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Computerized Rehabilitative Training in Older Adult Cochlear Implant users: A Feasibility Study

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Abstract

Purpose

Many older adult cochlear implant (CI) users struggle with speech recognition, suggesting a need for focused rehabilitation. Computerized "bottom-up" auditory training programs have demonstrated some efficacy, but "top-down" linguistic or neurocognitive training may be beneficial for some persons. Sixteen experienced older adult CI users were assessed for sentence recognition in quiet and in noise, along with phonological sensitivity, working memory, and CI-related quality of life (QOL). Twelve participants completed ten sessions of computerized auditory, working memory, or phonological training, with four participants per group, along with four controls. Broad variability was demonstrated among participants on changes in speech recognition, phonological skills, working memory, and QOL. This study confirmed the feasibility of a trial of computerized rehabilitative training for older adult CI users, but limitations of this approach are discussed.

Key Words: Auditory training; Cochlear implants; Cognition; Linguistic skills; Sensorineural hearing loss; Speech perception

Introduction

Cochlear implants (CIs) provide speech recognition benefits for many adults with acquired hearing loss. However, not all patients derive equal benefit, and 10 to 50% of adult CI users experience "poor" outcomes (Lenarz et al., 2012). For example, 35 to 50% of CI users cannot make use of the telephone (Rumeau et al., 2015), and 13% of adult CI users score less than 10% correct words in sentences in quiet (Lenarz et al., 2012). Even for those patients who do ultimately perform well with their devices, it may take greater than two years to reach a plateau in performance (Herzog et al., 2003; Lenarz et al., 2012), suggesting a prolonged period of central nervous system adaptation to the degraded input delivered by the CI. These findings together suggest an important role for aural rehabilitation following cochlear implantation, and this rehabilitation may be particularly important for poor performers.

To date, a variety of aural rehabilitation strategies have been developed, but a standardized approach for adult CI patients does not exist. Moreover, individualized one-on-one or group therapy with a trained Audiologist or Speech-Language Pathologist is rare in the United States, in part because it is rarely reimbursed by insurance providers (Sweetow & Palmer, 2005; Sweetow & Sabes, 2007). As a result, patients often turn to computer-based auditory training, which has shown inconsistent efficacy (Humes et al., 2009; Stacey & Summerfield, 2008; Stacey et al., 2010). These computer training programs generally provide what can be described as either "bottom-up" or "analytic" training, meaning the approach focuses on targeted training of recognition of individual perceptual units of speech, through repetition and feedback (Fu & Galvin, 2011; Henshaw & Ferguson, 2013;

Miller et al., 2008; Stacey et al., 2010; Wright & Zhang, 2009). In CI users, much of this work has been done by Fu and Galvin (2007; 2011), using one of several iterations of auditory training software (currently entitled Angel Sound™), focused on phoneme, digit, word, or sentence recognition. However, such training approaches do not always result in benefits, nor do they necessarily generalize to untrained speech materials. Moreover, previous training studies in adult CI users have not necessarily focused on older adults; for example, the 2007 training study by Fu & Galvin enrolled 10 adult CI users between the ages of 25 and 60, with mean age of only 42.4 years. Furthermore, older CI users likely experience aging-related declines that could impact their ability to understand degraded speech, through both deficits in auditory temporal and spectral processing (Fitzgibbons & Gordon-Salant,1994; Nambi et al., 2016) and cognitive processing (Salthouse, 1996). In particular, relevant aging-related declines in working memory capacity, inhibitory control, and processing speed may impact speech recognition in older adults (Tun et al., 2012; Wingfield & Grossman, 2006), and specifically in those with CIs (Moberly, Houston, & Castellanos, 2016).

There is some evidence that "top-down" or "synthetic" training may benefit patients with hearing loss (Chisholm & Arnold, 2012; Dubno, 2013; Sweetow & Palmer, 2005), though results are not entirely consistent (Wayne et al., 2016). These top-down approaches may actually be more effective than bottom-up training for older adults, at least for those with milder degrees of hearing loss (Rubinstein & Boothroyd,1987; Walden et al., 1981). Top-down approaches focus on training the patient to derive meaning from the speech input, and can include encouraging the listener to use context, linguistic skills, and neurocognitive functions to make sense of the signal. To our knowledge, there are only two published studies that have examined the use of more top-down computerized training strategies in CI users, focused on improving working memory and/or phonological skills, with both studies conducted in pediatric populations. Kronenberger and colleagues (2011) investigated the use of a working memory (WM) computer training program (Cogmed®) in nine prelingually deaf CI users between the ages of 7 and 15 years. As a group, the children demonstrated significant improvements on measures of verbal and nonverbal WM, as well as sentence repetition skills. Ingvalson, Young, and Wong (2014) took a similar approach in 10 pediatric CI users, ages four to seven years, except that the program was focused on training phonological skills along with auditory WM (Earobics®); the authors of that study also included nine control participants. Gains in expressive and composite language scores, including speech recognition, were found for children who underwent training, while no gains were identified for control participants. On the other hand, a study of adults with and without hearing loss failed to demonstrate benefits of WM training using Cogmed® on speech recognition in noise performance (Wayne et al., 2016). Nonetheless, findings in pediatric CI users suggest the potential for "top-down" training methods to improve outcomes in older adults with CIs.

In addition to a lack of studies examining top-down training approaches for adult CI users, to our knowledge, no studies have sought to investigate why some patients experience benefits from training while others do not. It is unclear whether particular linguistic and/or neurocognitive skills predict better gains in speech recognition performance as an effect of training; moreover, it is unclear if training itself can improve those linguistic and neurocognitive skills.

The purpose of this study was to determine the feasibility of an at-home computerized training study in older postlingually deaf adults with CIs, and to collect data examining speech recognition in quiet and in noise before and after training, along with phonological sensitivity and WM. Sixteen postlingually deaf adults with CIs were assigned to one of four groups: (1) Auditory training; (2) Working memory training; (3) Phonological training; or (4) No training (control). Goals were to assess the willingness of adult CI users to participate in a training study and to undergo repeat testing. Additionally the compliance of older participants to complete each of the training programs, and subjective perspectives on the three different training programs was also evaluated.

Materials and Methods

Participants

Sixteen adult CI users were consented to participate in this study. All had greater than one year of CI experience, were between the ages of 56 and 82 years (mean 68.4, SD 8.1), and were recruited from patients in the Otolaryngology department at The Ohio State University. Participants had varying etiologies of hearing loss and ages at implantation, but all users experienced a progressive decline in their hearing during adulthood. Age at implantation was between the ages of 48 and 76 (mean 63.6, SD 8.7), and duration of CI use was between 1 and 12 years (mean 4.8, SD 2.7).

A validated cognitive screening test, the Mini-Mental State Examination (MMSE), was used to rule out dementia or mild cognitive impairment (defined as a T score less than 29) prior to baseline testing (Folstein & Folstein, 1975). No participant demonstrated evidence of cognitive impairment. Participants were also assessed for basic word-reading ability, using the Word Reading subtest of the Wide Range Achievement Test, fourth edition (WRAT) (Wilkinson & Robertson, 2006), as a metric of general language proficiency; all participants demonstrated a standard score of ≥ 83, which is just below one SD below the normative mean. Demographic and audiologic data for the individual CI users are shown

Table 1. Participant demographics.

Participant	Training Group	Gender	Age (years)	Implantation Age (years)	Side of Implant	Better ear PTA (dB HL)	MMSE (T score)	WRAT (Standard Score)
1	Control	M	66	61	B	120.0	50	120
2	Control	M	69	65	R	78.8	30	99
3	Control	F	68	56	L	82.5	36	92
4	Control	M	82	76	R	98.8	61	114
5	Working Memory	M	79	76	R	88.8	63	107
6	Working Memory	M	78	74	B	115.0	38	94
7	Working Memory	M	68	62	R	82.5	50	90
8	Working Memory	F	72	66	L	120.0	50	83
9	Auditory	F	56	48	R	70.0	57	92
10	Auditory	M	58	57	B	112.5	57	122
11	Auditory	M	60	54	B	120.0	42	95
12	Auditory	F	59	56	R	115.0	59	90
13	Phonological	F	66	62	L	120.0	50	120
14	Phonological	F	62	59	L	108.8	35	92
15	Phonological	M	77	72	L	71.3	56	104
16	Phonological	M	75	74	R	87.5	63	111

Notes: PTA: pure-tone average; HL: hearing level; B: Bilateral; R: Right; L: Left; MMSE: Mini Mental State Examination; WRAT: Wide Range Achievement Test

in Table 1. All participants demonstrated better than 20/30 corrected vision as screened using a near-vision testing card. Participants were compensated $15 per hour of testing and training.

Equipment

All tests were performed in a soundproof booth or a sound-treated testing room. Participants were tested while using their usual devices (one CI, two CIs, or CI plus contralateral hearing aid), and devices were checked at the beginning of testing by having the tester confirm sound detection by the participant through each device.

Stimuli and Stimuli-specific Procedures

Speech Recognition Measures

Recognition was tested for several types of speech materials, with each word or sentence presented, and the participant was asked to repeat what was heard. All materials were presented at 68 dB SPL over a loudspeaker positioned one meter from the participant at zero degrees azimuth. Dependent measures were percent correct words. Because testing sessions were completed approximately one month apart, the researchers believed that procedural learning effects were unlikely to occur. Therefore, the same speech recognition materials were used at both testing sessions. Participant responses were audio- and video-recorded and scored later by two trained research assistants. These two research assistants double-scored 25% of responses independently to ensure inter-rater reliability, which was >95% for all tasks that required later scoring.

Sentence recognition in quiet. Two measures of recognition of words in sentences in quiet were included: (1) long, complex, and semantically meaningful sentences taken from the IEEE corpus (IEEE, 1969) ("Standard" sentences), such as "The wharf could be seen from the opposite shore"; and (2) Perceptually Robust English Sentence Test Open-set (PRESTO) sentences (Gilbert, Tamati, & Pisoni, 2013), which are also complex and high-variability sentences, such as "Our successors will have an easier task"; each sentence was recorded by a different talker to introduce gender and dialect variability. For each sentence type, listeners were presented with 30 sentences.

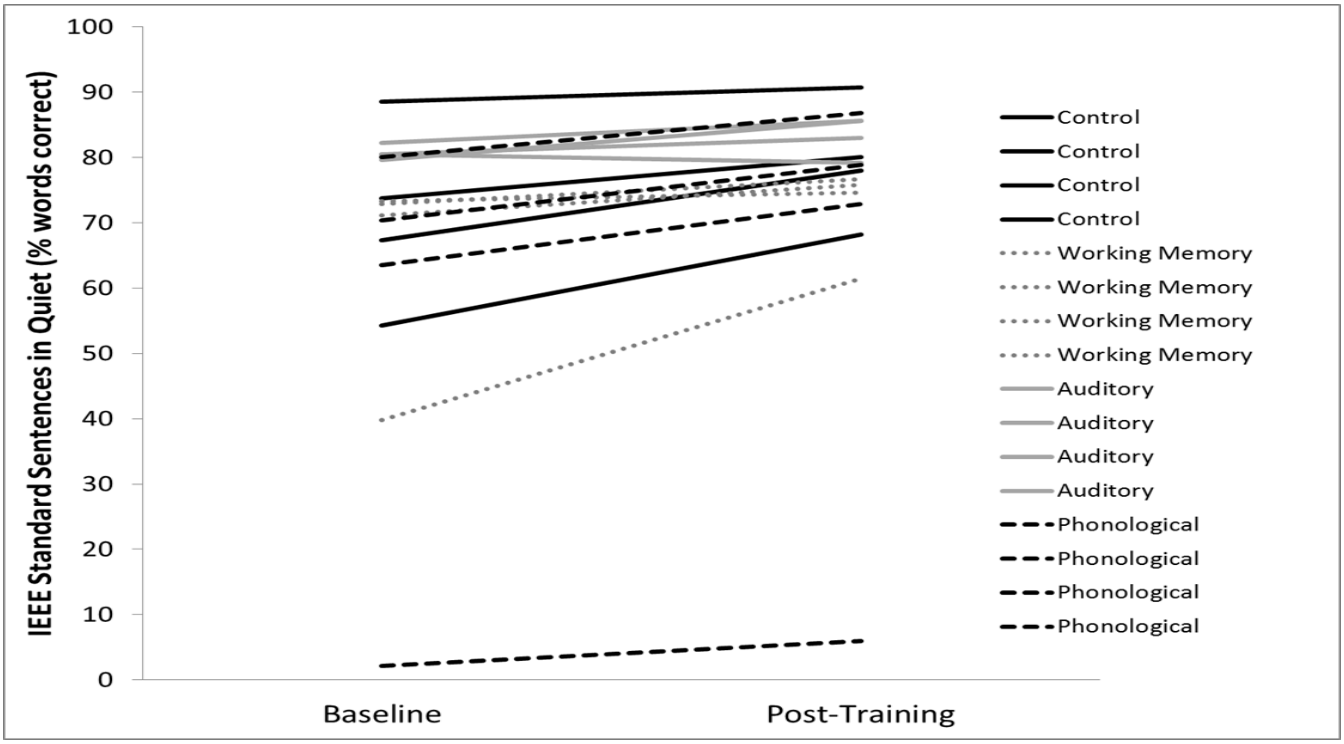

Figure 1. Individual participant scores for each group (control, working memory training, auditory training, and phonological training) on IEEE Standard sentence recognition in quiet at baseline (pre-training) and post-training.

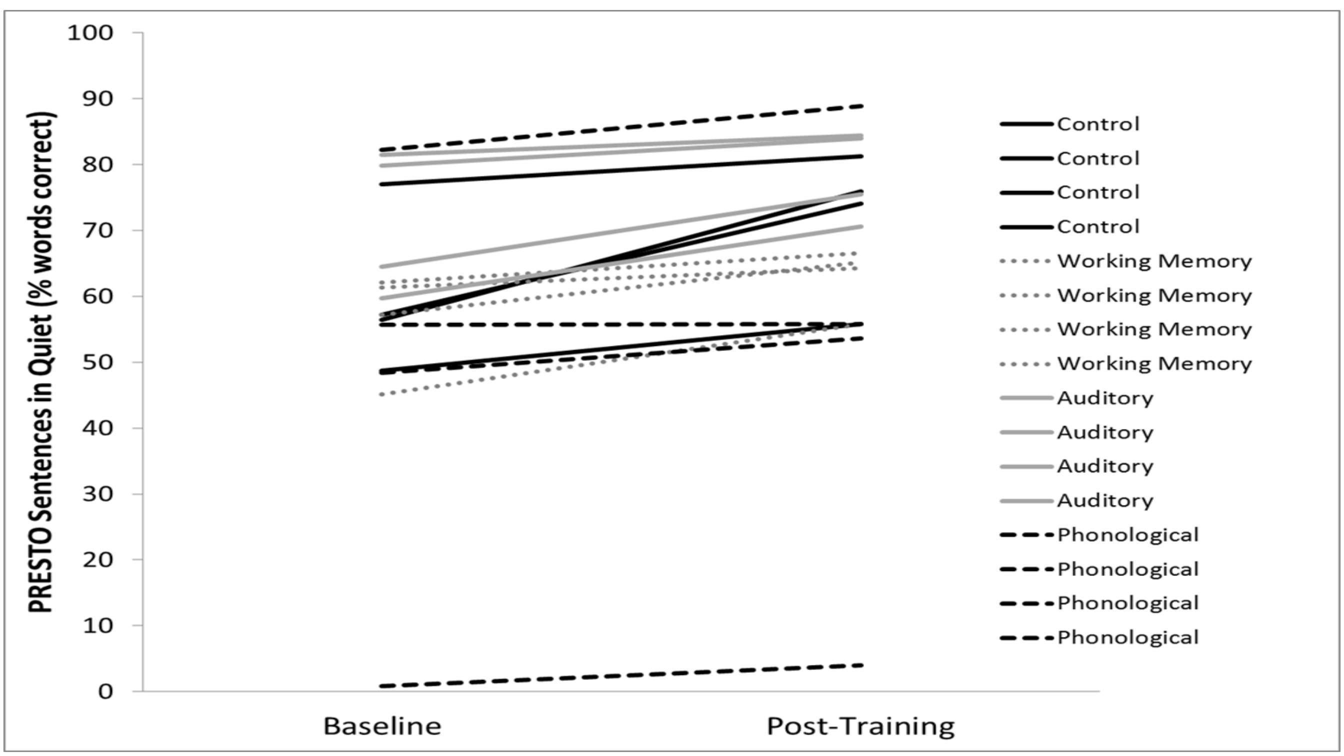

Figure 2. Individual participant scores for each group (control, working memory training, auditory training, and phonological training) on PRESTO sentence recognition in quiet at baseline (pre-training) and post-training.

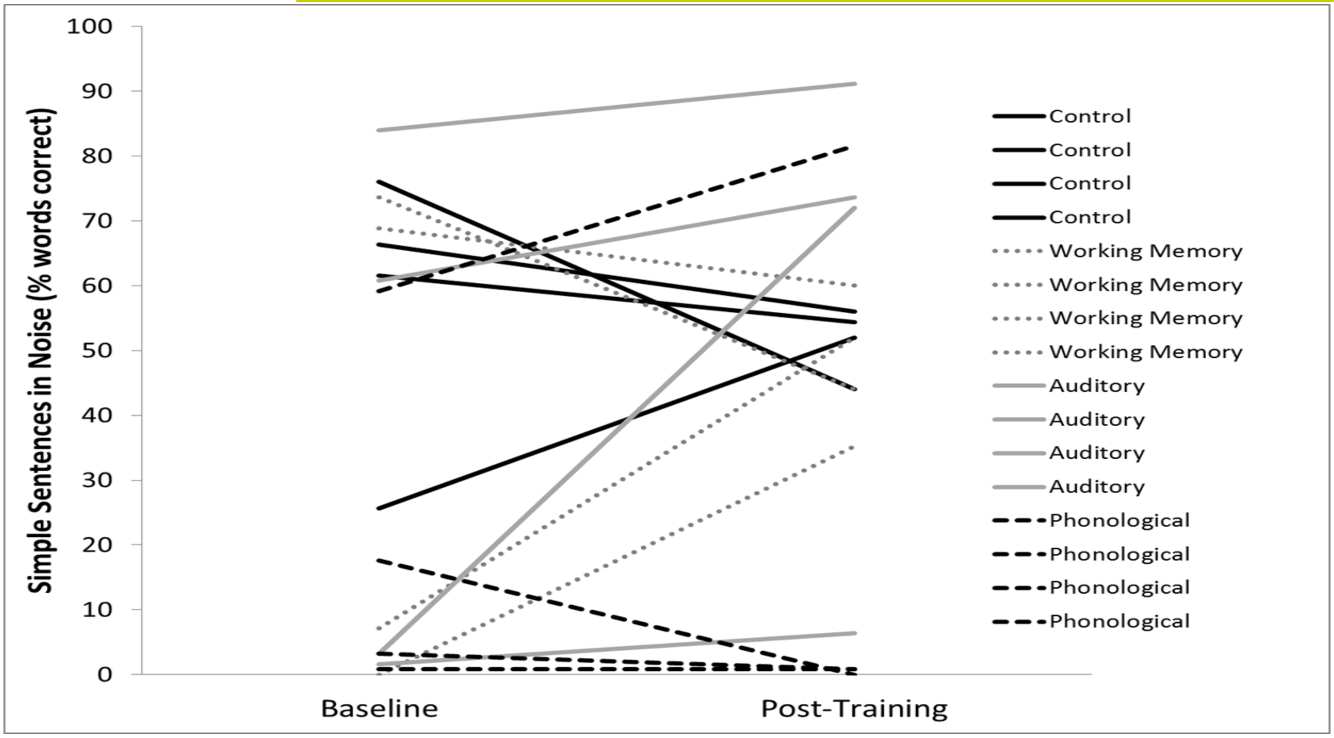

Figure 3. Individual participant scores for each group (control, working memory training, auditory training, and phonological training) on simple sentence recognition in speech-shaped noise at baseline (pre-training) and post-training.

Sentence recognition in noise. One measure of sentence recognition in noise was included. These were short, meaningful, five-word recorded sentences that were semantically predictable and syntactically correct, and followed a subject-predicate structure (e.g., "Flowers grow in the garden"); most of these sentences originated from the Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994), and this modified set was originally used by Nittrouer and Lowenstein (2014). Participants were tested in speech-shaped noise at + three dB SNR.

Phonological Sensitivity Measures

Two measures of phonological sensitivity were collected, and have been used previously in adult CI users (Moberly, Lowenstein, & Nittrouer, 2016; Moberly, Harris, Boyce, & Nittrouer, in press). These tasks consisted of a Final Consonant Choice (FCC) task and a Nonword Repetition task. Both tasks were administered using an audiovisual format, in which the participant saw a talker's face on a computer monitor and heard the talker over the speaker. This was done to maximize participants' ability to recognize the stimuli. By maximizing stimulus recognition, scores on these phonemic awareness tasks would provide a more explicit assessment of participants' phonemic sensitivity (i.e., their long-term phonemic representations), rather than simply auditory phoneme recognition. In the FCC task, participants were presented with a target word, which they were asked to repeat correctly. They were then given three word choices, and they had to select which of the three words ended with the same sound as the target word. Practice with feedback was provided before testing. During testing, the task was discontinued when a participant responded incorrectly to six consecutive items. All remaining trials during that test were scored as incorrect in those cases. If the participant was unable to repeat a target word correctly after three attempts, that item was skipped and was excluded from analyses (counted as neither correct nor incorrect). The percentages of correct answers were used as the measures of phonological sensitivity during analyses.

The second task of phonological sensitivity was a Nonword Repetition task. Forty non-words between one and four syllables in length, developed by Gathercole and Baddeley (1996) were video- and audio-recorded by a male talker. Equal stress was placed on all syllables for all stimuli, and fundamental frequency was kept consistent and flat. Stimulus amplitude was constant. During the task, participants saw and heard the talker saying each non-word, and they were asked to repeat each non-word immediately. Four non-words were presented at each syllable length. Participant responses were recorded and scored later by two trained research assistants, as described above. For this task, phonemes were scored as wrong if they were omitted or if substitutions were used. Distortions were not scored as wrong. Scores of total percent correct phonemes across all syllable-string lengths were used in analyses.

Working Memory Measures

Two measures of WM were collected, one for auditory verbal WM, and the other for visual verbal WM. The auditory verbal WM task was a task of serial recall of monosyllabic, nonrhyming words, which has been used previously in adult CI users (Moberly et al., in press) and was developed by Nittrouer and Lowenstein (2014). Stimuli consisted of a set of six nonrhyming noun words. The nouns used were ball, coat, dog, ham, pack, and rake. All words were spoken and recorded by a male talker. Prior to testing, the participant saw a series of six blue squares on a computer screen and was required to tap the squares in order from left to right as quickly as possible. Five trials were completed, and average time across those trials (the calibration time) was used to normalize response times to test items. Participants were familiarized with the words to be used before testing by seeing the pictures at the top of the monitor and hearing each word presented by itself. The participant needed to tap the picture representing the word heard to indicate that the association was made. This procedure was done prior to and subsequent to testing as a way of verifying that the participant recognized the words. During testing, words were presented at a rate of one per second without the pictures being shown; following presentation of the six words, all the pictures appeared at once (randomly positioned). The participant was instructed to tap the pictures in the order heard, again as quickly as possible. Ten trials of each condition were included. Response accuracy was used as the dependent measure.

The visual verbal WM task was a computerized digit span task, based on the original auditory version from the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV-I, Wechsler, 2003). Visual stimuli were used to eliminate the effects of audibility on performance. Sequences of digits were visually presented on a computer screen, one at a time, and participants were asked to reproduce the lists of digits in correct serial order. Total number of correct digits in correct serial order was used in analyses.

Quality of Life Measure

Nijmegen Cochlear Implant Questionnaire (NCIQ). Details of this measure can be found in the report by Hinderink and colleagues (2000). The NCIQ was designed for CI users, and it encompasses hearing and speech, psychological, and social domains. Three subdomain scores were used in analyses (Physical, Psychological, and Social), with higher scores representing better QOL. Questionnaires were completed by participants at home by self-administration with no time limit.

Table 2. participant scores on linguistic/cognitive tasks and quality of life at baseline (pre-training) and post-training.

		Baseline (Pre-Training)					Post-Training				
		Phonological Skills		Working Memory		QOL	Phonological Skills		Working Memory		QOL
Participant	Training Group	FCC (% CI)	NWR (% CP)	SRW (TCI)	VDS (TCI)	NCIQ (SS)	FCC (% CI)	NWR (% CP)	SRW (TCI)	VDS (TCI)	NCIQ (SS)
1	Control	85.4	81.3	45	77	227.3	83.3	73.0	42	97	231.3
2	Control	79.2	84.4	33	76	242.7	87.5	78.0	41	58	238.6
3	Control	47.9	76.0	27	43	256.2	58.3	77.0	31	24	272.7
4	Control	75.0	74.0	41	44	167.1	70.8	72.0	41	49	166.9
5	WM	20.8	69.8	21	30	161.8	41.7	72.0	28	21	174.5
6	WM	52.1	70.8	28	32	181.8	58.3	66.0	31	35	200.2
7	WM	47.9	72.9	37	34	275.1	52.1	61.0	30	22	250.7
8	WM	45.8	71.0	20	32	246.7	68.8	78.0	28	31	249.6
9	Auditory	85.4	74.0	46	46	181.9	85.4	80.0	31	46	-
10	Auditory	91.7	87.5	33	76	174.0	91.7	92.0	37	18	189.8
11	Auditory	87.5	81.0	44	44	141.3	79.2	80.0	46	59	145.4
12	Auditory	79.2	83.0	34	36	159.4	87.5	71.0	54	31	-
13	Phonological	89.6	76.0	42	63	229.6	89.6	77.0	33	79	247.9
14	Phonological	79.2	67.7	40	58	172.5	79.2	76.0	36	50	172.9
15	Phonological	70.8	48.0	22	24	156.5	-	73.0	-	33	174.6
16	Phonological	10.4	67.0	35	38	159.7	14.6	58.0	25	45	161.8

Notes: QOL: Quality of Life Measures; FCC: Final Consonant Choice; NWR: Non-word Repetition; SRW: Serial Recall of Words; VDS: Visual Digit Span; NCIQ: Nijmegen Cochlear Implant Questionnaire. %CI: % correct items; %CP; % correct phonemes; TCI: total correct items; SS: sum score.

Open-ended Questionnaires Regarding Training Programs

Participants completed a daily log recording when they completed their training session. They also completed an open-ended questionnaire at the post-training testing session that was developed and used to assess participant perspectives of training regarding feasibility and subjective experiences. Questions were asked about what participants did and did not like about the training program, barriers to training experienced, appropriateness of length of training sessions, training program features that seemed most and least beneficial, and willingness to complete more than two weeks of training.

Table 3. Participant subjective responses to questionnaires about training programs.

QUESTION	Auditory Training	Phonological Training	Working Memory Training
1. What did you like about the training program?	• It helped me to work to understand words better than I had. • It was hard and intense! • Feedback was good. Different constructs offered different learning. • Assistants were very accommodating to my schedule and always so patient and willing to help in any way.	• Challenging. Repeat button. • Variety of exercises. Progressive lessons. I liked the way programs flashed a red light for error and green for correct. Positive feedback was also nice. I liked the way the program started simpler and evolved into more difficult. • Even four years as a CI user, RhymeTime was challenging with loud background noise. • I really believe in strategies that promote success for a period of time, which I think many of these programs did in the beginning.	• It forces you to concentrate on remembering many things, sounds, moving objects, and organizing some things. • Made it convenient for home training set at my own pace. • Awareness.
2. What didn't you like about the training program?	• The noise in the background of some modules was really hard to hear past. Sometimes it sounded like the woman was saying the same thing three to four times in a row. • Equipment malfunction (keyboard). Positive feedback was time-consuming. Lingering on it (repetitions of correct and incorrect answers) was annoying. • These programs require intense focus and more than a second or two was annoying. After hearing the same sentences several times, I could figure out words I did not actually hear. • It handles misspellings as mishearing. The concatenated sentences has a bug that can place a word in the wrong column.	• It has verbal instructions for hearing impaired, and clarity of speech is poor. • Overly noisy and time was wasted. Lacked reinforcement. I would benefit from having the words/sounds printed on the screen after making the choice. • I did not like all the extra noisy sound effects between tasks. Those types of noises can be almost painful to hear. I would keep the training level quieter between tasks. I think trying to sound out all the various sounds in a one syllable word such as toy or dog is somewhat counter-productive. • If developing tasks with a noisy background, I think a noisy restaurant crown sound (real-life scenario) or whooshing air (sound of tires on pavement) might be better.	• When you did not correctly identify the answer, it did not show you what your mistake was. • The moving objects could be frustrating at times, especially the clock grid. • Made me feel stupid! The voice on the letters was tricky. • Tedious.
3. Do you feel as though your listening effort has improved following completion of the 2-week training program?	• Yes. • Maybe in the short term. Improvements probably won't last long. • Yes. • Yes.	• Don't know. • Yes, but also an awareness of sounds I am not hearing or differentiating. • As a four year CI veteran, I do not think this program made any difference at my stage of CI use.	• I have not noticed any differences, but maybe people around me can see an improvement. • Hard for me to say. • No.

Table 3 (Cont.)

4. Were there any barriers to participating in the training program?	• Just finding the time. I usually did the training at night which unfortunately was when I was most tired. • Equipment malfunction, vertigo attack. • The time commitment was problematic. • Finding an un-interrupted block of an hour was often challenging. Also, when I changed levels, the module could take twice as long, particularly on those that have long training cycles.	• No. • The computer would freeze about halfway through each session. I had to shut the computer down and start over. Also, speaker had to be unplugged from laptop each session or it would not operate. • No, had quiet environment at home in which to practice and no issues with technology.	• Just be sure to pick a quiet area. Noise in the background can be a problem. • No. • None for me. • No.
5. Were training sessions a good length, too short, or too long?	• Since they normally lasted 45-50 minutes, I thought they were a little lengthy. • They were a good length. • When I was scoring well, they were fine. When I wasn't, and the mistake training loops were wrong, it was taxing. • The day-to-day sessions were a good length for me.	• Length was fine. • Doing one activity per "game" wasted time. • Would be better to do several activities of each game. Too much "filler." • Good length for many who work.	• I had no problems with the length. • Need enough time to understand how to use the program and the computer. • I felt that they were a tad too long as some of them were more taxing toward the end. If I was doing well, it was too short. If I was doing bad, it was way too long. • Good length.
6. What particular features of training seemed the most beneficial?	• All of them had some benefit. • Forced me to make a regular time to test and focus. • A quick correction loop is helpful. • The sessions with light background noise helped me to concentrate more on what was being said.	• Don't know if one was better than the others. • RhymeTime was the most difficult, had to guess a lot. • Being able to repeat and re-listen. • To obtain and see results that one could share with audiologist would be nice.	• None. • My mind likes to "travel" so this helped me in trying to stay focused to a degree. • Vocal tasks.
7. Were there any particular features of training that did not seem helpful?	• No. • No. • I was frustrated when misspellings or phonetically identical words were treated as wrong. • Some parts had so much background noise I could not make out any words.	• RhymeTime because of the poor quality of speech. • Would benefit by putting printed words on the screen as the word was repeated. • Extra loud noises between tasks and programs were more than annoying, could frighten beginning CI user.	• Rotating Drills. • Reverse Numbers.

Table 3 (Cont.)

8. Were there any particular features of training that were too easy or too hard?	• For the noise module where you had to type back the sentences, you had to spell everything exactly right. Also when you got it incorrect it repeated everything too many times. • Speech babble was hard, but it was most like the challenges I face daily. • The sections with a lot of noise were too difficult so I guessed.	• No. • The introduction of background noise was unexpected, so introduce noise soft to loud. • RhymeTime with loud siren-like noise was annoying, and task was too hard.	• Certain problems where there were moving or spinning objects seemed to cause me more vertigo. • The easiest was repeating letters. The moving circles were the hardest. • Numbers in reverse order was too hard.
9. Is this training program something you would be willing to do for longer than 2 weeks?	• Maybe off and on but for me it was hard to get in 10 days with my work and life schedule. • Not sure. • Absolutely, I would like guidance on the modules that are most effective. • If it did not have to be daily then yes. If it is necessary to do the sessions daily then two weeks was fine.	• Yes, if the quality was better. • Yes, I actually wanted to complete the activities. • Yes, I would have used this program until I was getting 90% or better on most of the tasks.	• This program seems to get very repetitive after six to seven days. • Yes. • Yes. • Maybe.
10. Do you feel as though more training would further improve your listening skills with your cochlear implant (s)?	• Yes. • Not sure. • Absolutely. • Perhaps but on the parts with heavy noise it may help that when you replay the sentence that it becomes a little more clear.	• Yes. • Couldn't hurt. • At this point, I'm not sure.	• Maybe some other programs might help. • Possibly. • Cannot say. • Yes.
11. Additional comments?	• On typing sentences, make it easier to correct instead of having to backspace and retype. On concatenated sentences, don't have it repeat itself so many times. • Clearer feedback. • A few more seconds to read the words when listening for sounds. • There should be a "none of the above" or "best guess" button on babble to distinguish random guessing from educated guessing.	• I would include a variety of voices - women, men, children. • A variety of background noises. • Rehab would be better with a hearing partner.	• Wish it would show the correct answer so I know where my mistakes are. • Working with the alphabet and numbers was helpful. • I tried to train at different times of day to see how I would do, also checked my blood sugar. The only thing I felt was that late afternoon was not good.

Auditory Training

Angel Sound™ is an online PC-based interactive auditory training program developed by TigerSpeech Technology, is distributed freely by the Emily Shannon Fu Foundation, and can be accessed at http://angelsound.tigerspeech.com/angelsound_about.html. In brief, this program consists of a variety of self-paced modules with different types of adaptive listening exercises, and it provides audio-visual feedback. eight tasks over approximately one hour: (1) "Everyday Sentences" from the Basic Module – In this task, the participant hears a sentence in quiet and chooses from four closed-set options. (2) "Everyday Sentences" from the Noise Module – In this task, the participant hears a sentence embedded in speech babble and is asked to identify a keyword from that sentence, selecting from four closed-set options. (3) "Sentences" from the Openset Module – In this task, the participant hears a sentence and is instructed to type the sentence heard. This task begins in quiet, then in speech babble at 10 dB SNR and at 0 dB SNR as the participant progresses. (4) "Concatenated Sentences" from the Openset Module – This task is similar to "Sentences," but the participant clicks on the words that make up the sentence from columns of words choices; training is done in quiet and in speech babble at 10 dB SNR and 0 dB SNR. (5) "Speech Test in Noise" from the Assess Module – In this task, the participant hears sentences in speech babble and identifies a key word from a closed set of six options. Additional details of these tasks can be found on the Angel SoundTM website.

Working Memory Training

The Cogmed® Working Memory Training program (Pearson, San Antonio, TX) is a video game-like program that consists of exercises requiring auditory, visuospatial, and audiovisual short-term and WM skills. These tasks use an adaptive algorithm to increase difficulty as performance improves. Participants completed approximately one hour per day, which consisted of the following eight exercises: (1) "Sort" – boxes with numbers light up on the screen in a sequential order, and the participant is asked to click on the boxes in the correct numerical order using the mouse. (2) "Cube" – squares lining the sides of a cube light up in a certain order, and the participant clicks on the squares in the same order they lit up. (3) "Hidden" – Numbers are presented auditorily, and the participant clicks on the numbers on the screen in the reverse order they were presented. (4) "Twist" – Circles forming a four by four square light up on the screen as the larger square rotates, and the participant clicks on the circles in the same order they lit up. (5) "Assembly" – Several letters are presented auditorily, and the participant clicks on the letters on the screen in the order they were heard. (6) "Chaos" – Several shapes on the screen are moving in random fashion. Shapes light up one at a time but continue to move, and the participant recreates the sequence by clicking on the shapes in the order they lit up. (7) "Rotating" – A large circle consisting of small circles along its circumference rotates, and the smaller circles light up one at a time. The participant clicks on the circles in the order they lit up. (8) "Numbers" – Numbers are presented auditorily, and the participants click on the numbers on the screen in the reverse order they were presented.

Phonological Training

Earobics® (Houghton-Mifflin, Evanston, IL) version one for adolescents and adults was used. Four tasks were completed over approximately one hour per day: (1) "Sound Check" – The participant hears a target phoneme and uses the mouse to click on the associated letter representing that phoneme if the sound was heard individually or in a monosyllabic word. With progressive completion, the participant is asked to indicate if the sound is heard at the beginning, middle, or end of a word. (2) "Get Rhythm" – The participant hears a sound a certain number of times and then is asked to click on an object displayed on the screen once for each time the given sound is heard, initially for each syllable heard in a word, and then later for each phoneme heard in a word. (3) "Connectivity" – The participant clicks on pictures of words heard. With progressive completion, the participant clicks on the picture of the word that the syllables or phonemes create. (4) "Rhyme Time" – The participant clicks on a word that does not rhyme with the other words shown and heard. With progress, the participant selects which word shown visually rhymes with a word presented auditorily.

General Procedures

All procedures were approved by The Ohio State University Institutional Review Board. Participants were tested at baseline on one day during a single session of approximately two hours. First, hearing thresholds and screening measures were obtained. Following these, the order of presentation of tasks was randomized across participants.

After baseline testing, participants were allocated to one of four groups: (1) Auditory training; (2) Working memory training; (3) Phonological training; or (4) Untrained control. Because the primary purpose of this study was simply to evaluate whether older CI users would remain compliant with a training program, and explore their overall experiences with such home training options, patients were allocated to the four groups non-randomly. That is, we attempted to assign patients with the poorest WM to the WM training group, and those with poor phonological sensitivity to phonological training.

Each participant who received training was asked to complete 10 training sessions, each approximately one hour in duration, over two weeks. Except for the first session, training was completed at home using a laptop computer, mouse, and speaker provided by our lab. Each group underwent a pre-training workshop of approximately three hours prior to beginning training at home. This workshop consisted of a lesson with hands-on practice to set up the laptop, connect the mouse and speaker, test the sound, and log into the respective software program. Following this lesson and hands-on practice with the computer hardware, participants split up and completed their first one hour training session with the appropriate software program in separate rooms in our laboratory. This way, members of the lab were available to help troubleshoot the first training session for each participant. Several participants brought family members to assist them in setting up the training hardware at home. Participants and family members were able to email, text, or call laboratory research assistants as needed from home during the two week training period. They were asked to complete a daily log of training activities to verify completion of training. Objective computer reports were generated for participants who completed Auditory and Working Memory training, but these reports were not provided by the software for those who completed Phonological training.

Participants adjusted the speaker volume to their most comfortable listening level for training, and they wore their usual devices (one CI, two CIs, or CI with contralateral hearing aid) during training.

Following the two week training period, participants came back to the laboratory for repeat testing of speech recognition, phonological sensitivity, and WM. Control participants completed repeat testing between four and six weeks following baseline testing.

Data Analyses

Because this feasibility study consisted of a small number of participants, data analyses that could reasonably be performed were limited. Group means and standard deviations for speech recognition, phonological, WM tasks, and QOL were computed. Responses to open-ended questionnaires were summarized.

Results

All 16 participants completed pre- and post-training assessments. All 12 participants assigned to training groups completed all 10 sessions of training; which was verified by review of participants' daily log of training at the end of the training period (all participants demonstrated training for 10 sessions) and confirmed by computer output reports for those who completed Auditory and Working Memory training, as noted above. For those who completed Phonological training, individual training logs supported training completion, but no objective method was available to confirm this. Individual speech recognition scores plotted in Figures 1 through 3 show that a large amount of inter-participant variability was demonstrated across all measures. Speech recognition scores among some participants showed improvements, while other participants demonstrated similar or worse performance post-training. Although group sizes were too small to perform statistical comparison, visual inspection of speech recognition plots did not reveal clear performance improvements for one group over other groups. Notably, for all three speech recognition tasks, some control participants demonstrated improved scores between the first and second testing sessions.

Table 2 shows pre- and post-training scores on phonological, working memory, and QOL measures. Again, group sizes were too small for statistical analysis, but visual inspection of the raw data again demonstrates variable changes among individual participants on these measures. Similar to the speech recognition measures, control participants showed improvements on some measures between the first and second testing sessions.

Subjective responses to open-ended questionnaires are shown in Table 3. Several general themes deserve consideration. Overall, participants enjoyed being actively involved through training and trying to improve their speech recognition. They found the computer-generated feedback during the exercises to be helpful, and a variety of exercises in each training program seemed beneficial. However, several barriers to training were apparent. First, some participants experienced equipment/software malfunctions. Second, some patients found particular aspects of feedback or exercises annoying or tedious. For example, one program incorporated extraneous sounds to try to encourage attention of the trainee; instead the CI users found these environmental sounds distracting or even unpleasant. Thus, there were some frustrations regarding applying training programs that were not specifically designed for individuals with hearing loss – both the Working Memory and Phonological training programs – to clinical populations of hearing-impaired patients. Third, some particular training modules were particularly frustrating to complete; one module required open-set responses to be typed by the patient, but the response had to be spelled perfectly correctly to be counted as correct. Finally, over half of the participants either doubted that ongoing training would be beneficial, or they stated that they would not be willing to continue training with their program beyond the two-week period.

Discussion

This study was conducted to evaluate the feasibility of using at-home computerized training programs for postlingually deaf adults with CIs, most of whom were over age 60 years, using three different types of training programs in a small group of experienced CI users. Although the small sample size included in this pilot study precluded statistical analyses, several findings are worthy of discussion.

First, this study demonstrated that CI users were able to set up the at-home computerized training hardware, and completed all 10 sessions of at-home training. Compliance was high in our group (100%) for completion of 10 training sessions, and compared favorably with reported compliance rates in other studies, which have been found to be as low as 30% and as high as 100% (Henshaw & Ferguson, 2013; Sweetow & Sabes, 2006; Sweetow & Sabes, 2010). Our high rate of compliance may have been encouraged by our use of daily training logs and software that automatically output reports of training sessions, at least for the Auditory and Working Memory training programs. Furthermore, participants were paid to complete this training which may have also increased compliance. It was apparent during the pre-training workshop for each training group, that this workshop facilitated preparation of participants to set up and complete the computerized training at home. For example, several participant comments related to the exchange of questions and answers with our research assistants in relation to hardware troubleshooting. Several participants also required some ongoing assistance from our research assistants and/or family members during their at-home training period, through email or texting, in order to complete the sessions. This observation suggests that although computerized training programs are widely available to adult CI users, use of these applications creates technical challenges for some older adults. Thus, clinicians recommending training programs for their clients should consider that some older patients will need personal technological assistance to complete training effectively.

A second major finding of this feasibility study was that, although patients generally enjoyed taking a more active role in trying to improve their speech recognition performance through training, there were a number of limitations to computerized training. In addition to requiring technical support for the hardware/software use, some participants experienced equipment and software malfunctions that impeded training. Also, several training modules were too difficult, too tedious, or frustrating to complete, especially those modules not designed specifically for the hearing-impaired. Lastly, many participants simply did not feel as though the training was useful. They commented that they would not likely continue their particular training program beyond two weeks if given the option, and they did not think ongoing training would be beneficial.

A third finding of this study was that performance of the control group/condition is of particular interest. While all groups were comprised of small numbers, CI users in both the training groups as well as some members in the control group demonstrated speech recognition gains and some improvements in QOL. It is unclear exactly why these improvements were observed; however, researchers could not control whether or not the participants in the control group did any training on their own. One alternative to a passive control group (as applied here) would be to include a separate active control group that performs a task for a similar amount of time as the training participants, but uses a task that is unlikely to provide any sort of training benefit (such as performing a very easy task of a similar nature to the training task, or performing a task that is completely unrelated). A problem with this approach, however, is that control participants may realize that their training tasks seem completely unrelated to the outcome of interest, or that their training exercises are too easy and tedious to be compliant with training. Another option is to perform multiple repeat baseline assessments of performance in the training group, which allows each participant to serve as his or her own control. The benefit of this single subject design approach is that it eliminates the need to assign participants to a group in which no actual effect is expected; a downside, though, is the greater possibility of procedural learning effects as a result of multiple repeat measures using the same tasks. Nonetheless, incorporation of a control group is essential in training studies, as evidenced by the performance improvements demonstrated by some of our control participants who did not undergo training.

This study clearly has several limitations. First and foremost, as a feasibility study, the sample was very small, and statistical analyses could not be performed to identify inter-group differences in training benefits between "bottom-up" and "top-down" training approaches. Second, patients were not randomly assigned to training groups; instead, they were assigned to training program based on their pre-training performance on measures of phonological skills and WM. For example, a participant with relatively poor phonological skills was assigned to the phonological training group. This was done by design to try to optimize participants' chances of benefitting from their assigned type of training and also to maximize participant enrollment for this feasibility study. Third, researchers and participants were not blinded to the group to which participants were assigned. In a future, larger-scale study of training, participants will need to be randomly assigned to control and training groups, and researchers (at least those performing the pre- and post-training testing) will need to be blinded to participant treatment group. Finally, test-retest improvements in outcome measures should be considered, particularly since some control participants demonstrated improvements between the first and second testing session. The same speech materials were used in the pre- and post-training assessments. Although these testing sessions generally took place approximately one month apart, it is possible that participants demonstrated list learning effects. A potential solution is to develop test lists that have been used in a control population and have demonstrated list equivalency, and/or to include a large control group in the main study for which test-retest learning effects can be assessed.

Although this study demonstrated the feasibility of implementing a computerized rehabilitative training study in older adult CI users, we are not convinced that the patient-driven computerized training approach should be applied broadly to older adults with CIs. Some participants needed support from family members or lab assistants for computer hardware/software issues. Some participants found training to be tedious, or aspects of the programs were annoying. Subjective comments demonstrated that by the end of two weeks of training, several participants probably would not have continued training if given the opportunity. Because of these limitations, our group is now exploring clinician-guided aural rehabilitation approaches to training for adult CI users to investigate the potential to optimize speech recognition outcomes. For example, CI patients are seen once a week for six to eight weeks by a speech-language pathologist to perform clinician-guided training exercises, using a combination of tasks like speech tracking, text following, sentence repetition with cueing, following verbal directions, and sentence completion using the surrounding context.

Finally, this feasibility study did not allow us to determine whether bottom-up or top-down training is more effective for older adults with CIs. The "bottom-up" and "top-down" training programs used in this study may hold potential for improving speech recognition performance, phonological skills, working memory, and QOL. A current study is comparing the effects of bottom-up versus top-down training, using clinician-guided aural rehabilitation approaches. In contrast, some authors have recommended the use of an "integrated auditory-cognitive" approach to training (Ferguson & Henshaw, 2015), where cognitive processes are targeted within speech training tasks, rather than by training cognition directly.

Conclusions

Adult CI users demonstrated successful completion of short at-home computerized training programs, including those who were elderly. However, significant limitations of computerized training approaches exist for this population. These specifically include hardware/software issues, the ongoing need for support from research assistants and/or family members, the tedious and sometimes frustrating nature of computerized training modules, and the perceived lack of benefit gained from some training exercises. Clinicians recommending training programs for older adult CI users should use discretion in selecting the type of training for any given patient.

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