Benefits of Speech Tracking Training on Sentence Recognition, Tracking Rate, and Self-Assessed Communication Function in Adult Cochlear Implant Users

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This study investigated 2 methods of Speech Tracking training, traditional and computer-assisted, for enhancing receptive communication skills in postlingually deafened adult cochlear implant users. Ten participants engaged in an 8 week auditory-only training program. Both methods showed significant gains in tracking rate ($p < .001$) and sentence recognition ($p < .001$) following training,

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maintained 3 months post. Training was also associated with improvements in personal communication goals. The computer-assisted method had significantly smaller test-retest error variance and provided a more precise measure of improvement. Speech Tracking training can be a valuable rehabilitation tool to help adult cochlear implant users maximize benefits from their implant.

In recent years there has been a resurgence of interest in the role of auditory training for enhancing auditory perceptual and communication skills of adults with hearing loss (Boothroyd, 2007; Kricos & McCarthy, 2007; Stacey et al., 2010; Stacey & Summerfield, 2008). Developments in the area of neuroplasticity of the auditory system (Hayes, Warrier, Nicol, Zecker, & Kraus, 2003; Neuman, 2005; Russo, Nicol, Zecker, Hayes, & Kraus, 2005; Tremblay & Kraus, 2002) underscore the importance of including auditory training to facilitate the development of these skills. The availability of inexpensive personal computers has provided the means for developing these improved methods of auditory training. Findings from numerous studies looking at auditory training indicate that computer-based training can improve speech recognition for adults with hearing loss (Ross, 2005; Sweetow & Palmer, 2005; Sweetow & Sabes, 2007), and adult cochlear implant users in particular (Fu & Galvin, 2007; Miller, Watson, Kistler, Wightman, & Preminger, 2008; Stacey et al., 2010). The efficacy of this training, however, also needs to be considered in terms of improved speech recognition, communication skills, and on how this may translate into subjective improvements in social participation, confidence, and quality of life.

This study focuses on the development of a computer-assisted method of connected discourse tracking as a training method with adult cochlear implant users. Connected discourse tracking, referred to in this paper as "Speech Tracking," was first introduced by DeFilippo and Scott (1978). This technique was an attempt to simulate the interactive nature of speech communication. The original form of the tracking procedure was described by DeFilippo (1988):

> The sender (a talker) read(s) from a prepared text, phrase-by-phrase, and the receiver (the speechreader or listener) repeat(s) verbatim what the sender has said. If the receiver does not give a verbatim repetition, the sender is to apply some oral strategy to correct the response before going on to the next phrase. The procedure is timed and scored in number of words per minute (wpm) transmitted. (p. 216)

Since Speech Tracking was introduced it has been widely used clinically for both training and evaluation of communication skills of people with hearing loss. The technique has been found to be particularly useful in evaluating performance with cochlear implants and tactile aids (Plant, Gnosspelius, & Levitt, 2000; Punch, Robbins, Myers, Pope, & Miyamoto, 1987; Robbins, Osberger, Miyamoto, & Kienle, 1985). An investigation by Tobey et al. (2005) used pharmacological enhancement during the training process with 8 adult cochlear implant users and demonstrated significant learning after training with traditional Speech

Tracking. Their findings were supported by both improved speech recognition performance along with notable changes in functional MRI scans.

Since its first implementation the technique of Speech Tracking training has been used successfully to cover a wide range of communication skills (Levitt, Waltzman, Shapiro, & Cohen, 1986). A valuable feature of Speech Tracking is that it can make the training process enjoyable by using humorous or other training materials of personal interest to the client. Although Speech Tracking has been found to be a valuable tool in auditory rehabilitation, the technique nevertheless has several shortcomings. Tye-Murray and Tyler (1988) cite a lack of control over a number of variables which may limit its use. Factors which may affect performance can include those intrinsic to the hearing impaired listener, including linguistic competency, motivation, and attention. According to Owens and Raggio (1987) other variables which may also affect performance could include text complexity, correction strategies, and speaker characteristics. There are large inter-sender differences which limit the effectiveness and precision of the technique, particularly when used as an evaluative tool (Schoepflin & Levitt, 1991).

In order to address concerns regarding variability of the tracking technique, Dempsey, Levitt, Josephson, and Porrazzo (1992) developed a computer-based variation of Speech Tracking designed to compensate for inter-sender differences. The technique, known as Computer-Assisted Tracking Simulation (CATS) effectively controlled for talker/sender variability by making use of pre-recorded utterances and a programmed set of correction strategies. This computer-assisted approach used laserdisc technology and, although effective, has not been transferred for use into current computer technology.

Another computer-assisted approach to speech tracking was developed at the Royal Institute of Technology in Stockholm (KTH) by Gnospelius and Spens (1992). To operate on a modern, inexpensive personal computer, the KTH Speech Tracking technique was modified by the Rehabilitation Engineering Research Center on Hearing Enhancement at Gallaudet University (GU) in collaboration with Geoff Plant at MED-EL. The KTH Speech Tracking technique maintains the inherent structure of Speech Tracking, at the same time reducing variability by providing a strict set of correction strategies. Because the system is implemented in real time on a computer, the client's performance is continually monitored and analyzed. In light of the range of variables that may impact tracking as an assessment tool, the KTH Speech Tracking technique was used solely for the purpose of training.

This investigation looked at the extent to which KTH, a computer-assisted procedure which uses a strict set of rules, improves the Speech Tracking technique. One would expect a reduction in variability using a structured set of rules. One would also expect that it would result in a better tracking rate. Our primary interest was whether the KTH method is more repeatable than the traditional method of Speech Tracking (TRAD). If KTH is more repeatable, then is it as effective as or more effective than the TRAD method? A more important question is whether gains in speech tracking performance extend beyond the task itself. Are there corresponding improvements in other independent measures of speech recognition? We were most interested to know whether training with Speech Tracking translates into real life benefits. Are improvements in Speech Tracking performance associated with self-reported improvements in communication function and measures of personal adjustment in day to day life?

In developing this investigation ancillary questions regarding Speech Tracking training and the receptive communication skills of adult cochlear implant users were also considered. Does short-term training with Speech Tracking result in improved tracking rates for postlingually deafened adult cochlear implant users? How much training is needed to yield improvements in receptive communication skills?

METHOD

Participants

Ten postlingually deafened cochlear implant recipients participated in this study. Six of the participants were evaluated at GU and 4 were evaluated at the University of South Florida (USF). Two additional participants began but did not complete the experiment owing to illness, or moving to another location. As a result, a complete data set was obtained for 10 adventitiously deafened individuals with cochlear implants. Participants were volunteers who were motivated to join the study to improve their communication skills. Inclusion in this study was limited to those who had their implant activated for at least 3 months to allow for acclimatization. Additional inclusion requirements were English as a first language and no evidence of cognitive impairment (e.g., post-stroke, signs of Alzheimer's or dementia). All participants had a period of amplification before obtaining their implant and reported no prior rehabilitation training. To avoid floor effects and minimize a participant's potential frustration with Speech Tracking, a criterion of tracking rate at baseline was required to be at least 20 wpm. Tracking rate was calculated as the number of words correctly repeated divided by the time elapsed.

Table 1 provides demographic information on the adult cochlear implant users who participated in this study.

As a training study, the clinicians who conducted the intervention may also be considered as participants. In the current study both clinicians hold a PhD in Audiology, both work at academic institutions, and both have over 20 years of experience providing aural rehabilitation services to adults with hearing loss. One faculty clinician administered the training onsite at GU and the other administered the training onsite at the USF. Both clinicians had at least 5 years of experience using the TRAD method of Speech Tracking and at least 2 years using the

Table 1

Demographic Information of Adult Cochlear Implant Participants

Participant	Age/sex	Cause of deafness	Duration of deafness prior to implantation	Time post-implantation	Level of education/occupation
GU01	85/Male	Noise-induced	3 years	1 year, 8 months	GED/retired military
GU02	67/Male	Noise-induced	9 years	3 years, 6 months	MEd/vocational rehab counselor
GU03	55/Female	Autoimmune and familial	5 years	3 months	PhD/public health director
GU04	35/Male	Viral infection	10 years	3 months	BS/coach & personal trainer
GU05	58/Female	Family history – progressive loss	15 years	2 years	BA/teacher
GU07	60/Female	Enlarged vestibular aquaduct disorder	15 years	5 months	PhD/biologist
USF01	52/Male	Family history – progressive loss	5 years	1 year, 10 months	BS/environmental specialist
USF02	81/Male	Presbycusis	10 years	1 year, 2 months	BA/retired
USF03	63/Female	Meniere's	10 years	1 year, 3 months	BS/retired teacher
USF04	84/Male	Noise-induced	15 years	3 months	BS/retired iron foundry worker

Note. GU = Gallaudet University participants; USF = University of South Florida participants; BA = Bachelor of Arts; BS = Bachelor of Science; GED = General Equivalency Diploma; MEd = Master of Education; PhD = Doctor of Philosophy.

KTH method with adult cochlear implant users.

At GU the faculty clinician directly provided the training to the participants. At the USF, the faculty clinician directly supervised the provision of training by graduate clinicians. All graduate clinicians received training in aural rehabilitation practicum and were at the stage of graduate training just prior to externship placement. All graduate and faculty clinicians spoke standard American English. In an effort to attain consistency between participating clinicians and sites, all clinicians were instructed to present the material using clear, enunciated speech at a normal conversational speech rate, on average between 125 and 135 wpm. Talker rate was modeled and informally evaluated by the faculty clinician.

For the TRAD Speech Tracking method, the faculty clinicians established the strategies to be used prior to the study and all graduate clinicians were instructed on their use. For the KTH Speech Tracking method, a recorded video tutorial on the procedure was presented to all graduate clinicians. All received a minimum of 2 hr training on the KTH procedure prior to their first session with a participant. Further, the supervising faculty clinician observed the sessions to ensure appropriate implementation of the procedure.

Experimental Design

The experiment consisted of 14 training and assessment sessions. The first 13 sessions were spaced approximately a week apart followed by a final assessment session 3 months after the termination of training. Table 2 provides a summary of the 14 sessions. Sessions 1 and 2 were pre-training assessment sessions. Sessions 3 to 6 were training sessions followed by two more assessment sessions.

Table 2

Overview of Assessment and Training Sessions

Visit	Purpose	Acronym
1	Pre-assessment 1	PRE1
2	Pre-assessment 2	PRE2
3	Training session 1	TR1
4	Training session 2	TR2
5	Training session 3	TR3
6	Training session 4	TR4
7	Mid-assessment 1	MID1
8	Mid-assessment 2	MID2
9	Training session 5	TR5
10	Training session 6	TR6
11	Training session 7	TR7
12	Training session 8	TR8
13	Post-assessment 1	POST1
14	Post-assessment 2	POST3M

The pattern was then repeated. Sessions 9 to 12 consisted of training sessions followed by an assessment session at the end of training, and a final assessment session 3 months after the termination of training, Sessions 13 and 14, respectively.

Each training session consisted of four Speech Tracking trials of 5 min duration. The choice of four tracking trials per session was selected to reduce the variability of the mean for each session (Plant et al., 2000). A balanced design was used in which half of the participants began with four training sessions using the KTH method (Sessions 3 to 6) followed by four training sessions using the TRAD tracking method (Sessions 9 to 12). The remaining group of participants began with the TRAD tracking method followed by the KTH method. The participants were assigned randomly to the two groups. Of the 10 participants who completed the study, 6 GU participants formed a balanced set, 3 beginning with the KTH method and 3 beginning with the TRAD method. The 4 USF participants who completed the experiment all began with the KTH method.

Speech Tracking Training

Materials. The materials used for tracking consisted of short passages (i.e., this was operationally defined as a word count of 200 words). Sixteen short stories were taken from the *Reader's Digest* library collection. They were selected based on their interest to readers combined with accessibility to a larger number of readers at the 4th to 6th grade reading level. Since the participants' educational level was not known a priori, this reading level was chosen to ensure that all participants would be able to access the story and rule out reading level as a factor limiting understanding of the material. It was also used in an effort to have a degree of equivalence across passages. The use of stories provided contextual information for participants. For each story, a list of the most difficult or uncommon words were presented at the beginning of the training session. Word lists for the *Reader's Digest* stories typically included the proper nouns used in the story (e.g., names of people, places), multisyllable words not commonly used in conversation, along with any topic specific vocabulary and technical terms. A list was generated for each story. Before the tracking session began with a given story, this list was presented in both written format and presented auditorally with visual clues. This process was done for all stories and with all clinicians. Each session began with a new story. Stories were presented in a pre-determined randomized order across participants.

Procedure. Training with Speech Tracking was conducted in a quiet room with ambient noise level of less than 20 dBA. For both the TRAD and KTH Speech Tracking procedures, the participant was seated across the table from the clinician at a distance of 1 m. All material was presented in auditory only presentation mode. The clinician used an acoustic screen to ensure that the participant was not able to access speechreading cues. For the KTH procedure, the clinician used a laptop to read the story line by line from the computer screen whereas in the TRAD procedure the clinician read the story from a printed version. Training was conducted bimodally for those participants with both a cochlear implant and a hearing aid (i.e., with the cochlear implant and hearing aid combined). At the beginning of each session, basic checks were made regarding battery strength, implant function, and volume control setting. All participants were asked to use the setting on their implant which they most commonly used. Once a setting was selected, it was noted in their folder and used throughout the course of the training.

The TRAD and KTH methods of Speech Tracking have the same basic structure. During Speech Tracking, the clinician reads a story to the listener, one line at a time, and the listener repeats back what he/she heard verbatim. A pre-determined length of text is used to ensure that all listeners received the same text in the same way. The listener repeats what is said. If the repetition is correct, the clinician moves on to the next phrase or sentence. If the repetition is incorrect, the clinician then makes use of a correction strategy to help the listener repeat what was said correctly. The TRAD and KTH tracking methods differ with respect to correction strategies. In the TRAD method, the clinician is free to choose any correction strategy which the clinician considers reasonable and there is no well-defined limit to how many attempts the listener is allowed. In the current study, however, both sites and all clinicians used the same correction strategies for the TRAD method. The three key strategies included repetition of the word itself as opposed to the entire remaining phrase, the use of speechreading cues for missed words, and the use of parsing of long phrases to break the information down into shorter segments. The strategy of using a related hint, while effective with listeners, was not included because graduate clinicians were not able to use this particular strategy with equal consistency compared to the three strategies described above. The number of attempts extended to the listener in this study was limited to three. With the TRAD method there was also more discussion about performance between training blocks as compared to the KTH method of Speech Tracking training where feedback was provided only at the end of the entire tracking session.

In the KTH method, when the participant is unable to repeat a word (i.e., he/she "blocks" on that word), the line of text is repeated from the blocked word on. If the individual still blocks on the word after three presentations (i.e., one presentation and two repetitions), the word the participant blocked on is presented visually on a computer monitor screen, which is placed facing the participant at a distance of approximately 0.5 m. With the KTH method, the listener is allowed a maximum of three repetitions. Once the listener understands the word, the clinician continues to present the story from that word on, auditory-only. This strict set of rules, whereby the computer sets a limit on the number of repetitions, requires how the repetition must be made (i.e., that the blocked word and the remaining text on the line are all to be repeated), and that the blocked word is then presented visually, distinguishes the KTH method from the TRAD method of Speech Tracking. The KTH computer-assisted approach to Speech Tracking enables the clinician to both control the presentation of material and easily keep track of an individual's mean tracking rate in a systematic format.

Assessment Procedures

Objective measurement of speech recognition. Everyday, topic-related sentences were used to "provide an estimate of word recognition in sentences where the topic is known" (Hnath-Chisolm & Boothroyd, 1992, p. 1161). These sentences offer high face validity as a measure of perception of conversational speech, and have been widely used as a measure of speech recognition ability with cochlear implant recipients (Gifford, Shallop, & Peterson, 2008; Orabi, Mawman, Al-Zoubi, Saeed, & Ramsden, 2006; Skinner et al., 2002). The sentences were first developed by Boothroyd (1987) at City University of New York (CUNY) and are known as the CUNY Topic-Related Sentences.

Professional audio-visual recordings were made of two talkers (one male, one female) producing the CUNY Topic-Related Sentences. These recordings have subsequently been included in CasperSent, a multimedia program whose main purpose is sentence-level speech perception training and testing for persons with hearing loss (Boothroyd, 2008). The corpus consists of 60 sets of 12 sentences. Each set of 12 sentences relate to 12 different topics (e.g., food, family, health) which remain constant from set to set.

Four sets of sentences were administered in each assessment session, as recommended by Boothroyd, Hnath-Chisolm, Hannin, and Kishon-Rabin (1988). The average score for four sentence sets allows for a clinically significant difference, of greater than or equal to 10 percentage points, to be detected at a 90% confidence level. Each participant was assigned either a male or female recording, the assignments being made at random. Similarly, the sentence sets were presented in randomized order. A separate randomized schedule was developed for each participant (McLeod, 1985). The randomization schedule ensured that four different lists were administered at every assessment session and for every participant. Participants never received the same sentence twice.

The speech recordings were played to participants in a double walled Industrial Acoustics audiologic test booth using a Grason-Stadler Instruments GSI 61 audiometer. The audiometer was calibrated by Kimmetrics. Sentences were delivered by an Allison Laboratories Incorporated speaker. Participants were seated facing the speaker (0° azimuth) at a distance of 1 m. Speech was presented at a sound level of 70 dB SPL at the position of the listener's head. Sentences were administered in auditory only presentation mode. Each sentence presentation was preceded by the topic cue and guessing was encouraged. Participants were asked to listen to the stimuli and repeat back what they heard.

Self-assessment measures. In addition to using untrained materials to measure speech recognition in each assessment session, two self-assessment measures were administered at the start and at the end of the training program. The Communication Profile for the Hearing Impaired (CPHI), was used to obtain a self-assessment in four areas – Communication Performance, Communication Environment, Communication Strategies, and Personal Adjustment to Hearing Loss. The Client Oriented Scale of Improvement (COSI) was used to identify listening situations in which the client would like to hear more clearly, and then to assess the extent to which these goals were achieved at the end of the training program.

The CPHI was developed by Demorest and Erdman (1986, 1987, 1988) and was normalized over a large clinical database ($n = 1004$) from five audiology centers with diverse populations in terms of race/ethnicity, gender, educational level, employment status, and hearing aid experience. Demorest and Erdman report that their results show consistency of the overall CPHI profile across centers.

The COSI, created at the National Acoustic Laboratories (NAL) by Dillon, James, and Ginis (1997) and Dillon, Birtles, and Lovegrove (1999), is an open-ended assessment tool which allows the client to target specific listening situations for improvement. The COSI provides a structured format for obtaining communication goals of importance to each individual. It can be used as both a counseling tool regarding expectations, and a means of assessing the effectiveness of a training program in terms which relate directly to each client's wants and needs.

RESULTS

Speech Tracking

The current study examined the effects of Speech Tracking training on both tracking rate and sentence recognition performance in adult cochlear implant users. The pre-post assessment period spanned a 13 week time frame, with 8 weeks of training interrupted midway by 2 weeks of assessment. The first level of inquiry was whether the tracking rate can be improved with training. Applying a general linear model repeated measures analysis of variance, using SPSS 16.0, for the factors Training Session (8 levels), Tracking Trials within a Session (4 trials), repeated over participants (10), we found significant main effects for Training Session ($F = 8.61$, $df = 7/63$, $p < .001$) and Tracking Trials within Sessions ($F = 5.97$, $df = 3/27$, $p = .0032$). There were no significant interactions.

Figure 1 shows mean tracking rate as a function of Training Session. Three regression lines are shown: (a) mean tracking rate averaged over all participants, (b) tracking rate of the participant showing the smallest improvement, and (c) tracking rate of the participant showing the largest improvement. The fitted linear regression line for the mean tracking rate averaged over all participants reflected an increase from first session to last session of 16.0 wpm. The regression line through the mean tracking rate across 8 sessions, with four 5 min trials per ses-

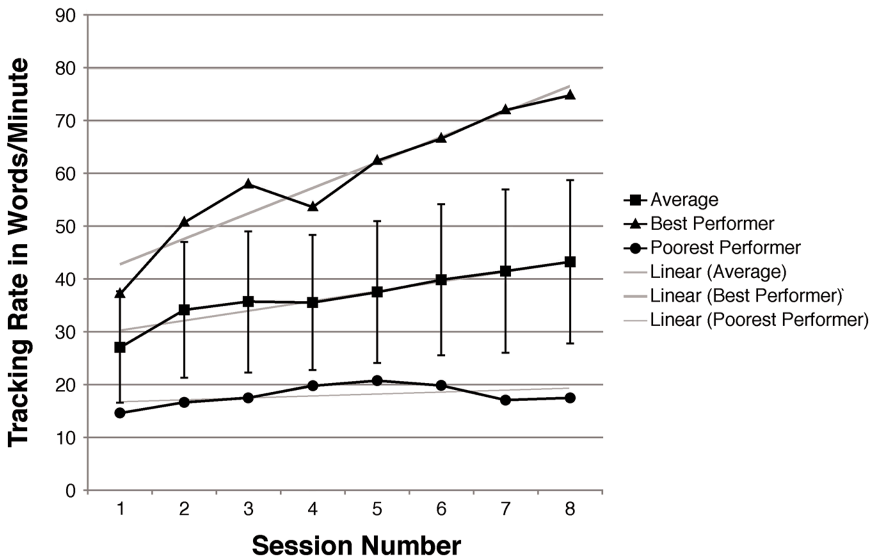

Figure 1. Improvement in tracking rate across all trials: average, poorest, and best performance.

sion, had a slope of 0.50 wpm per tracking trial. There was, however, one significant deviation from the linear regression line. On average, the participants showed an improvement in tracking rate of 1.5 wpm for each training session, except for Training Session 1. At the end of Training Session 1, the average improvement was 7.1 wpm. This large improvement at the start of the training program can probably be attributed to task learning.

In light of the initial increase in performance observed from Training Session 1 to Session 2, additional analyses were performed to determine whether improvements in tracking rate were sustained and significant beyond adaptation to the tracking task. As noted earlier, the repeated measures analysis of variance showed a significant main effect for Training Session ($p < .001$). Pair-wise comparisons were made between the estimated means of the training sessions. Results showed that the estimated means for Training Sessions 7 and 8 did not differ significantly from each other, but were significantly better than the mean for Training Session 2 ($p < .05$; $p < .01$ respectively). A significant training effect was observed.

The average tracking rate for the first trial in a training session was slightly less than that of the last trial of the previous week's training session. The average difference was small (1.4 wpm) and not significant ($z = 1.70$, $p = .089$). This may be attributed to the fact that a new story was introduced each week. There was a significant average improvement on the next trial ($z = 2.04$, $p = .041$) followed

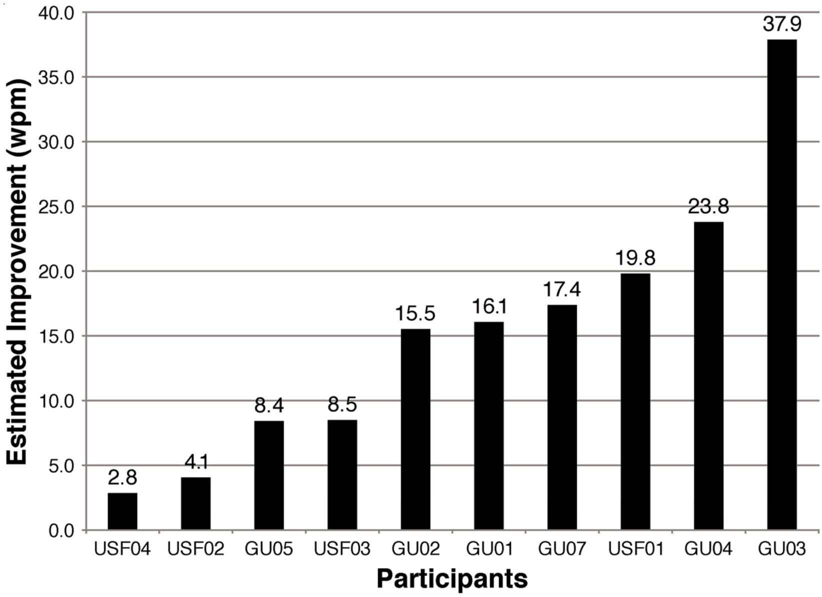

Figure 2. Tracking performance improvement. *Note.* wpm = words per minute; GU = Gallaudet University participants; USF = University of South Florida participants.

by a steady average improvement for the remaining trials in the training session so that, on average, the improvement in tracking rate between sessions was 2.0 wpm. It is likely that the improvement in wpm noted within the course of a session was related to the fact that predictability of content increased. Since all 4 trials in a session were from the same story, as the story unfolded the context of the story provided multiple clues, accounting for some of the increases in wpm observed over a session.

As seen in Figure 1, the fitted regression line for the participant showing the least improvement reflected an increase of 3.1 wpm which was not statistically significant. Clinical observation of this participant suggested that aging may have been a critical factor in his performance. This individual exhibited difficulty with short-term memory on the Speech Tracking task. It was also noted that while the story was presented with clearly enunciated speech, this individual would have benefited from a much slower rate of speech. On the other end of the spectrum, the participant showing the largest improvement exhibited an increase of over 35 wpm, which more than doubled her tracking rate over the 8 week training period. This participant was highly educated and had to deal with a very demanding communication environment at work. As such, she was strongly motivated and very attentive during the Speech Tracking training task. She also set high goals for herself in terms of expectations for auditory only listening capaci-

Table 3

Tracking Method Order and Performance

	Mean tracking rate (wpm)		
Participant	**Initial**	**Post 4 weeks**	**Final**
KTH method first			
GU02	34.8	36.7	50.0
GU03	37.5	54.0	75.2
GU07	26.3	35.7	43.9
USF01	26.3	20.7	42.7
USF02	15.8	32.7	35.2
USF03	26.6	28.9	29.9
USF04	14.6	19.8	17.7
TRAD method first			
GU01	19.7	28.2	32.1
GU04	18.5	37.4	44.4
GU05	50.6	62.4	62.0

Note. wpm = words per minute; KTH = Royal Institute of Technology method of speech tracking; GU = Gallaudet University participants; USF = University of South Florida participants; TRAD = Traditional method of speech tracking.

ties. A combination of these factors may have been responsible for her remarkable improvement in speech tracking performance.

Slope intercept calculations were used to estimate the improvement in tracking rate for each of the participants. Figure 2 displays improvement in tracking rate for each participant, which ranged from 3 to 38 wpm. The average improvement was 15.4 wpm, with a standard deviation of 10.4 wpm. Note that the average improvement is slightly lower than the average improvement obtained from the regression line in Figure 1 (15.4 vs. 16.0 wpm). Because the former estimate is based on individual performance as opposed to group data it may have greater clinical relevance. Six participants showed a tracking rate improvement of 15 wpm or greater, with 1 presenting a dramatic improvement of 38 wpm. An additional 2 participants demonstrated a gain of more than 8 wpm. Motivation and attention, secondary to communication needs and goals, seemed to play an important role for those who gained the most improvement in Speech Tracking rate. Only 2 participants showed little change over the course of the training. Difficulty related to short-term memory and with the rate of conversational speech affected these, but not all, of the older participants in this study.

Table 3 compares order of tracking method, and presents mean tracking rate at the initial session, after 4 weeks of training, and at the final session once training was completed. Learning was found to be greatest in the first 4 weeks, regardless of tracking method. Six out of 10 participants showed an improvement

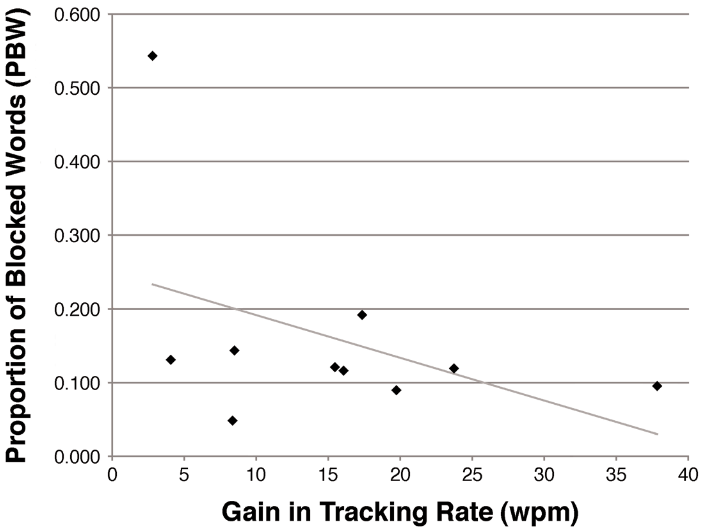

Figure 3. Gain in tracking rate versus proportion of blocked words.
Note. wpm = words per minute.

greater than or equal to 10 wpm in the first 4 weeks of training. As seen in Table 3, for those who started with KTH first, 3 out of 6 showed improvement greater than or equal to 10 wpm. For those who started with TRAD first, 2 out of 3 showed improvement greater than or equal to 10 wpm.

From Table 3 we also observe that the tracking rate continued to improve even after the first 4 weeks of training, regardless of method. Of those who started with KTH tracking first, and then had TRAD method for the second 4 week period, 4 out of 6 continued to improve. Three showed improvement greater than or equal to 10 wpm, and 1 other participant showed improvement of 8 wpm. Of those who started with TRAD first, and then had KTH method for the second 4 week period, 2 out of 3 continued to improve. One improved by 7 wpm, and the other by 4 wpm. In all, the majority of participants continued to improve and did not reach a plateau in performance at the end of 8 weeks of training.

For the KTH method, data on the proportion of blocked words (PBW) was accessible from the computer software. PBW is a measure of blocked words divided by total number of words presented. The relationship between PBW and tracking rate is shown in Figure 3. As predicted, there was an inverse relationship between PBW and tracking rate. For almost all the participants, as the tracking rate increased the proportion of blocked words decreased. Those who showed the lowest proportion of blocked words had the highest tracking rates and conversely, those who showed the highest proportion of blocked words had the lowest tracking rates.

The TRAD and KTH tracking methods were compared with respect to rate of improvement. A four-factor fixed effect analysis of variance was performed on the data for the 6 subjects who completed the balanced experimental design. A fixed effect analysis was used because there were too few subjects to warrant a repeated measures design. The use of a fixed effects analysis limits the conclusions to the specific participants in the experiment rather than the population in general. The factors were: Tracking Method (TRAD, KTH), Training Session (4 levels), Training Sequence (TRAD first, KTH first), and Participants (6). The participants were grouped in pairs, 1 member of the pair being trained first with the TRAD method (for four sessions) followed by training with the KTH method; the second participant in a pair receiving KTH method first. There was no significant difference in rate of improvement between the TRAD and KTH methods. Similarly, Training Sequence did not show a significant effect. There was some evidence of a significant Participant × Training Sequence interaction ($F = 4.70$, $df = 2/36$, $p = .015$). Three of the participants showed a significantly greater rate of improvement during the first four training sessions although 1 participant showed a significantly greater rate of improvement for the last four training sessions. Closer review of the interaction suggested large individual differences as opposed to a consistent pattern, as evident from Table 3.

The TRAD and KTH methods were also compared with respect to between-trial variability. The standard deviation of the tracking rates within a training session was obtained for each training session. The data were then submitted to a three-factor repeated measures analysis of variance. The factors were: Training Method (TRAD, KTH), Training Session (1, 2, 3, and 4), and Participants (10). The KTH method was found to be significantly less variable than the TRAD method ($F = 8.78$, $df = 1/27$, $p = .015$). The average standard deviation for a tracking trial was 3.8 wpm for the KTH method as opposed to 5.1 wpm for the TRAD method. There were no other significant effects. Every participant showed less variability in tracking rate for the KTH method. This result suggests that the KTH method may be a more efficient approach to training. However, it should be noted that although the data for TRAD tracking may be more variable, there was no significant difference between the two methods in the average improvement shown with each method.

Sentence Recognition

In order to determine whether the benefits of training using Speech Tracking can generalize to other communication skills, we used an untrained stimulus set to measure sentence recognition performance (i.e., CasperSent). Four replications of CasperSent recorded sentences were presented audio-only on Visits 1, 2, 7, 8, 13, and 14. Replication refers to repeated testing of performance, in this case sentence recognition. This was accomplished with 4 different sentence lists. A randomization schedule ensured that different lists were administered at every

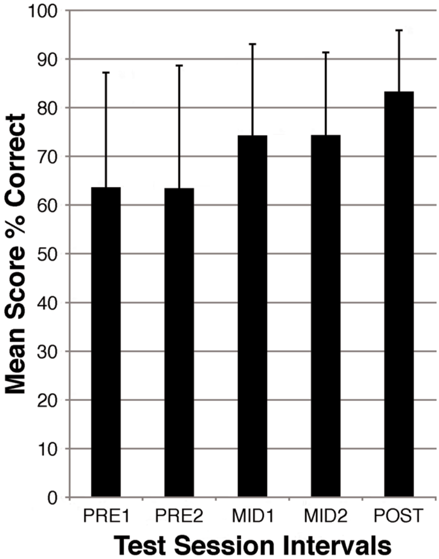

Figure 4. Mean sentence recognition at pre-, mid-, and post-assessment intervals.
Note. PRE = Pre-assessment; MID = Mid-assessment; POST = Post-assessment.

assessment session and for every participant. As shown in Table 2, these assessment sessions are identified as Pre-Assessment 1 (PRE1), Pre-Assessment 2 (PRE2), Mid-Assessment 1 (MID1), Mid-Assessment 2 (MID2), Post-Assessment 1 (POST1), and Post-Assessment 2 (POST3M), respectively.

Note that assessments PRE1 and PRE2 were obtained 1 week apart before any training. Assessments MID1 and MID2 were obtained 1 week apart after 4 weeks of training. Assessment POST1 was obtained after an additional 4 weeks of training and assessment. POST3M was obtained 3 months later with no training in the intervening period.

A repeated measures analysis of variance was performed on the sentence recognition data for the factors: Assessment Session (PRE1, PRE2, MID1, MID2, POST1), Replications within Assessment Session (4 lists), and Participants (10). Mean sentence recognition scores at all assessment intervals through 1 week post are presented in Figure 4. Because the sentence recognition scores were in the form of percentages, an arcsine transformation was used to stabilize the error variance (Studebaker, 1985). A second repeated measures analysis of variance was performed on data from the 8 participants who returned for the final visit (POST3M). The purpose of this analysis was to determine if there was any change in sentence recognition ability 3 months after the termination of training. The factors in this analysis were: Assessment Session (POST1, POST3M), Replications within Assessment Session (4 lists), and Participants (8). As before, an

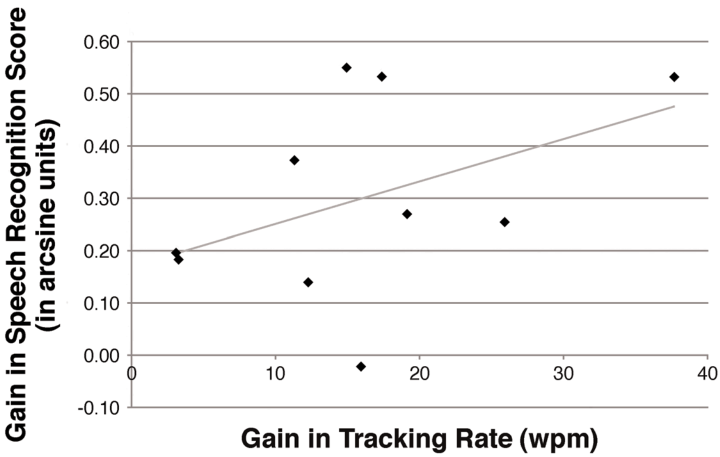

Figure 5. Increase in sentence recognition score versus increase in tracking rate. *Note*. wpm = words per minute.

arcsine transformation was used to stabilize the error variance.

The results of the first analysis showed a significant effect for Assessment Session ($F = 13.89$, $df = 4/36$, $p < .001$). A post-hoc analysis showed that sentence recognition scores were not significantly different for Assessment Sessions PRE1 and PRE2, and for MID1 and MID2, but the mean recognition score for Assessment Session POST1 was significantly higher than for sessions MID1 and MID2 and that the scores for these two sessions, in turn, were significantly higher than for the initial sessions PRE1 and PRE2. There was also a small, but statistically significant effect for Replications within Sessions ($F = 3.05$, $df = 3/27$, $p = .045$). A post-hoc analysis indicated that the scores for Replications 1 and 2 were slightly lower than those for Replications 3 and 4 (78% vs. 80 to 81%).

The second analysis of variance did not show any statistically significant difference between the sentence recognition scores for Assessment Sessions POST1 and POST3M; scores were virtually identical. As in the previous analysis, sentence recognition scores for Replications 1 and 2 were slightly lower than those for Replications 3 and 4 (87 to 88% vs. 90 to 91%), but the difference was not statistically significant. Bear in mind that the second analysis of variance had fewer participants with fewer degrees of freedom and the statistical tests were less sensitive.

A correlation analysis was performed to determine if there was a significant relationship between improvement in tracking rate with improvement in sentence recognition score. Figure 5 shows the improvement in tracking rate (in wpm) versus the improvement in sentence recognition score (in arcsine units). Note that a gain in sentence recognition score of 0.1 arcsine units corresponds to a gain

Table 4

Gain in Speech Recognition by Tracking Order and Training Period

Participant	Tracking order	Gain	
		MID-PRE	**POST-MID**
GU01	TRAD/KTH	-4.5	14.3
GU04	TRAD/KTH	8.0	2.8
GU05	TRAD/KTH	8.8	6.5
Average gain – TRAD first		**4.1**	**7.8**
GU02	KTH/TRAD	20.3	7.0
GU03	KTH/TRAD	9.5	6.3
GU07	KTH/TRAD	19.3	6.0
USF01	KTH/TRAD	-1.5	0.3
USF02	KTH/TRAD	0.5	8.3
USF03	KTH/TRAD	7.5	1.3
USF04	KTH/TRAD	-2.8	8.3
Average gain – KTH first		**7.5**	**5.3**
Average gain – all participants		**6.5**	**6.1**

Note. MID-PRE = Mid-assessment minus pre-assessment; POST-MID = Post-assessment minus mid-assessment; GU = Gallaudet University participants; TRAD = Traditional method of speech tracking; KTH = Royal Institute of Technology method of speech tracking; USF = University of South Florida participants.

of five percentage points in the region of 50% correct and to three percentage points, approximately, in the region of 90% correct. A linear regression line has been fitted to the data indicating that, on average, the increase in sentence recognition score increases with the increase in tracking rate resulting from the training. The correlation between the two variables was $r_S = 0.433$ which is not statistically significant. However, 1 of the participants, USF01, had a sentence recognition score of 99% at the start of training, so that for this subject, there was no room for improvement in sentence recognition score with training. Not surprisingly, this participant is the only one who shows no change in sentence recognition score with training (see the lowest plotted point in the figure). If this participant is omitted from the analysis, the correlation between the two variables increases to .53 which is just below the $p = .05$ significance level.

Further analysis was performed comparing improvement in sentence recognition on CasperSent for the first 4 week training period to the second 4 week training period, including a breakdown by training method. Results are presented in Table 4. With respect to gain in sentence recognition, the results indicate that training was associated with greater improvements with the KTH method, regardless of whether that occurred during the first or second 4 week period of training. For the 3 participants who started with TRAD first, the average gain was greater for the second 4 week period of training conducted with KTH (i.e., an average of 4.1 vs. 7.8 for first and second periods respectively). For the 7 participants who began with KTH tracking followed by TRAD, the average gain was greater for the first 4 week period of training (i.e., an average of 7.5 vs. 5.3 for the first and second periods respectively).

Comparing the first 4 week period of training to the second 4 week period of training, 5 out of 6 of the Gallaudet participants showed greater improvement in the first 4 weeks of training, regardless of tracking method. This might suggest that the greatest learning occurred during the first 4 weeks of training. For the USF participants, 3 out of 4 participants showed greater improvement during the second 4 week training period when receiving training with the TRAD method. On closer observation it was noted that of the 4 participants whose performance improved the most during the second 4 weeks of training, 3 were older adults over the age of 80. It may be that age played a more important role than tracking method in that the older participants in this study needed additional time to gain the maximum benefits from training.

COSI Results

COSI results were obtained for 9 of the 10 participants on two client-specific goals related to the use of their cochlear implant. Results on the COSI directly reflect specific communication goals selected by the participant for areas in which they were seeking improvement. COSI goal statements fell into the following five categories for the primary communication goal: Communication with one or two people in quiet; Communication with one or two people in noise; Conversation with a group in noise; Familiar speaker on the phone; Unfamiliar speaker on the phone. Participant goal statements on COSI are presented in Table 5.

On their primary communication goal, 5 of the 9 participants indicated that following training they were functioning "slightly better," 3 reported that they were "better," and 1 reported functioning "much better." This was combined with a corresponding improvement in the participants' estimate of their final ability to hear in this situation, which ranged from 50 to 70% of the time. COSI results were distributed similarly for the second communication goal selected. In all of the situations a common goal was to improve their ability to understand communication when relying on audition alone.

The association between the participant's ratings of relative improvement on communication goals and improvement in tracking rate was analyzed by means of a non-parametric correlation analysis. The participant's ratings of relative improvement on communication goals were ranked. Similarly, the improvements in tracking rate were ranked. Figure 6 shows the rankings for increase in communication goals versus the rankings of increase in tracking rate. A linear regression line has been fitted to the data indicating that the ratings of relative improvement

Table 5

Client Oriented Scale of Improvement (COSI) Goal Statements of Participants

COSI categories	Goal statements for participants
Communication with one or two people in quiet	• to hear my wife and son better when we have dinner together • to understand the other two students when we meet to work on a group project together for class (in a small quiet room) • to understand my two neighbors better when we meet to chat in my garden room which is quiet
Communication with one or two people in noise	• to hear my two close friends better when we meet at church and there is background noise
Conversation with a group in noise	• to better hear my son and his friends from the sports team when they talk together in the kitchen with lots of noise going on
Familiar speaker on the phone	• to understand my coworkers better when they call on the phone daily to discuss a work project • to be able to understand my colleagues on the telephone which is very important for my work
Unfamiliar speaker on the phone	• to be able to answer the phone at work and field questions from people I don't know

increases with improvements in tracking rate. The Spearman rank correlation coefficient (formerly rho), r_S, for the two sets of ranks was statistically significant ($r_S = 0.783$, $df = 8$, $p = .01$). In all, gains in personal communication goals, as determined by the COSI technique, were obtained as a result of the training program, and these gains were associated with improvements in speech recognition.

CPHI Results

Pre- and post-assessment results for each participant on the CPHI were first combined to obtain mean group data. Mean group pre-assessment results were then subtracted from mean post-assessment results to determine whether there were any significant improvements across CPHI categories. Differences noted in this study were compared to the table of CPHI retest differences reported for the Walter Reed sample (Demorest & Erdman, 1988). Results indicated no significant group effects in any category.

The data for each participant were then analyzed to determine if individual subjects showed significant improvements on one or more categories of the CPHI. Of the 10 participants who completed the CPHI before and after training, 4 participants demonstrated significant improvements on three or more categories of the CPHI. Another 3 participants showed improved performance on one or

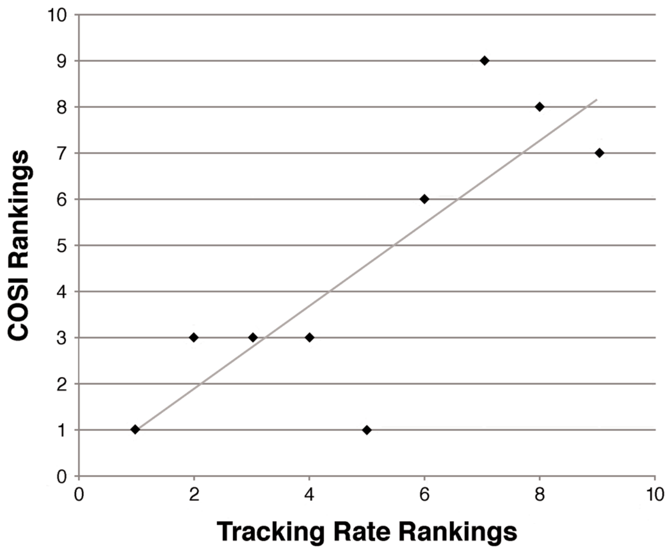

Figure 6. Rankings of improvement on communication goals (COSI) versus rankings of increase in tracking rate. *Note.* COSI = Client Oriented Scale of Improvement.

two categories. In all, two thirds of the participants showed improvement on specific categories. Five participants demonstrated improvement in Communication Performance, 3 participants improved in Communication Strategies, and 3 participants improved in Personal Adjustment. Note that although the majority of participants showed statistically significant improvement on one or more categories of the CPHI, the subjects showed improvements on different categories so that when the improvements were averaged across categories for all participants, the average improvements were not statistically significant.

The participant who showed the greatest improvement on the CPHI (GU07) improved in all categories, with the greatest amount of improvement in Personal Adjustment. Improvements were seen across the subscales that included: Self-Acceptance, Acceptance of Loss, Anger, Exaggeration of Responsibility, Discouragement, Stress, and Withdrawal. The data indicate that this participant made significant strides personally to adapt to the cochlear implant during the training period. Some insight was offered by the participant's self-report that training afforded her a greater sense of self-confidence, which, in turn, had a major impact on communication and on important relationships both at home and at work.

A correlation analysis was performed to determine if there was a significant relationship between improvement in sentence recognition score and improvement on individual subscales of the CPHI. Because of the small sample size ($n = 10$), for a correlation to be statistically significant it must be relatively large (/R/ > 0.55) to be statistically significant at the $p = .05$ significance level. Of the five categories of the CPHI, Personal Adjustment showed a positive correlation with increase in sentence recognition. An analysis of the nine subscales of the Personal Adjustment category showed that eight of the subscales demonstrated an improvement with an improvement in sentence recognition. The correlation coefficients for the following subscales were statistically significant at the $p = .05$ level: Discouragement ($R = 0.56$), Withdrawal ($R = 0.59$), Anger ($R = 0.64$), and Acceptance of Loss ($R = 0.69$). Diagrams showing the change in subscale value (rating after training minus rating before training) versus the change in sentence intelligibility score for each of the above four subscales are shown in Figure 7. Linear regression lines have been fitted to the data. Statistically significant correlations ($R > 0.55$, $p < .05$) were obtained for the subscales of Withdrawal, Anger, Discouragement, and Acceptance of Loss. Note that the scales are reversed in sign so that an increase in the rating represents an improvement.

DISCUSSION

The most significant finding in this clinical study was that training with Speech Tracking was associated with significant improvements in both tracking rate and speech recognition for postlingually deafened adult cochlear implant users. The improvement in speech recognition was demonstrated with a novel, untrained stimulus set of recorded sentence material (CasperSent). Nine of the 10 participants showed improved sentence recognition after 8 weeks of training with Speech Tracking. The 1 participant who did not show an improvement had a sentence recognition score of 99% at the start of the study, so that there was no room for improvement.

Benefit from Speech Tracking training was also found on self-assessed communication function using the CPHI. Although improvement on the CPHI, averaged over both participants and categories of the CPHI was not statistically significant, individual subjects showed significant improvements on subscales of the CPHI. A number of the subjects showed improvements on the subscales relating to Personal Adjustment and these improvements were found to correlate with improvements in sentence recognition. Even with a small sample of 10 participants, statistically significant correlations were noted between improvements in speech recognition and improvements on the Personal Adjustment subscales evaluating Withdrawal, Anger, Discouragement, and Acceptance of Loss.

Further, gains in personal communication goals, as determined by the COSI technique, were obtained following the training program. As in the case of the CPHI, these gains were also associated with improvements in speech recognition. Several themes emerged from the COSI for the adult cochlear implant users in this study. Improvements were found in areas of daily life ranging from better listening ability in quiet and noise, particularly in a group setting, and for both fa-

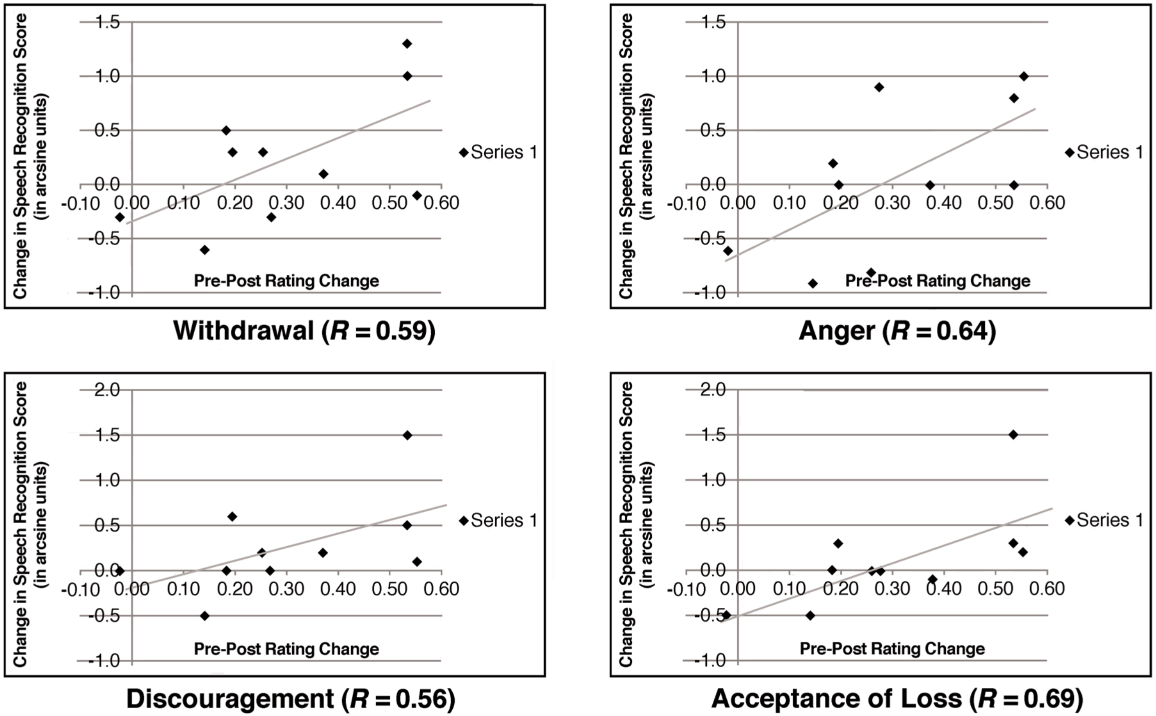

Figure 7. Correlation between increase in intelligibility and improvement in the Communication Profile for the Hearing Impaired subscales. Statistically significant correlations ($R > 0.55$, $p < .05$) were obtained for the subscales of Withdrawal, Anger, Discouragement, and Acceptance of Loss. All of these subscales are within the Personal Adjustment category. Note that the scales are reversed in sign so that an increase in the rating represents an improvement.

miliar and unfamiliar speakers on the phone. The ability to rely on audition alone was central to many of the adult cochlear implant users' goals in this study. It is of interest that many of the cochlear implant users in this study also reported that they were experiencing greater self-confidence in their daily communication following this training. A more structured means of capturing this effect should be considered in future studies on the benefits of intervention.

The independent measures of benefit used in this study (CasperSent, CPHI, and COSI) suggest that training using Speech Tracking can translate into significant real-life benefits. Improved speech recognition, as evidenced by performance on an untrained measure of sentence recognition (i.e., CasperSent) is of great importance for everyday communication. The achievement of desired communication goals as determined using the COSI technique also represents a significant individualized real-life benefit for each participant. The improvements in speech recognition were also linked to improvements in several areas of personal adjustment measured with the CPHI. A pattern emerged in which improvements in speech recognition following the training program were also associated with improved personal adjustment in that participants became less withdrawn, less angry and discouraged, and showed greater acceptance of their loss. The connection between auditory training and psychosocial function warrants further investigation.

While Speech Tracking training was clearly associated with improved tracking rate and speech recognition for the adult cochlear implant users in this study, there may be other factors, alone or in combination, that affected the outcomes. Participants at either end of the performance spectrum have offered us some preliminary insight into these factors. For the participant with the least improvement on tracking rate, short-term memory issues and the need for a much slower rate of speech seemed to impact the performance of this older adult. For the participant on the other end of the spectrum, a combination of factors may have been responsible for her dramatic improvement in speech tracking performance. Faced with a demanding communication environment at work, she set high communication goals for herself, and was very motivated and attentive during the Speech Tracking training task. Further research is needed to help identify those who may benefit the most from this type of intervention.

In the current study KTH Speech Tracking was found to be effective as a rehabilitative training method for improving receptive communication skills of postlingually deafened adult cochlear implant users. Both methods of Speech Tracking training were associated with improvements in speech recognition. In both cases the participants needed to focus their attention, and in both cases work at listening. It may be that changes in listening behavior derive from this active form of focused attention that is part of both methods of Speech Tracking training.

Although training with both methods of Speech Tracking served to improve tracking rate, the KTH Speech Tracking method demonstrated significantly less variability in performance as compared to the TRAD Speech Tracking method. The fact that the KTH method was less variable allowed for a more sensitive assessment of progress, making it possible to detect at an earlier stage of the training program whether a participant was making progress or not making progress than when the TRAD method was used. This, in turn, would lead to a more efficient planning of the training program. In all, KTH tracking proved to be a more structured, systematic, and efficient approach to training. From a clinical perspective, another advantage of the KTH training program was that it had a more consistent protocol for clinicians to follow. Further, it gave immediate feedback to the client on their performance in terms of tracking rate (wpm), and was a timesaver because the tracking rate and other relevant variables (such as proportion of blocked words) can be calculated automatically by the computer as the training progresses. This feature allows the clinician to track and record a client's progress conveniently over time.

One of the ancillary objectives in this study was to try to determine how much training is needed to yield improvements in receptive communication skills, as this may in turn impact clinical practice. For the postlingually deafened adult cochlear implant users in this study, the results indicated that a significant improvement can be obtained over a 4 week period of training, while 4 more weeks of training yielded a comparable additional improvement. A caveat to this is that for the older participants in this study over the age of 80, greater improvement was seen during the second 4 weeks of training suggesting that they may need additional time to gain the maximum benefits from training. For most participants the learning curves did not show evidence of a plateau after 8 weeks indicating that they would continue to benefit from further training. It should be noted that since there was no evidence of saturation after two 4 week periods of training, and the participants continued to improve, it is likely that had there been another 4 week session they would continue to improve. In terms of longer-term impact, even after the 8 week training period was completed, the improvement in speech recognition skills observed at the end of the training period was maintained for at least 3 months after the cessation of training. Additional research is needed to identify when the rate of improvement begins to saturate and the amount of training needed to improve communication skills in a cost-effective way.

The importance of auditory training with adult cochlear implant users to maximize the benefits they can receive from their implant is recognized in the rehabilitation literature (Fu, Galvin, Wang, & Nogaki, 2005; Kricos & McCarthy, 2007; Miller et al., 2008; Ross, 2005). Although most improvements with cochlear implants are observed in the first few months post-implantation (Gray, Quinn, Court, Vanat, & Baguley, 1995; Spivak & Waltzman, 1990; Waltzman, Cohen, & Shapiro, 1986), newer findings on auditory plasticity suggest a more prolonged time period for improvement (Tobey et al., 2005; Tyler, Gantz, Woodworth, Fryauf-Bertschy, & Kelsay, 1997). This, in turn, may afford a longer window of opportunity for greater improvements in cochlear implant user performance when enhanced by auditory training. The participants in this study had their implants for a period of time ranging from 3 months to over 3 years. It is interesting to note that even for adult postlingually deafened cochlear implant users in this study who have had their implant for greater than 1 year's time, we found that training can still yield improved speech recognition performance. It may be that participants in this study were highly motivated in light of the fact that they self-referred for training even after having their implants for a long period of time.

This study used a predominantly top-down/synthetic approach to auditory training with adult cochlear implant users conducted with a clinician. It needs to be recognized that Speech Tracking is only one component of an auditory training program and one part of a comprehensive aural rehabilitation program. For synthetic auditory training in general, few studies have met the criteria for evidence-based investigations outlined by Sweetow and Palmer (2005) in their review of the literature in auditory training. They did, however, note a trend that supports the use of synthetic training for improving speech recognition skills.

In terms of the strengths and limitations of this study, the current study made use of several, but clearly not all, of the quality criteria for evidence-based investigations outlined by Sweetow and Palmer (2005). Specifically, this study incorporated a randomized assignment for tracking procedure, feedback on performance, generalization to other materials, as well as outcome measures with a clear relationship to communication skills. Although this study did not include a control group, subjects served as their own control. A repeated measures design, outlined in Table 2, allowed verification that participant performance on speech recognition measures remained unchanged on test-retest intervals (PRE1 and PRE2, and MID1 and MID2 intervals), while capturing effects of intervention after each 4 week segment of training. In terms of sample size, a larger number of participants would have enhanced the significance of the findings. Some data were collected on the longer-term impact of training at 3 months post, but future studies may want to consider extending this time frame out to 6 months or even a year post-training.

Computer-assisted auditory self-training has been at the forefront of advances in recent years in the area of aural rehabilitation (Fu & Galvin, 2007; Miller et al., 2008; Stacey et al., 2010; Sweetow & Henderson-Sabes, 2004). Although improved outcomes have been observed in research using this approach to deliver rehabilitation services to adults with hearing loss in general (Sweetow & Henderson-Sabes, 2004), and with adult cochlear implant users in particular (Fu & Galvin, 2007; Miller et al., 2008; Stacey et al., 2010), it is not possible to directly compare the results of the current study with those studies given the different modes of training (i.e., clinician-directed vs. self-directed training at home using a computer).

The findings of this clinical trial contribute to the growing body of research into the effectiveness of auditory training with postlingually deafened individuals using cochlear implants. To determine what constitutes optimal and effective training protocols for adult cochlear implant users, future research may need to consider comparative-effectiveness. That is, research studies that aim to assess the relative benefits of different interventions. For example, we have yet to determine whether auditory training conducted with a clinician, alone or in combination with self-directed computer-assisted training, is of greater or equal benefit to that received with auditory self-training alone. This will have significant implications for intervention and for individuals with cochlear implants.

Speech Tracking is only one component of a comprehensive aural rehabilitation program. Further research will need to define and explore what components are important and what approach constitutes an optimal cost-effective rehabilitation program for adult cochlear implant users. The work of Heydebrand, Mauze, Tye-Murray, Binzer, and Skinner (2005) lends support to the importance of intensive rehabilitation programs for adult cochlear implant users which combine auditory training with communication and psychosocial coping strategies. The role and importance of communication strategies, alone, or in combination with auditory training needs further study and will be important for shaping clinical practice. Although self-directed computer training is providing much needed auditory training experience, and is cost effective, the value of clinician directed aural rehabilitation should not be overlooked. In all, the translation of benefit from training to the real-life communication and psychosocial function of adult cochlear implant users is perhaps the most important outcome we can hope to achieve.

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