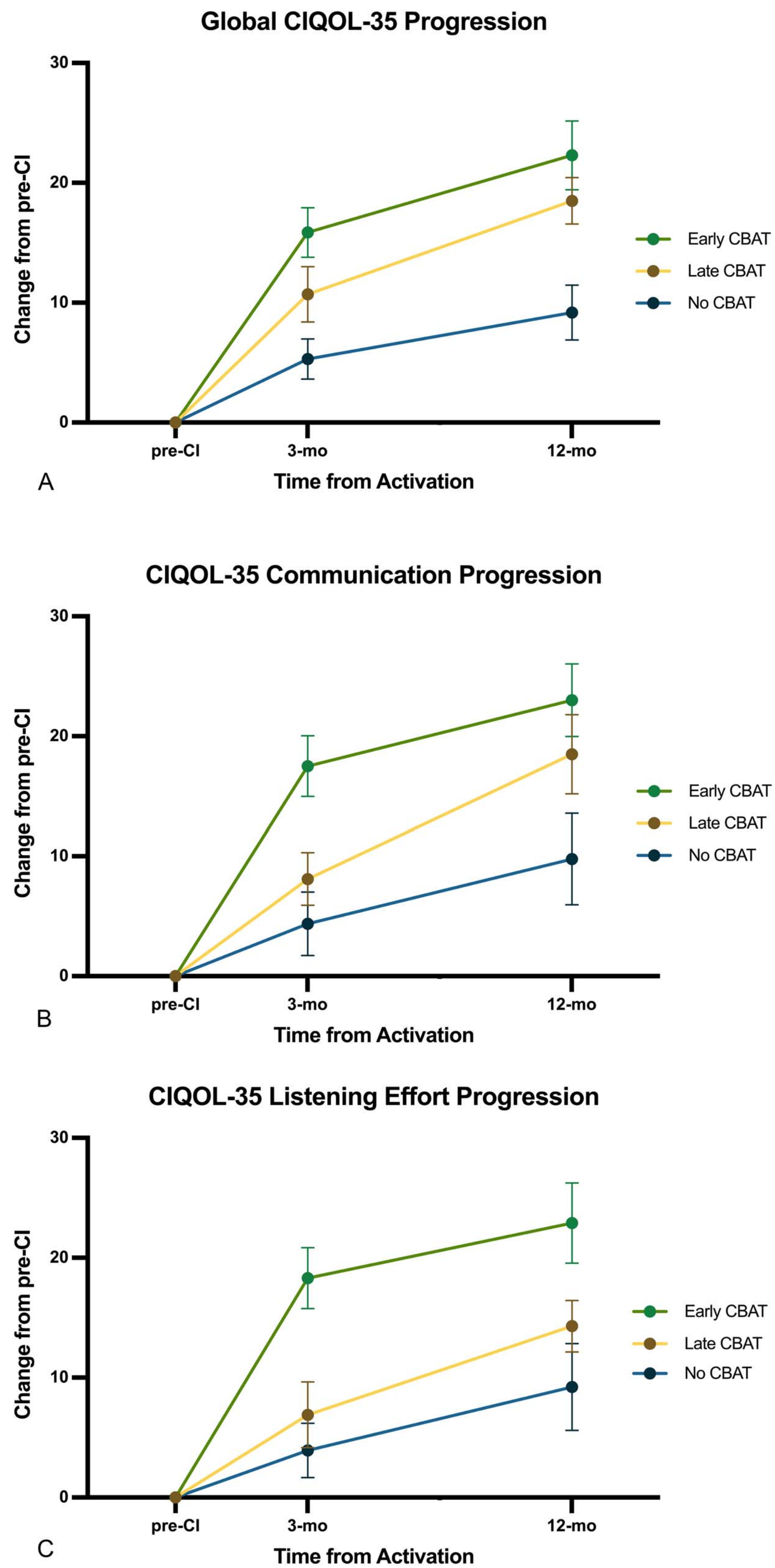

FIG. 2. Comparing improvement in CIQOL-35 (*A*) global, (*B*) communication domain, and (*C*) listening effort domain scores over the first year postactivation in early and late CBAT users. Brackets represent standard error. The No CBAT group is representative of a prior analysis (17).

in some patients (5,8). As such, early CBAT use, soon after activation, may theoretically have increased benefits compared to CBAT use at a later time point postactivation.

In this study, we examined the differential effects of early and late CBAT use in new adult CI users followed over their first year postactivation. In doing so, we demonstrated that by 12 months, all patients that used CBAT achieved similar benefits, with respect to speech recognition and CI-specific quality of life, regardless of when training was initiated. We observed that early CBAT use was associated with greater improvements at 3 months post-CI in speech recognition and CIQOL scores. However, by 12 months, there was no significant difference between these two groups with respect to either speech recognition or CIQOL scores.

The extant literature supports the use of CBAT in adult implant recipients (9), but few studies have detailed the outcomes of this intervention when used shortly after activation (11–14). For those studies that have analyzed CBAT or any other auditory training format used shortly after activation, outcomes were generally reported as favorable, with improvements reported in each study on at least one measure of speech recognition of patient-reported functional ability (11–14). Studies detailing auditory training in experienced CI users likewise showed benefits (9). Only one study from this limited pool of literature compared early or late interventions (13). This study showed no difference in benefit between patients with greater than or less than 6 months of CI experience at time of training. However, the analysis may have been limited by sample size as their trained cohort only included five patients with less than 6 months of experience. As such, our understanding of the impact of CBAT timing in CI recipients is still limited from review of the CI literature. However, these findings are generally in line with what we have demonstrated here. Namely, very new and "experienced" CI users appear to equally benefit from CBAT at 1 year post-CI.

Our hypothesis was that early CBAT use may offer greater benefit in CI users due to the fact that it intervenes when improvements greatest, offering earlier support of speech recognition skills. Alternatively, early training may help develop good habits, social networks, or other beneficial skills that may nonetheless be reflected in improved quality of life. However, we do see that, ultimately, the difference between early and late users is nonsignificant at 12 months postactivation once all patients have started using CBAT. To this end, we must consider that patients within the first year after activation are still in a period of active learning and, as such, may be equally able to learn using CBAT.

One must also consider the fact that CBAT likely has a beneficial effect, even beyond the initial learning phase for CI users. This is demonstrable in the previously detailed literature, which primarily focuses on experienced users (9). In this manner, practice with CBAT may be a useful tool to help CI recipient to "catch-up" if underperforming. This is illustrated most effectively in Fig. 1. Initially, at 3 months, CI users who have not yet used CBAT underperform, compared to early CBAT users, but, after initiation of CBAT, these users reach similar speech recognition score improvements. As such, CBAT may be a valuable tool for many adult CI users, particularly those who may be struggling. In fact, Fu et al. (16), in early work on what would become Angel Sound, showed that CBAT use by experienced, but underperforming, adult CI users provided significant improvement in speech recognition with training, approaching average scores for the CI population. With this in mind, an algorithm for postactivation CI care may encourage immediate CBAT use for many CI users, as it may yield earlier acquisition of speech recognition skills, but would still encourage training beyond the initial "early" period, particularly if patients are not meeting performance expectation or if they initially struggled, preventing use of a common CBAT programs early on.

Limitations for this study were primarily related to reliance on patient self-report and selection of CBAT. In order to maintain ecological validity of this study, patient compliance with auditory training was not enforced. As such, the validity of patient-reported data could be questioned. An additional limitation is the rather long timespan between surveys. Since surveys were done several months apart, we cannot pinpoint a specific time point for initiation of CBAT usage and can only comment on whether patients started training before or after different survey time points. This limits the power of our study in assessing the influence of starting CBAT at specific time points postactivation.

However, the major limitation is the selection bias inherent in this observational study design. Patients in the late CBAT group may have delayed use of CBAT if they had not reached a functional level necessary for engagement with the training software. For example, a patient still struggling with more rudimentary programming and adaptation may not have chosen to seek out CBAT until their "basic" CI functional abilities stabilized. Other patients may not elect to use any intervention until they or their audiologist notice their functional abilities are lagging behind population norms. In either case, patients in the late CBAT group may have demonstrated poorer performance overall, regardless of when CBAT was initiated. Nevertheless, it is still encouraging that these patients ultimately reach similar CIQOL and speech scores by 1 year post-CI. Contrary to this, we have previously shown that patients who never use CBAT have lower CIQOL scores a year after activation compared to those who do use CBAT at some point in that first year. With this in mind, future studies comparing early vs late start times require a randomized trial to control for many of the confounding effects of voluntary CBAT usage, differences in total duration of training, and reliance on patient self-report. Such a trial should also consider some data logging of CBAT usage, so that specific information on dose-dependent effects or the effectiveness of specific types of exercises can be assessed.

CONCLUSION

Auditory training with self-directed CBAT may yield speech recognition and quality-of-life benefits for new adult CI recipients. In this study of 65 new adult CI recipients, we demonstrated the following:

- CBAT use within the first 3 months post-CI yielded greater improvement in speech recognition and CIQOL scores at 3 months compared to those who had not yet started CBAT.

- As late CBAT users started to use and receive benefit from training, the difference in scores between early and late users diminished, and by 12 months, speech recognition and CIQOL scores were not significantly different between patients who stared CBAT before or after 3 months post-CI.
- These data support that CBAT offers useful benefits, even if not started immediately post-CI.

Future studies are needed to confirm these effects and develop specific timelines/algorithms of use, but data presented here may be sufficient to recommend CBAT use at any time within the first year for new adult CI recipients.

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