WHAT MAKES EFFECTIVE SELF-DIRECTED AUDITORY TRAINING?

by

Haley O'Connor

Copyright © Haley O'Connor 2022

Audiology Doctoral Project Submitted to the Faculty of the Department of

SPEECH, LANGUAGE AND HEARING SCIENCES

In Partial Fulfillment of the Requirements

For the Degree of

DOCTOR OF AUDIOLOGY

In the Graduate College

THE UNIVERSITY OF ARIZONA

2022

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Audiology Doctoral Project Committee, we certify that we have read the Audiology Doctoral Project prepared by: Haley O'Connor
titled: What Makes Effective Self-Directed Auditory Training?

and recommend that it be accepted as fulfilling the Audiology Doctoral Project requirement for the Degree of Doctor of Audiology.

Barbara Cone
Barbara Cone — Date: Apr 7, 2022

Linda Norrix
Linda Norrix — Date: Apr 7, 2022

Aneta Kiealr
Aneta Kiealr — Date: Apr 8, 2022

Erica Hansen
Erica Hansen — Date: Apr 7, 2022

Linda Shaw — Date: Apr 7, 2022

Final approval and acceptance of this Audiology Doctoral Project is contingent upon the candidate's submission of the final copies of the Audiology Doctoral Project to the Graduate College.

I hereby certify that I have read this Audiology Doctoral Project prepared under my direction and recommend that it be accepted as fulfilling the Audiology Doctoral Project requirement.

Barbara Cone
Barbara Cone — Date: Apr 7, 2022
Speech, Language and Hearing Sciences

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to Dr. Cone for her guidance and her dedication to my doctoral project. I express gratitude to my mentor, Dr. Hansen, for her constant encouragement and support throughout my entire audiology career and for reaching out to me for the foundation of this project. I would also like to thank Dr. Norrix, who also served as my mentor for ArizonaLEND this year. Lastly, I would like to acknowledge Dr. Kielar, Dr. Shaw, and Dr. Marrone and thank them for their commitment and assistance in this project.

DEDICATION

I would like to dedicate this paper to my five classmates who have ~effectively masked~ my stress and have been my morale-boosting support system. I also want to dedicate this paper to my close friends and family for their endless love and encouragement in all my endeavors.

Table of Contents

List of Figures

List of Tables

Abstract

Auditory training resources and techniques have been developed for adult cochlear implant (CI) users. However, it is unclear which aural rehabilitation programs are most effective. A literature review was conducted to investigate the characteristics of an effective self-directed auditory training program. The questions addressed by this literature review were: 1.) What evidence supports the effectiveness of the program? 2.) What are the gaps in our knowledge concerning self-directed auditory training programs for adult CI-users? and 3.) What recommendations can be made about self-directed auditory training programs? The results of the review revealed five self-directed auditory training programs. Auditory training was found to increase speech perception abilities and quality of life for adult cochlear implant users. Additionally, retention of improvements after auditory training were shown to remain after the duration of training. The effects of auditory training are also seen in measures derived from neuro-imaging and auditory evoked potentials that are attributed to brain plasticity. The evidence of the efficacy of self-directed auditory training for adult cochlear implant users published and assessed in this literature review is weak because only 7 of the 22 publications in this literature review were randomized controlled trials, explicitly 4 of which were investigating cochlear implant users. To overcome this lack of evidence, a self-directed auditory training effectiveness study has been proposed that could be carried out at the University of Arizona Hearing Clinic.

Keywords: cochlear implant, adults, aural rehabilitation, auditory training, literature review

Introduction

Speech perception abilities vary considerably in adult cochlear implant users. This variation may be influenced by patient-related factors including duration of severe or profound sensorineural hearing loss, residual hearing, and age of implantation. Cochlear implants provide electrical stimulation to spiral ganglion cells of the auditory nerve to overcome the loss of mechano-sensory function of the impaired cochlea. Although speech perception abilities often improve rapidly (compared to the pre-implant measures) over the first three to six months after initial cochlear implant activation, an individual may benefit from auditory training that includes various structured brain- and listening-training activities to *optimize* the benefit from the cochlear implants (Schumann et al., 2015). These structured training activities are believed to enhance central auditory system plasticity and engage brain areas for attention and memory that benefit the cochlear implant user (Yu et al., 2017).

What is Aural Rehabilitation? Arthur Boothroyd (2007) defines adult aural rehabilitation as, “the reduction of hearing-loss-induced deficits of function, activity, participation, and quality of life through a combination of sensory management, instruction, perceptual training, and counseling”. Boothroyd further defines function, activity, participation and quality of life. Function is the perceptual capacity as measured in a clinic or lab. Function includes hearing threshold, spectral and temporal resolution, direction and distance perception, attention, working memory, processing speed and noise resistance. Activity includes a person’s wants or needs pertaining to hearing in the real world. The activities of most concern are perceiving the speech of others and engaging in spoken language communication. Participation is the contribution of these activities to daily life, such as relationships, employment, social interactions, leisure, learning, control and creativity. Boothroyd posits that quality of life is influenced by function, activity, and participation but is not determined by them. Quality of life in Boothroyd's model consists of a self-assessment of the current life experience and can include: enjoyment, meaning, purpose, usefulness, value, freedom of choice, and independence.

Audiologists address these targets of aural rehabilitation in several ways. Providing amplification (hearing aids, cochlear implants, assistive listening devices) targets function. Auditory training activities, whether formal or informal, target function and activity and lead to greater participation. Quality of life can be targeted by addressing patients' emotions and exploring ways to overcome challenges and enhance participation in everyday life situations. In summary, these components of aural rehabilitation include: sensory management (to target and enhance auditory function), instruction (to increase probability of a positive outcome from sensory management), perceptual training (to target activity by focusing on learning opportunities provided by everyday communication), and counseling (to target issues of participation and quality of life that may result from deficits of function and activity).

Aural rehabilitation outcomes are influenced by multiple factors of the hearing-impaired individual (Boothroyd, 2007). These factors are: motivation, readiness, expectations, sense of entitlement, personality, adaptability, lifestyle, cognition, resources, and support from others. The design and implementation of an aural rehabilitation program for an individual must consider these individual factors that may influence success. Furthermore, aural rehabilitation programs must be evidence-based: which Boothroyd defined as: "the explicit and thoughtful use of current best evidence in making decisions about the care of individual patients."

Auditory Training for CI users. Aural rehabilitation strategies and resources have been developed for post-lingually deafened adults who use cochlear implants, but there is no consensus on what constitutes an effective duration, dosage, or type of aural rehabilitation. Some adults who use cochlear implants make use of a variety of post-operative strategies such as attending support/aural rehabilitation groups, clinician-based training or “self-directed” activities, but others do not use any regular program of auditory rehabilitation/listening skills training. Clinician-based auditory training requires an audiologist or speech-language pathologist present and administering auditory training alongside the cochlear implant user. “Self-directed” in this context means that training and/or practice can be undertaken by the CI-user without the assistance of a clinician or communication partner. Self-directed programs in this literature review will focus on computer-based auditory training. This review will focus on activities that formally measure progress. “Effectiveness” of these activities is defined as a measurable change in speech perception or quality of life, depending on the definition of effectiveness used. There is limited published literature on the effectiveness of “self-directed” auditory training. This literature review will focus on the literature that that supports auditory training for adults with hearing loss, with a focus on methods that are designed to be self-directed, as well as elements of other programs that could be incorporated into self-directed programs.

Purpose

The purpose of this literature review was to answer the following questions: 1) What are the characteristics of an effective auditory training program? 2) What is the evidence that supports the effectiveness of the program? 3) What recommendations can be made about self-directed auditory programs on the basis of this literature review? 4) What are the gaps in our knowledge concerning self-directed auditory training programs for CI-users?

Methods

Information Sources

Arizona Libraries, Cochrane library, MEDLINE, and Psychinfo databases were searched for relevant studies from the peer-reviewed literature on January 19^{th}, 2021. There were no limitations put on the search for date of publication. The earliest publication found was published in 1991. The search strategies are listed in Appendix. A.

Eligibility Criteria

The eligibility criteria include publications that are peer-reviewed/scholarly resources. Peer-reviewed/scholarly articles are more likely to be scientifically valid. The resources could be experimental, case studies, or overviews. To be eligible, the publications had to reference individuals with post-lingual hearing loss. Publications included a method of aural rehabilitation that was for an individual, not group-based. All individual aural rehabilitation techniques and intervention types were eligible.

Selection Process

Exclusion. Articles including the terms: "brainstem implants", or "prelingually deaf" in the title or abstract were manually excluded from the search. Duplicated results were manually excluded. Systematic reviews were also manually excluded from the search.

Inclusion. A total of 58 publications were identified and met the search strategy criteria. The 58 publications were entered into EndNote, an online resource to manage bibliographies and references. Two audiology doctoral project committee members (faculty) and the author independently examined the titles and abstracts of the 58 articles, eliminating articles that contained any further exclusion criteria or were not deemed relevant. All lists were compared and discrepancies were discussed and resolved. The final set of 22 publications that met inclusion and exclusion criteria remained.

Data Management

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009) were followed for this literature review and the numbers of studies reviewed at each stage of the systematic process were recorded in a PRISMA flow diagram (Moher et al., 2009).

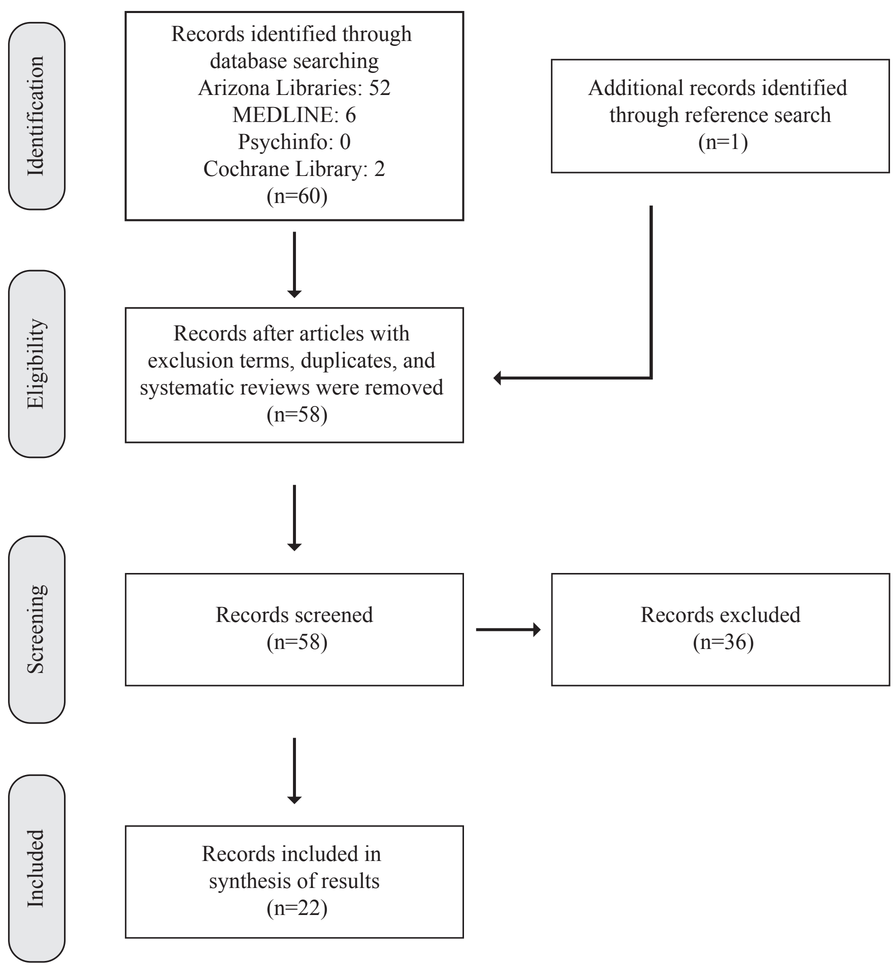

Figure 1. PRISMA flow diagram

Data Extraction and Synthesis

The author first completed an annotated bibliography in order to determine the common topics, relevant similarities and variances in the findings. The 22 publications were then organized into a taxonomy created by the author in order to synthesize relevant information from each included study in an organized manner. The taxonomy included four categories:

1. What Auditory Training Programs are Available?
2. Factors Associated with Effectiveness of Auditory Training
3. Auditory Training Outcomes
4. Why is Auditory Training Effective?

Publication	Type of Aural Rehabilitation	Methods	Main Findings	Limitations/Related Factors	Level of Evidence
Fu, Q.J., & Galvin, J. J., 3rd. (2007)	*Computer-Assisted Speech Training (CAST)	CAST program to conduct auditory rehabilitation at home and consequently measure passive and active learning in adaptation to changes in CI speech processing.	1.) Cochlear implant recipients may significantly benefit from auditory training even when infrequently performed. 2.) The difference in outcomes may be due to the training stimuli rather than the time spent (multitalker speech stimuli). 3.) Generalized improvements in performance were observed. 4.) Anecdotal subjective reports of benefit in everyday listening experiences outside of the laboratory. 5.) Improvements in music perception	1.) Some recipients may require different training materials depending on their abilities. 2.) Patient-related factors such as: number of implanted electrodes, insertion depth, and duration of deafness impact performance. 3.) Cost of implanted device and CAST software. 4.) Effort, time and commitment to training.	Case study
Kwak, Chanbeom, Kim, Saea, You, Sunghwa, & Han, Woojae. (2020)	*Hearing Rehabilitation for Older Adults (HeRO): Mobile or Web Application	1.) Self-assessment for hearing screening of the elderly (SHSE-R) was used to determine participants' extent of hearing loss to determine intervention. 2.) HeRO Training development and use of training by participants (auditory training and working memory training) 3.) Evaluation of technology using the technology acceptance model (TAM) questionnaire	1.) Older adults considered the HeRO application easy to use, believed it would provide beneficial to their life, and were willing to adopt and use the HeRO application. 2.) The application was designed to inform user and clinician of error patterns and real-time reports of results to determine changes in hearing devices or training routine.	1.) The deteriorated abilities of older adults can be compensated by the use of technology. 2.) Factors such as health conditions, attitude toward life and satisfaction, physical functioning and technological anxiety should be considered in future studies.	Overview
Okell, Elise, & Lind, Christopher. (2012)	Speech Tracking	Three pairs of communication partners participated in a 20 minute unstructured conversation followed by a 20 minute period of tracking for two sessions.	The conversational qualities of repairs in tracking are limited by the requirement for repetition and the associated criterion of 100% accuracy in this study.	1.) Requires the collaborative effort of the speaker and the participant. 2.) The associated criterion of 100% accuracy requirement was the main limitation. 3.) Further investigation needs to be taken in order to establish which results can be generalized beyond test conditions.	Case study
Plant, G., Bernstein, C., & Levitt, H. (2015)	Speech Tracking	A long-term one-subject case study training results of speech tracking procedures.	1.) Clinician-directed auditory training using speech tracking can result in significant improvements in tracking rate and speech recognition for adult cochlear implant users. 2.) The ability to optimize outcomes for adult cochlear implant users using long-term training may differ by patient. The difficulty, condition or parameters may need to be adjusted when a plateau is reached.	1.) Deliberate practice is highly demanding mentally. 2.) Compliance has impact on outcomes. 3.) Long-term training is expensive and places great demands on the resources of clinical facilities	Case study
Shafiro, V. (2008)	*Environmental Sound Perception (with easily identifiable and familiar sound sources)	Subjects were tested in a pre- and post-test design. They labeled 160 stimuli to a sound source for five training sessions.	1.) The overall average identification accuracy between the pretest and post test sessions improved from 33% correct to 63% correct. 2.) Positive effects of training on the identification of spectrally degraded environmental sounds can improve with training and can generalize to other sounds.	1.) Small number of subjects tested limits reliability. 2.) The number of exemplars necessary to ensure the sound source identification accuracy has not been determined for environmental sounds as it has been for speech sounds.	Retrospective case report
Sweetow, Robert W, & Sabes, Jennifer Henderson. (2007)	*1). Computer-Assisted Speech Training (CAST) *2). Speech-Tracking *3). Speech Training *4). Listening and Communication Enhancement (LACE)	Review of similarities and differences of these program designs.	1.) All of the training programs use some type of stimulus-response interaction with feedback provided 2.) Adapting the stimuli and training to the communication needs and interests of the individual will render compliance 3.) It is important to establish that auditory training programs provide substantial benefit to users	1.) No long-term data reflection whether additional training is required. 2.) Studies of the efficacy of aural rehabilitation are difficult to conduct because results are dependent on many patient factors. 3.) Patient compliance (cost, time, effort)	Review

van Besouw, Rachel M, Oliver, Benjamin R, Hodkinson, Sarah M, Polfreman, Richard, & Grasmeder, Mary L. (2015)	*Music Awareness Program	1.) An interactive design and evaluation approach was used to create an Interactive Music Awareness Programme (IMAP) for users with cochlear implants to create and manipulate music on. 2.) 16 participants completed sessions over a 12-week period.	1.) A general, but not statistically significant, increase in music listening habits were observed. 2.) Overall ratings for the prototype were 4 out of 5 and feedback for improvements were provided. 3.) Cochlear implant users were eager to receive music aural rehabilitation	1.) Results of melodic contour identification were inconclusive due to unexpected ceiling effects 2.) Differences in participant characteristics 3.) Further research is needed to investigate the efficacy and effectiveness the IMAP as a music aural rehabilitation program.	Case reports
Zhang, M., Miller, A., & McNutt Campbell, M. (2014)	*Computer Based Auditory Training (CBAT)	Nine CBAT programs were evaluated in the review: Angel Sound Training/Sound and Way Beyond, Computer-Assisted Speech Perception (CASPER), Computer-Assisted Speech Training (CAST), eARena, Listening and Communication Enhancement (LACE), Read my Quips, Seeing and Hearing, Sound Scape, Speech Perception Assessment and Training System (SPATS), and The Listening Room-CLIX and Thumbprint mp4	1.) It is important that the decision for provision of auditory training and the type of auditory training be considered on an individual basis. 2.) A user needs to consider and discuss their strengths and areas for auditory improvement so that customization of training can be beneficial. 3.) Benefit depends on many factors: age, duration after implant, computer literacy, personality, support system, and time spent on training.	1.) It does not summarize any research that exists related to any of these programs 2.) The study focuses on adult CBAT, and does not include children programs.	Overview

Table 1. What Auditory Training Programs are Available? *Starred studies indicate self-directed auditory training.

Publication	Aim of the Study	Methods	Main Findings	Limitations	Level of Evidence
Abdrabbou, Marwa F, Tucker, Denise A, Compton, Mary V, & Mankoff, Lyn. (2018)	To assess the need for a quality of life assessment in biopsychosocial aural rehabilitation practices with late deafened adults with cochlear implants	Two adults enrolled in a CAST program and quality of life assessment: Nijmegen Cochelar Implant Questionnaire (NCIQ)	1.) CAST mean percentage scores indicate both patients performed well (above 95% accuracy) with their cochlear implants in a quiet therapy room environment 2.) Both patients reported experiencing difficulties across the two listening subdomains. 3.) Both patients reported low self-esteem scores (40% or below) that demonstrated each patient's perception of hearing loss as undermining her self-confidence 4.) Speech recognition test results alone cannot provide hearing health professionals with information regarding the impact of hearing loss on an individual's daily life.	1.) A small sample size (two participants) was evaluated 2.) Patient A and Patient B differed in ratings on the questionnaire- emphasizing the importance of rehabilitation related to the needs of each individual patient	Case study
Bennett, Rebecca J, Meyer, Carly J, Eikelboom, Robert H, Atlas, Julian D, & Atlas, Marcus D. (2018)	To investigate participant factors that influence hearing aid management skills and knowledge and their impact on hearing aid outcomes	Email and paper-based self-report surveys (Hearing Aid Skills and Knowledge Inventory and International Outcomes Inventory for Hearing Aids) were distributed to 518 participants ranging from 18 to 97 years of age.	1.) Factors associated with hearing aid skills and knowledge included: participants' age, gender, style of hearing aid, age of current hearing aid, and total years of hearing aid ownership. 2.) Higher levels of hearing aid management skills and knowledge were better associated with better hearing aid outcomes and higher self-reported satisfaction with hearing devices 3.) Hearing aid difficulties were greatest for older people, women, and owner of behind-the-ear hearing aids	1.) The evaluation of hearing aid knowledge being self-report increases the likelihood of response bias 2.) A longitudinal study is required to determine whether this represents deterioration in skills over time 3.) Further studies should investigate cognitive ability, dexterity, physical deficits, visual acuity, ability to learn new tasks, motivation to learn hearing aid management tasks, and self-efficacy for completing tasks.	Case Report
Reis, M., Boisvert, I., Beedell, E., & Mumford, V. (2019)	To describe audiologists' practices toward auditory training and to assess the cost of different methods for clients and service providers in comparison to no auditory training delivery	A survey was distributed to approximately 230 Australian Cochlear Implant Audiologists with a 16-33% response rate	1.) Most audiologists agreed auditory training refers to "structured listening activities that aim to improve speech perception". 2.) 85.5% of respondents agreed that auditory training is necessary to improve outcomes in adult cochlear implant users 3.) 53.6% of clinicians use a combination of auditory training methods (home-based or face-to-face) 4.) Limitation of resources, not knowing how to conduct auditory training, and the clinic not offering auditory training services were the main reasons for referring clients to another provider 5.) Clinicians relied on printed exercises, audiobooks, CBAT, and manufacturer manuals to guide auditory training sessions 6.) Counseling and support of clinician team members were discussed to motivate clients' adherence. Along with discussing assessment results, providing educational knowledge, discussing brain plasticity, and making a contractual agreement 7.) 21/36 respondents indicated evaluating whether the training was beneficial to their clients 8.) Cost for client varied up to AUD 1438.98 per client and up to AUD 175.28 per hour of intervention for service providers	1.) The responses of the survey represent 16-33% of practicing Audiology Australia members working with adult cochlear implant users. 2.) Responses were highly variable throughout the survey could be due to the lack of strong evidence supporting the effectiveness of auditory training. 3.) The absolute costs may differ between countries.	Case Report
Smith, Sherri L, & West, Robin Lea. (2006)	To provide a comprehensive overview of the self-efficacy framework and its application to audiologic rehabilitation	A literature review was conducted on self-efficacy and its relevance to successful interventions in several health domains.	1.) Self-efficacy is a powerful predictor of behavior change 2.) Interventions founded on a self-efficacy framework produce better treatment outcomes than do interventions that are not self-efficacy-based 3.) Self-efficacy should play a role in the success of audiologic rehabilitation activities aimed to treat hearing loss, tinnitus, and balance disorders	Those with low self-efficacy would be unwilling to try challenging activities and therefore would be more limited than an individual with a higher self-efficacy	Review
Smith, Sherri L, Saunders, Gabrielle H, Chisolm, Theresa H, Frederick, Melissa, & Bailey, Beth A. (2016).	To determine if patient characteristics or clinical variables could predict who benefits from individual auditory training	A randomized controlled clinical trial with 263 participants that compared treatment effects of at-home auditory training programs in hearing aid users	Hearing aid users with poorer aided word-recognition-in noise scores and greater residual activity limitations and participation restrictions will show the largest improvements and should be considered candidates for supplemental audiologic rehabilitation regardless of the type.	Changes in performance might be associated with learning/practice effects of testing rather than effects of the interventions themselves	Experiment with randomized controls

Table 2. Factors Associated with Effectiveness of Auditory Training

Publication	Title	Methods	Main Findings	Limitations	Level of evidence
Castiglione, A., Benatti, A., Velardita, C., Favaro, D., Padoan, E., Severi, D., Pagliaro, M., Bovo, R., Vallesi, A., Gabelli, C., & Martini, A. (2016)	Aging, Cognitive Decline and Hearing Loss: Effects of Auditory Rehabilitation and Training with Hearing Aids and Cochlear Implants on Cognitive Function and Depression among Older Adults	•125 subjects (20 normal hearing, 105 hearing-impaired) •65 years or older •Divided into 6 groups •Montreal Cognitive Assessment (MoCA), Geriatric Depression Scale (GDS), Digit Span Test (GST), and Stroop color-word test were used •Hearing rehabilitation applied was considered based on type of device and degree of hearing loss	1.) Positive effects of providing effective auditory input with hearing aids or cochlear implants combined with auditory training beyond hearing function alone 2.) The level of depression screened by the use of the GDS prior to implantation and after implantation confirmed significant positive impact of implant treatment 3.) Cognitive function improved following implant treatment (using the MoCA) 4.) The greatest increment after auditory treatment was observed for long-term memory skills 5.) Short-term memory contributes to word identification and correct recall 6.) Early auditory rehabilitation is important and can lead to extended benefits beyond hearing ability (cognitive function and depression)	1.) It is difficult to assess and evaluate the real effect of mood disorders among hearing impaired patients 2.) A placebo effect of receiving hearing amplification or auditory training may play a role when patients are asked to self-report 3.) Further studies are needed to confirm this preliminary data	Experiment with randomized controls
LaRocque, Margaret, Hassan, Rajaa, Vidas, Silvia, Gagne, Jean-Pierre, & Parnes, Lorne S. (1991)	Effectiveness of an Intensive Speech Perception Training Program for Adult Cochlear Implant Recipients	•Four adults with profound sensorineural hearing loss acquired after the development of speech and language •Nucleus Mini 22-channel cochlear implant users •Ages: 27, 64, 36, & 32 •An individualized aural rehabilitation program was selected for each subject (based off recommendations from the Nucleus 22 Channel Cochlear Implant System: Rehabilitation Manual (shown in Table 1 of the publication) •12 weekly 3-hour sessions	1.) Cochlear implants improve speech perception abilities a.) Improvements were observed soon after the initial stimulation b.) The improvements may be attributable to the everyday use, experience, and practice 2.) Improved telephone communication and more effective use of communication strategies were found to be provided by the program 3.) It was not possible to reach a definitive conclusion concerning the effects of intensive aural rehabilitation on the basis of these findings 4.) The subjects in the investigation reported that they benefited from the training the received	1.) It was not possible to establish unequivocally that the post-implant improvements in speech perception were attributable to the rehabilitation program 2.) The test protocol may have been inadequate 3.) Ceiling effect on some of the tests 4.) The length of aural rehabilitation services may have been too short	Case study
Moberly, A., Vasil, K., Baxter, J., Klamer, B., Kline, D., & Ray, C. (2020)	Comprehensive Auditory Rehabilitation in Adults Receiving Cochlear Implants: A Pilot Study	•19 adults with post-lingual hearing loss •Between the ages 49 and 91 years •Participants were split into three groups: a.) Comprehensive auditory rehabilitation: 1 hour weekly for 8 weeks- individualized based on functional assessments and goals). Also 30 minutes of daily home practice using computer-based training (AngelSound) and a 1 hour counseling session b.) Passive control: CI evaluation, implantation, and post-operative visits at 2, 4, and 8 weeks after activation c.) Active control: in addition to the passive control protocol, they received the preoperative 1 hour counseling session •The Nijmegen Cochlear Implant Questionnaire (NCIQ), the Hearing Handicap Inventory for Adults/Elderly (HHIA/HHIE), and the Speech, Spatial and Qualities of Hearing Scale (SSQ) were used	1.) The comprehensive approach to aural rehabilitation was generally feasible (compliance was maintained and participant retention was 79.2%) 2.) Variability in speech recognition and self-report quality of life 3.) Improvements in sentence recognition improved from preoperatively to 1 month (quiet) and 1 to 3 months (in babble and quiet) but not from 3 to 6 months after activation 4.) In contrast, significant improvements in word recognition continued through 6 months after activation 5.) The trajectory of improvement may have been more rapid for the comprehensive auditory rehabilitation group - more rapid recovery of speech recognition function	1.) A larger trial is needed to investigate whether this approach leads to better outcomes or faster improvement 2.) The main difficulty of the data collection was getting participants to mail in QOL assessments (should be done in person for future studies) 3.) Measuring outcomes to only 6 months may have limited the ability to find longer-term benefits 4.) Ceiling effects for some participants	Experiment with randomized controls
Moberly, A., Vasil, K., Baxter, J., & Ray, C. (2018)	What to Do When Cochlear Implant Users Plateau in Performance: a Pilot Study of Clinician-guided Aural Rehabilitation	•9 experienced adult cochlear implant users completed the program fully •Clinician guided aural rehabilitation (CGAR) program guided by a speech-language pathologist and audiologist •1 hour weekly for 8 weeks •Individualized based on functional assessments, a combination of analytic and synthetic training modeled after the Adult Aural Rehabilitation Manual published by Cochlear Limited •Patients also received 10 minutes of device troubleshooting and counseling during each session •30 minutes of daily home practice	1.) There are benefits to speech recognition and quality of life as a result of clinician-guided CGAR but responses are highly variable 2.) Participants who respond well to aural rehabilitation are likely those who have the most to gain in baseline speech recognition performance 3.) A weak relationship between quality of life and speech perception improvements: some participants reported improvement in quality of life without speech perception improvement 4.) It remains unclear what CGAR approaches are most effective but conjecture that most adult patients could benefit from at least a short course of CGAR 5.) CGAR represents a potentially efficacious approach to improving speech recognition and hearing-related quality of life for adult cochlear implant users who have reached a performance plateau	1.) Selection of outcome measures is critical and challenging: avoid ceiling effects and floor effects 2.) Participants should not be tested repeatedly due to concern for learning the lists 3.) A randomized control trial is required to evaluation the efficacy of CGAR in adult cochlear implant users 4.) Financial sustainability was a concern of clinicians interested in implementing CGAR	Case study
Moradi, Shahram, Wahlin, Anna, Hällgren, Mathias, Rönnberg, Jerker, & Lidestam, Björn. (2017)	The Efficacy of Short-term Gated Audiovisual Speech Training for Improving Auditory Sentence Identification in Noise in Elderly Hearing Aid Users	•25 native Swedish speakers with a symmetrical bilateral mild to moderate hearing loss •Ages ranged from 63 to 75 years •Hearing aid users for at least 6 months •Randomized into experimental (audiovisual) and control (auditory training) groups by coin flipping •Underwent hearing-in-noise test (HINT), audiovisual or auditory speech identification training •Patients returned 1 month later for HINT follow-up testing	1.) Prior exposure to gated audiovisual speech identification tasks subsequently improves auditory sentence identification in noise ability 2.) The effect of audiovisual speech training was retained 1 month after the training 3.) Gated audiovisual speech training can be used in a reliable aural rehabilitation program for people with hearing loss 4.) No significant improvement in the HINT performance for the control group (auditory training without audiovisual training) 5.) Audiovisual speech training is not "better" than auditory speech training as there was no significant different in HINT scores	1.) The auditory training group may have been somewhat discouraged by their poorer performance as they needed longer exposure (higher number of training tasks) 2.) The effect of the audiovisual training group may have been due to higher motivation and compliance 3.) The interaction between compliance, participation and benefit needs to be investigated further	Experiment with randomized controls

Schumann, A., Liebscher, T., & Hoppe, U. (2015)	Computer-Based Auditory Phoneme Discrimination Training Improve Speech Recognition in Noise in Experienced Adult Cochlear Implant Listeners	•27 cochlear implanted adults with two or more years of experience (all implanted with implants from Cochlear) •Training and control group were randomly allocated •Participants were native German speakers •Training group participants completed 9 sessions (three week period 45-60 minutes twice per week) and two personal effort sessions weekly •Stimuli were presented using a computer running MAT-LAB (3 training sets) •The statistical analysis was structured into 3 different steps: training effects for sentence recognition pre to post training, long-term retention of training effects after 6 months, changes in performance of the trained materials over the training period	1.) A computerized structured listening training program (phoneme-discrimination tasks using nonsense syllables) is an effective intervention to further improve speech perception in experienced adult cochlear implant users 2.) Overall benefit in hearing performance can be gained from analytic auditory training for experienced cochlear implant users 3.) Auditory training may improve other recognition abilities (incidental learning) 4.) The training group participants showed improvement for sentence recognition in both noise conditions whereas the control group participants showed no significant development 5.) Retention was observed over a period of 6 months for the training group participants- auditory training elicits a statistically significant long-term retention of the benefit for speech recognition	1.) The found improvement for the training group may have been due to the training setup which included training in background noise (the control group only consisted of speech in quiet) 2.) Further research is needed to explain the heterogeneity of individual improvements in order to establish an optimal training program for cochlear implant listeners	Experiment with randomized controls

Table 3. Auditory Training Outcomes

Publication	Research Design	Number of Participants	Age	Main Findings	Limitations	Level of Evidence
Miller, Sharon, Zhang, Yang, & Nelson, Peggy. (2016)	Pre and post electroencephalogram (EEG) measures were taken while a computer-based training program was given between the pre and post test to determine whether training-related improvements in phonetic perception were correlated with neural markers associated with phonetic learning.	13	30.1 to 75.3 years old (mean: 55.3)	1.) With training, neural plasticity related to phonetic learning was successful. 2.) The mismatch negativity (MMN) can be used to assess phonetic categorization and speech discrimination for individual cochlear implant users	1.) The individual trainees were highly variable in their ability to categorize the contrasts. 2.) Further studies will need to be done to determine the role of temporal cues and whether they can be exploited to enhance phonetic learning in adult cochlear implant users. 3.) Future studies will need to focus on refining the double oddball paradigm for collecting MMN responses.	Case study
Yu, Luodi, Rao, Aparna, Zhang, Yang, Burton, Philip C, Rishiq, Dania, & Abrams, Harvey. (2017).	Functional magnetic resonance imaging (fMRI) cortical plasticity associated with hearing aid use. And fMR data of cortical plasticity for heaing aid use and rehabilitative training (8 week auditory rehabilitation program ReadMyQuips (RMQ)).	2	68 year old male & 52 year old female	Evidence of cortical plastic change involving the auditory cortex and visual regions from both patients is associated with hearing aid use and auditory training targeting AV speech processing	1.) It is difficult to determine the effects related to hearing aid use versus auditory training given the overlapping timeline of the two treatments. 2.) The two subjects did not match in age, gender, or degree of hearing loss 3.) Further investigation is warranted to investigate the neural basis for short-term and long-term effects of auditory training protocols.	Case study

Table 4. Why is Auditory Training Effective?

Results

What Auditory Training Programs are Available? What is the Evidence-Base for Each?

The auditory training programs delineated from this literature review are all computer-based auditory training (CBAT) programs. CBAT is typically completed by the user at home. Zhang, Miller and McNutt Campbell (2014) published an overview of nine home-based computer-based auditory training programs for adult cochlear implant users, including Angel Sound Training, LACE and CASPER. Zhang et al. identified 29 features of these programs split into three categories: general product and purchase information, design features, and auditory and communication targets. A summary of the design features and auditory and communication targets for nine computer-based, potentially self-directed programs, based upon Zhang et al. is provided in Table 5. Three other commercially available programs were discovered in the literature review: Hearing Rehabilitation for Older Adults (HeRO), Environmental sound training and an Interactive Music Awareness Program (IMAP).

	Angel Sound Training	CASPER	eARena	LACE	Read my Quips	Seeing and Hearing Speech	Sound Scape	SPATS	The Listening Room-CLIX
Progress measurements	×	×		×		×	×	×	×
Adaptive to client progress (difficulty adjusted automatically)	×		×	×	×			×	
Stimuli from a variety of speakers	×	×		×	×	×	×	×	×
Stimuli in background noise /multitalker	×		×	×	×	×	×	×	×
Connected speech stimuli	×	×	×	×		×	×	×	×
Listening training/ repair strategies	×			×			×		×
Visual stimulus (lip reading option)		×			×	×			
Music	×						×		×
Telephone	×						×		×
Everyday environmental sounds			×						
Auditory memory			×				×		

Table 5. Collapsed view of Zhang et al. tables comparing nine CBAT programs

Angel Sound Training (http://angelsound.tigerspeech.com) software was developed at the House Ear Institute and TigerSpeech Technology, Inc. and became available in 2005 (Fu & Galvin, 2007). It provides a software programs that allows cochlear implant patients to practice and develop their listening skills at their own pace and convenience. Cochlear implant recipients can use Angel Sound Training at home, on any computer, or in conjunction with auditory rehabilitation from a clinical provider. The program can be adjusted to the match the user's developing listening skills. Angel Sound Training provides feedback during the training so users are able to self-correct and gauge progress. Training data can be shared with the provider for further advice and guidance. Fu and Galvin reported Angel Sound Training as an effective auditory training method after 10 participants demonstrated improvements in speech recognition performance after using the program for up to two hours daily, five days per week, for one month or longer. Fu and Galvin studied a small sample size with no control subjects, making it difficult to determine if the improvements were due to Angel Sound Training or to cochlear implant activation alone.

Speech tracking is described by Okell and Lind (2012) and Plant, Bernstein, and Levitt (2015). Speech tracking aims to provide an interactive and conversation-like task rather than traditional stimuli-response paradigms. Speech tracking typically requires two participants: a sender and a receiver. The sender reads aloud from a chosen text in chunks, typically, about a sentence long, and the receiver (the hearing-impaired individual) repeats the spoken text. If the text is repeated with 100% accuracy, the sender may move on. If the text is not repeated verbatim, the sender must repeat the text and the receiver must attempt to repeat it accurately. The receiver is scored on how many words are correctly repeated in a given time period of training. More recently, a computer-based speech-tracking software has been introduced so that speech tracking can be self-directed. Sweetow and Sabes (2007) discuss speech training, or computer-assisted speech-perception testing and training at the sentence level (CASPER), a multimedia program that can be self-administered, administered with the aid of a non-professional, or clinician controlled. CASPER can be presented in visual (lip-reading) only, auditory (hearing) only, or visual plus audio modes. The trainee indicates understanding of the message by using a computer-mouse to click on words correctly identified. Okell and Lind (2012) state tracking has been a widely used and researched assessment and intervention tool due to its ability to address communicative and perceptual skills. One of the interesting things that CASPER does is train communication breakdown by repairing incorrect responses through recasting.

eARena is a DVD product from Siemens hearing aid company that can only be purchased by audiologists for use by their clients. eARena is no longer currently available as Siemens has been bought by Signia. It was developed for hearing aid users, but provides connected speech, vowels, consonants and background noise training, similar to Angel Sound Training.

Listening and communication enhancement (LACE): https://laceauditorytraining.com/ is a software-based program that can be used by the individual at home or in a clinic setting (Sweetow & Sabes, 2007). It provides a variety of interactive and adaptive tasks divided into three categories: degraded speech, cognitive skills and communication strategies. Immediate feedback is provided to the user for each task using LACE software. Additionally, a graph depicting cumulative daily improvement and progress is shown at the end of each training session. The results of users' training sessions are tracked electronically and are accessible to the audiologist. Sweetow and Sabes assessed the efficacy of individualized auditory training using

LACE for 65 subjects who completed 5 training sessions per week for 1 month. Using a randomized, cross-over-control design, the investigators showed improved scores on speech in babble, competing speaker and time compressed speech tasks after 1 week. Auditory memory was shown to improve after 3 weeks.

"Read my Quips" (https://www.sensesynergy.com/) is also intended to assist hearing aid users, but targets to improve speech perception from a variety of speakers, and in background noise. Read My Quips provides a visual stimulus option similar to CASPER.

"Seeing and Hearing Speech" (https://www.sens.com/products/seeing-and-hearing-speech/) is a program that provides progress measures, and focuses on improvement in speech perception from a variety of speakers, in background noise, and trains using connected speech, vowels, consonants, and speakers talking at different rates of speed.

The Sound Scape Series of programs was produced by Med El, a research, development and cochlear implant manufacturing company (https://www.medel.com/en-us/support/rehab). It is comprised of several different programs and includes those for music and auditory memory training in addition to training speech perception of connected speech.

Speech Perception Assessment and Training System (SPATS) (Communication Disorders Technology, http://www.comdistec.com) was developed for hearing aid users. The developers recommend that a client train with a clinician initially before advancing to a self-directed program. SPATS has recommendations for duration and frequency of training sessions, is adaptive to user progress, and provides progress measurements.

The Listening Room-CLIX (https://thelisteningroom.com/) program was developed and offered by the Advanced Bionics Corporation, another research, development and manufacturing company for cochlear implants. The program provides speech perception training from a variety of speakers, in background noise, using connected speech, vowels, consonants and has targeted improvement for both music and television listening.

HeRO (not available to the public). Kwak et al., (2020) developed a mobile application-based aural rehabilitation tool for the elderly, named Hearing Rehabilitation for Older Adults (HeRO). HeRO contains four types of auditory training sets: syllable, sentence, discourse, and working memory. The training components (excluding working memory) have three levels of difficulty- easy, moderate, and hard. Training results are tracked and summarized on a monthly basis, which can help the user to identify progress. An error pattern is also calculated in training results to indicate incorrect answers. HeRO can provide a real-time report of training results to the provider to guide the training and make changes to the program as needed. The developers/authors reported that the HeRO application offers the key benefits of time, resource, and cost-effective intervention that can be easily accessed, tailored to individual needs, and remotely monitored by their provider. A main focus of the development of HeRO was to consider older adults' willingness to adopt the use of health-related technology. Older adults are often considered "digitally divided" and their outlook on technology may negatively impact their commitment to auditory training. In the development of the HeRO application, Kwak et al. had all 44 participants complete a technology acceptance model (TAM) questionnaire following HeRO training for 10 days. The reported results indicate a positive perception and willingness to use the application in addition to recognizing HeRO as beneficial to their life.

Environmental sound training. Environmental sound training with spectrally degraded stimuli consists of listening to familiar sound sources (such as human and animal vocalizations, mechanical sounds, water-related sounds, aerodynamic sounds, and electric and acoustic signaling sounds) and identifying the source from a list (Shafiro, 2008). Shafiro recognizes that little information is currently available on the effects of spectral degradation on the perception of other sounds in the environment, or about perceptual adaptation to these changes. According to Shafiro, environmental objects and events are important to the listener because they can warn of potential dangers, provide esthetic satisfaction, and generally contribute to the listener's sense of awareness, well-being and quality of life. The evidence-base of Shafiro's work stems from previous research demonstrating similarities that have been found in the acoustic characteristics and cognitive and neurophysiological processes involved in the perception of speech and environmental sounds. The findings from Shafiro's publication conclude positive effects of training on the identification of spectrally degraded environmental sounds for 7 normal hearing individuals after five individualized training sessions. The mean performance improved by 86% for the sounds that were used in training and 36% for the sounds that were not used in training. This finding suggested that training improved sound identification. Furthermore, an improvement in the identification of sound sources not used in training demonstrates that training effects can generalize to other sounds. This was a small sample study that did not evaluate cochlear implant users but supports the need for further work to evaluate environmental sound perception and the effects of training in adult cochlear implant users.

IMAP (https://morefrommusic.org/). Interactive music awareness program (IMAP) was created by van Besouw et al., (2015). IMAP is available online and is a rehabilitative tool that enables users to transform and manipulate recorded music to their satisfaction and liking through a variety of standalone applications. One is the "Mixer" which is a simple graphical mixer that allows the user to control the instrumental and vocal mix by changing the pitch and speed of different songs. Users can manipulate the different instrumental and vocal lines to determine what sounds best. IMAP development was inspired by cochlear implant users frequent dissatisfaction of music quality perceived through their implant. IMAP was developed in response to a need for music-based aural rehabilitation for adult cochlear implant users. The authors state that there is evidence to suggest that training can improve their appraisal and perception of music (van Besouw et al., 2015). A prototype IMAP program was created and evaluated by 16 adult cochlear implant users over 12 weeks. Results demonstrate overall positive ratings of the training by the users and indicated that the program met users' needs. Van Besouw et al., further developed the IMAP in response to users' feedback and is currently freely available online.

Synthesis of auditory training programs available. Twelve auditory training programs were examined in the publications reviewed. Eleven of them are self-directed and administered on a computer (environmental sound perception training was performed in a clinic supervised by an audiologist so is considered clinician-based auditory training). Environmental sound perception training could be adapted as self-directed aural rehabilitation in the future with a development of a self-directed computer-based program. Of the CBAT programs reviewed, LACE and CASPER have been the only two programs evaluated in controlled experimental trials. No information on effectiveness has been published for the remaining CBAT programs. Zhang et al. point out the lack of research foundation contributes to the challenge of making a selection of auditory training programs for cochlear implant users. Their review can assist audiologists in making decisions based on individual patient needs and goals. Zhang et al. indicate that eARena and Read my Quips are not targeted at cochlear implant users, but may serve beneficial to individuals with specific needs found within these programs. There are anecdotal subjective reports of benefit of self-directed auditory training in everyday listening experiences outside of the laboratory (Fu et al., 2007). Self-directed auditory training may be of benefit because the user because it offers the convenience of the user being able to complete training on their own time.

Factors Associated with Effectiveness of Auditory Training

Effectiveness is defined as a measurable change in speech perception, self-assessment of handicap reduction or increase in quality of life. Historically, effectiveness was measured only by speech perception scores pre- and post- cochlear implant activation. More recently, health related quality of life measures have become another major component of cochlear implantation. Adult cochlear implant users may perceive effectiveness as an increase in quality of life tied to their ability to better communicate with their loved ones.

Patient-related factors. Numerous factors associated with effectiveness of computer based auditory training were discussed in the publications in this literature review. Smith et al. (2016) performed a multisite randomized control clinical trial with 279 new and experienced bilateral hearing aid users. The participants were split into four treatment groups: 1.) 20-day computerized LACE training 2.) 10-day LACE training completed on a DVD 3.) 20-day computerized "books-on-tape" training (placebo) and 4.) an active control group who received only educational sessions but no formal auditory training. They measured progress using the Words-in-Noise test, and the Hearing Handicap Inventory for Adults/Elderly (HHIA/E) and the Abbreviated Profile of Hearing Aid Performance (APHAP) surveys. The results showed that the informal and formal auditory training programs were no more effective at improving outcomes than educational counseling sessions. Hearing aid users who had poorer word-recognition in noise, greater residual activity limitations, and participation restrictions showed the largest improvement from self-directed auditory training, however. Smith et al. suggested that patients with those characteristics should be considered candidates for training, regardless of the method or type provided. This appears as a “something is better than nothing” approach. It is not known whether these results from hearing aid users would also be generalizable to those who use cochlear implants.

Through the means of a self-report survey, Bennett et al., (2018) determined that certain groups of people have more difficulty managing their hearing aids than others: 1) people over the age of 76; 2) women; and 3) users of behind-the-ear hearing aids (compared to those with in-the-ear hearing aids). The investigators considered many additional factors associated with hearing aid management and knowledge including: participants’ age, gender, style of hearing aid, age of current hearing aid, and total years of hearing aid ownership. Importantly, Bennett et al. found that higher levels of hearing aid knowledge and hearing aid management were associated with better hearing aid outcomes and higher self-reported satisfaction with their hearing devices. These outcomes were derived from the Hearing Aid Skills and Knowledge Inventory (HASKI) survey and the International Outcome Inventory for Hearing Aids (IOI-HA) survey. As in the Smith et al. (2016) report, these patient-related factors were found for hearing aid users, and were not studied in those who use cochlear implants. Age and device management are likely to be factors affecting the outcome of auditory training programs for the adult who uses a cochlear implant just as it is for hearing aid users.

Quality of life. An adult cochlear implant user’s definition of effectiveness or success should include a quality of life measurement. Abdrabbou et al., (2018) specified that speech recognition test results alone cannot provide hearing-health providers with information regarding the impact of hearing loss on an individual’s daily life. They emphasized the need of a quality of life assessment in conjunction with aural rehabilitation practices. The authors use the Nijmegen Cochlear Implant Questionnaire (NCIQ) to assess quality of life in two cochlear implant users who undertook CBAT auditory training. Results from the CBAT training demonstrated that patients performed well (above 95% accuracy for speech perception) when using their cochlear implants in a quiet therapy room environment. On the other hand, both patients reported low self-esteem scores (40% or below) that demonstrated that each patient's perception of hearing loss decreased their self-confidence. Although both patients exhibited positive speech perception scores, their personal perception of "success" measured by quality of life rating did not correspond. Similarly, Moberly et al. (2020) reported a weak relationship between quality of life and speech perception improvements: some participants reported improvement in quality of life without statistical significant improvement in speech perception scores.

Self-efficacy. Self-efficacy in the context of auditory training reflects an individual's belief in his or her ability to improve their speech perception scores or quality of life rating. A patient with a high level of self-effifacy would be more likely to have positive outcomes because of high motivation and commitment to training involved. On the other hand, a patient with a low level of self-efficacy is more likely to have negative outcomes because of a lack of confidence, effort and participation.

Smith and West (2006) investigated the importance of self-efficacy in audiologic rehabilitation. The authors completed a review of literature on self-efficacy and its relevance to successful interventions in several health domains. Their review suggests that interventions founded on a self-efficacy framework (mastery experience, vicarious experience, verbal persuasion and physiological and affective states) produce better outcomes than do interventions that are not self-efficacy based. Their findings indicate that self-efficacy should play a role in audiologic rehabilitation activities aimed to treat hearing loss, tinnitus and balance disorders. Smith and West state that self-efficacy is a powerful predictor of behavior change. The authors also emphasize the importance of individual based goals. Patients with low self-efficacy would be unwilling to try challenging activities and would be more limited than patients with high self-efficacy. This review suggests self-efficacy is a factor to incorporate into a self-directed auditory training program.

Barriers to success. Reis et al., (2019) surveyed cochlear implant audiologists in Australia to determine audiologists' practices toward auditory training, and to assess the cost of different methods for clients and service providers. The survey included clinician-led, in-person auditory training, individual home-based, and group-based auditory training. The results from 230 Australian cochlear implant audiologists suggest that the cost of aural rehabilitation for both patients and providers may be a factor for not providing auditory training. Additional reported reasons for referring clients to other providers included limitation of resources, and not knowing how to conduct auditory training. This survey represented 16-33% of practicing audiologists in Australia working with adult cochlear implant users. Nearly 85.5% of respondents agreed that auditory training is necessary to improve outcomes in adult cochlear implant users, but only 53.6% of responding clinicians used auditory training methods. The authors reported that the responses to the survey were highly variable, which could be due to the lack of strong evidence supporting the effectiveness of auditory training.

Synthesis of factors associated with effectiveness of auditory training. Success or effectiveness of self-directed auditory training can be measured in multiple ways. Factors that may impact effectiveness can be patient characteristics, quality of life perception, self-efficacy or willingness to participate, access to a self-directed auditory training program, and cost of a self-directed auditory training program. It is important to consider these factors when determining a self-directed auditory training program for each individual adult cochlear implant user.

Auditory Training Outcomes

Depending on the definition of effectiveness, a variety of outcomes of auditory training are measurable including speech perception abilities, quality of life, retention of improvements, and feasibility. This literature review strictly included formal measurements of outcomes.

Speech perception abilities. Moberly et al., (2020) examined 19 cochlear-implanted adults with post-lingual hearing loss between the ages of 49 and 91 years. The participants were split into three different treatment groups including those who received: 1) comprehensive auditory training (1 hour weekly for 8 weeks, 30 minutes of daily home practice, and a 1 hour counseling session), 2) a passive control who received no training and 3) an active control (1 hour counseling session). The findings stated that the trajectory of improvements were more rapid for the group receiving comprehensive auditory rehabilitation compared to those who were in the passive or active control groups. The authors state that perhaps comprehensive auditory training does not lead to better overall speech perception outcomes, but rather more rapid recovery of speech perception function.

Schumann et al., (2015) examined 27 adult cochlear implant users with two or more years of cochlear implant experience. The randomly allocated training group completed 9 sessions of 45-60 minutes twice per week of self-directed computer-based auditory phoneme discrimination training. The control group received the same amount of auditory training but only received speech in quiet stimuli. The training group participants showed improvement for sentence recognition in noise conditions (speech babble) whereas the control group showed no significant improvement. They concluded that a self-directed computerized structured listening training program at the phoneme-level is an effective intervention to further improve speech perception in experienced adult cochlear implant users.

Quality of life outcomes. Moberly et al., (2020) used the Nijmegen Cochlear Implant Questionnaire (NCIQ), The Hearing Handicap Inventory for Adults/Elderly (HHIA/HHIE), and the Speech, Spatial and Quality's of Hearing Scale (SSQ) to measure pre-surgery status and post surgery outcomes as well as the outcomes from an aural rehabilitation training program. The most significant changes were seen from preoperative to 1-month post cochlear implant activation. Previously, Moberly et al., (2018) used the NCIQ, HHIA/HHIE and the SSQ to measure the outcomes of clinician guided auditory training for 9 adult cochlear implant users. There were improvements in quality of life measures at 1, 3 and 6 months post activation. The group as a whole demonstrated a significant improvement on the mean NCIQ total score, significant improvement on the HHIA/HHIE emotional subscale, and a trend towards improvement on the speech subscale of the SSQ.

Retention of improvements. Schumann et al. (2015) examined a control group (12 subjects) and training group (15 subjects) who underwent a computer-based auditory training program. They found that retention was observed over a period of 6 months for the training group, indicating that self-directed auditory training provided a statistically significant long-term retention of benefit for speech recognition. Moradi et al., (2017) tested 25 subjects ages 63 to 75 years. 14 participants received audiovisual speech training, which consists of a speaker on the screen so there is access to both audio and visual cues. Eleven participants were in the control group who received auditory training only with no visual cues. The subjects underwent hearing-in-noise testing (HINT) before and 1 month after audiovisual or auditory speech identification (control group) testing. They found that audiovisual speech training was retained one month after training. Additionally, no improvement in the HINT performance was found for the control group.

Feasibility. Moberly et al. (2020) reported that comprehensive aural rehabilitation (both at-home self-directed and clinic-based training) is feasible based on participant compliance being maintained and measured 79.2% participant retention six months after completion of training. The authors calculated this based on full completion of training and surveys. A patient's attitude toward technology may negatively impact their willingness to participate in or complete auditory training using technology.

Synthesis of auditory training outcomes. Aural rehabilitation outcomes need to be evaluated with formal measurements to determine effectiveness of treatment. A variety of outcome measurements, including speech perception, self-reported hearing handicap, and quality-of-life methods, can document effectiveness. Aural rehabilitation outcomes depend on a variety of characteristics, but have been proven to positively impact speech perception, quality of life, retention of improvement and feasibility.

Why is Auditory Training Effective?

Evidence of cortical plasticity due to auditory training can be measured by electrophysiologic and neuro-imaging tests. For example, Yu et al., (2017) performed functional magnetic resonance imaging (fMRI) on two adults who were first-time hearing aid users before and after an 8-week period. One patient was assigned Read my Quips auditory training for the last 4 weeks of the 8-week study period. The regions of interest for the fMRI study included the auditory cortex, visual cortex, and the superior temporal sulcus. The results of the study showed experience-dependent changes involving the regions of interest. Specifically, the patient who received auditory training showed significant increase in activity for the auditory regions of interest. This result was thought to reflect greater involvement of the auditory modality in response to acoustic signals after initial hearing aid use *and* auditory training. Additionally, the uni-sensory regions of interest (auditory and visual cortices) became more synchronized with the multi-sensory regions of interest (superior temporal sulcus) from pretest to posttest in audio-visual incongruent conditions.

Yu et al. acknowledged the limitations of the report including difficulty determining if effects were related to hearing aid use alone and auditory training. They also explained that speculative interpretation of the results should be noted because the two subjects did not match in characteristics such as: gender, age, and degree of hearing loss. This study used a small sample size and did not examine cochlear implant users.

Miller, Zhang, and Nelson (2016) aimed to examine the fine-scale behavioral and neural correlates of phonetic learning in adult cochlear implant users. Particularly, they investigated whether high-variability identification training improved phonetic categorization of the /ba/-/da/ and /wa/-/ja/ speech contrasts. Nine cochlear implant users completed a computer-based training program that used high variability identification of non-native phonetic contrasts. The authors used identification training compared to discrimination training because it encouraged listeners to attend to higher, category-level differences across stimuli. The experimental group completed four two-hour sessions over two weeks while the control group (4 cochlear implant users) did not receive any auditory training. Pre- and post training perceptual measures included eight behavioral test blocks of 20 trials in which the participants were asked to click on a screen with orthographic labels of the two-endpoint stimuli from a given continuum (“ba” “da” “wa” or “ya” for clarity). The electrophysiologic measure was the Mismatch Negativity (MMN) auditory evoked potential. MMN amplitude significantly increased with training for both the /ba/-/da/ and /wa/-/ja/ contrasts, indicating improved salience of phonetic variants. The control group did not have observable changes in MMN response across test sessions. Perceptual results indicated training significantly enhanced behavioral sensitivity to the across-category stimulus pair for the /ba/-/da/ contrast but did not alter behavioral identification of the /wa/-/ja/ stimuli. The behavioral and EEG training findings suggest that high-variability identification training altered perceptual sensitivity reflected in the MMN response for both speech contrasts. The results of this study indicate that auditory training can induce neural plasticity and enhance phonetic categorization of speech contrasts.

Discussion

The purpose of this literature review was to answer the following questions: 1.) What are the characteristics of an effective auditory training program? 2.) What is the evidence that supports the effectiveness of the program? 3.) What recommendations can be made about self-directed auditory training programs on the basis of this literature review? 4.) What are the gaps in our knowledge concerning self-directed auditory training programs for CI-users?

Characteristics of an effective auditory training program. I began this project in hopes of defining effective characteristics of self-directed auditory training programs. It has been difficult to pinpoint these characteristics in the findings of this literature review. I still hold the premise that practice and compliance with a self-directed auditory training program should provide benefit and improvement that goes being just daily, informal listening experience following cochlear implant activation. An effective auditory training program would promote self-efficacy because interventions founded on a self-efficacy framework produce better outcomes than do interventions that are not self-efficacy based (Smith et al., 2006). An effective auditory training program would also measure and provide progress during training. The following programs provide progress during or following training: CBAT (Angel Sound Training, Seeing and Hearing Speech, Sound Scape, SPATS and The Listening Room), HeRO, CASPER, and LACE.

An effective auditory training program would also adapt to the cochlear implant users progress throughout the training, changing the difficulty as needed. CBAT (Angel Sound Training, eARena, Read my Quips, and SPATS), and LACE utilize automatic adaptation dependent on user progress. HeRO can be adjusted manually by the provider. In order to measure the effectiveness of an aural rehabilitation program, formal quality of life and speech perception measurements would be taken pre-, and 1- and 3- months post auditory training program in order to measure retention of improvement.

Quality of evidence. Boothroyd (2007) indicates an important aspect of developing best practice is not just to consult the research, but also to evaluate the quality of the evidence it provides. He explains a hierarchy of levels of evidence. The top of the hierarchy includes meta-analyses and systematic reviews. This is why the committee members and the author chose to include overviews of information in this literature review. Next are individual experiments with random assignment of patients to conditions and the inclusion of control conditions. Case studies are next on the hierarchy and can be useful if they are replicated with a small sample. Retrospective case studies are less valuable because of the absence of randomization and control conditions. The lowest level of evidence is expert opinion, for example, “this is the way we have always done it”. This literature review contains overviews (but not meta-analyses), individual experiments with randomization and controls, and case studies. In several studies, including those of Shafiro (2008), Abdrabbou et al. (2018) and Moberly et al. (2020) small sample sizes were acknowledged as limitation of their studies. Overall, the evidence of the efficacy of self-directed aural rehabilitation for adult cochlear implant users published and assessed in this literature review is weak because only 7 controlled trials with adequate sample sizes have been reported.

Yet, as Martin Rees stated and is often quoted "Absence of evidence is not evidence of absence". Certainly evidence of the effectiveness of auditory training exists. Evidence may be deemed unreliable due to studies being too small to detect an effect, the effect being too small, too few data or not enough studies, low quality evidence or poorly designed studies. There is strong evidence from studies in this literature review with small sample sizes and control groups, but the publications in this literature review did not contain strong evidence for large sample sizes, nor whether results from hearing aid users could be generalized to cochlear-implant users. In order for the evidence to be stronger, larger sample sizes need to be evaluated, with clearly defined self-directed auditory training protocols for adults with cochlear implants.

Gaps in knowledge and Limitations. Many common limitations were discussed in the 22 publications reviewed. Multiple patient related factors were discussed by eight of the 22 publications. Nine of the 22 publications explained that further investigation was needed from their publications. Six publications stated effort, time, and commitment, highly demanding practice or compliance as limitations. Three publications mentioned small sample size, or test protocol/length of auditory training not being sufficient. Ceiling effects, placebo effects, response bias were also mentioned as limitations. Placebo effects from participating in aural rehabilitation can impact a patient’s perspective (both positive or negatively) of improvement depending on their emotions towards the experience. Another limitation mentioned was changes in performance due to learning or practice. Repeated training stimuli that are used in auditory training programs and then tested to determine progress may be due to memorization or familiarity with the stimuli versus improvement in performance. Additionally, availability of long-term data or outcomes was stated as a limitation for Sweetow et al., (2007), Bennett et al.,

(2018) and Moberly et al., (2020) from the literature review. The dose-dependence of auditory training outcomes has not been determined. This represents an area in need of investigation.

It must be stated that sensory management, that is, providing access to sound, is crucial to the success of any aural rehabilitation program. Cochlear implantation provides access to sound. Indeed, the provision of an implant, and experience using an implant without a formal, clinician- or self-directed AR program provides many benefits including increased cognitive function, level of depression, quality of life, and improved long-term memory skills (Castiglione et al., 2016). These investigators examined 125 subjects 65 years or older who were either hearing-impaired or had normal hearing. They used the Montreal Cognitive Assessment (MoCA), Geriatric Depression Scale (GDS), Digit Span Test (short-term memory task), and the Stroop test (measures reaction time, executive function and selective attention) to measure the benefits of sensory management with cochlear implants. The authors stated that cognitive function improved following cochlear implant treatment. Additionally, cochlear implant treatment was correlated to positively impact patients level of depression using the Geriatric Depression Scale (GDS) pre- and post-operatively. The greatest increment after auditory treatment found by Castiglione et al., was long-term memory skills. Castilgone et al., emphasized that sensory management with cochlear implants can lead to cognitive and memory benefits.

Studies such as those of Miller et al. (2016), Moberly et al. (2020), Moradi et al. (2017), Shafiro (2008), and Schumann et al. (2015) in which there were a control groups, were able to demonstrate benefits that go beyond those from sensory management and experience alone. More research is required to investigate gains made with auditory training compared to the improvement individuals get with cochlear implant activation and listening experience with the cochlear implant.

Currently, information on effective dose duration and intensity of self-directed auditory training programs has not been defined. More evidence on long-term outcomes is needed to determine appropriate aural rehabilitation assignments for adult cochlear implant users. Additionally, more randomized control studies comparing intervention (auditory training) and no intervention need to be investigated further because LaRocque et al., (1991), Castiglione et al (2016) and Moberly et al., (2020) found that cochlear implantation without formal auditory training will improve speech perception abilities.

Clinical Implications

The University of Arizona Hearing Clinic does not currently provide opportunities for adults with cochlear implants to complete self-directed auditory training. A longer-term goal for this project is to design and implement an evidenced-based self-directed auditory training training suite into the University of Arizona Hearing Clinic. A proposed study is as follows:

Self-Directed Auditory Training Effectiveness Study

Participants

30 adult cochlear implant users between the ages of 45 and 75 years will be recruited from The University of Arizona Hearing Clinic. This is a randomized crossover design. The 30 participants will be randomly placed in one of two groups. The groups will be balanced based on age, sex, and onset of hearing loss. 15 participants will complete a self-directed auditory training program in person (experimental group) at The University of Arizona Hearing Clinic AR Training Suite. 15 participants will serve as a wait-list control group.

Inclusion criteria will include participants with post-lingual severe-profound hearing loss and use a cochlear implant in at least one ear. The participants will need to have their cochlear implant(s) activated prior to participation in this study. Participants must have 6 months of experience with their cochlear implant(s). Participants must pass a cognitive screener, with a score of 26 or higher, using the Montreal Cognitive Assessment (MoCA). Participants may be native English or Spanish speakers.

Exclusion criteria include patients who have pre-lingual hearing loss and patients who have history of a brain injury.

Methods

All 30 participants will undergo an evaluation with their implant prior to initiating a rehabilitation program. This consists of measuring sound field thresholds and T's and C's. The Measure of Audiologic Rehabilitation Self-Efficacy for Hearing Aids (West & Smith, 2007) (Appendix B) will be modified and distributed to evaluate the participant's self-efficacy with hearing technology. The Functional Assessment of Comfort Employing Technology (FACETS) (Lepkowsky, 2017) will be used as a pre-test to determine participants comfort with technology.

The following measures will be repeated pre- and at 1-month and 3-months post completion of the aural rehabilitation program in order to measure retention of improvement.

1. Speech perception testing will be measured using AzBio sentences in quiet and at +5 dB SNR.
2. The Nijmegen Cochlear Implant Questionnaire (NCIQ) will be used to assess cochlear-implant related quality of life (Appendix C).

3. Auditory memory will be measured using The Auditory Sequential Memory Test. A digit repetition task that progresses from 2 to 8 numbers. Results will demonstrate if auditory memory increases due to the auditory training program.
4. The Geriatric Depression Scale (GDS) will be used to assess depression over time in a clinical setting.

Auditory training program elements. The experimental groups will complete Angel Sound Training, a self-directed computer-assisted auditory training software. Angel Sound Training promotes self-efficacy because it is interactive, and easily accessible. Angel Sound Training utilizes automatic adaptation based on user progress. Additionally, Angel Sound Training provides progress measurements throughout training.

Schedule of training. The experimental groups will be assigned aural rehabilitation three times weekly, for 45-minutes each session, over a 4-week period. The wait-list control group will not receive any formal training during the 4 weeks. The wait-list control group will begin training after 1-month post-test measures are taken.

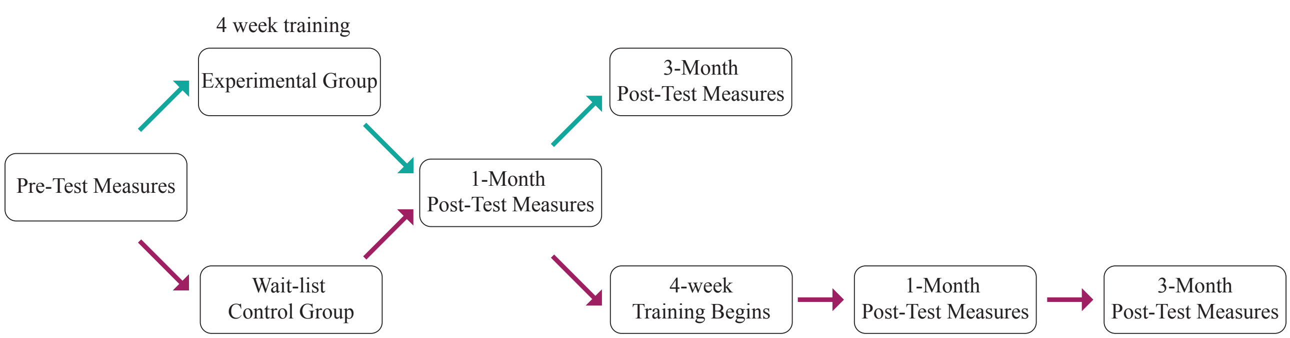

Figure 2. Timeline of Proposed Study

Data Analysis

Repeated measures analyses of variance will be used to determine if there are differences in speech perception abilities, CI related quality of life, and auditory memory as a function of experimental group (in-person vs. wait list). Other factors for analysis include self-efficacy, depression, age and retention of improvement.

Expected outcomes

The experimental group will show greater improvement in speech perception abilities and quality of life ratings, auditory memory, and depression scale ratings compared to the control group. This group may show even greater improvements in speech perception abilities and quality of life measures due to more motivating factors including: driving to the clinic for treatment, being in a clinic environment, having immediate accountability to the audiologist for engaging with the training program and having a consistently reliable computer.

Self-efficacy ratings pre- auditory training program should correlate with better speech perception abilities, quality of life ratings, and depression scale ratings post- auditory training program. I predict that younger patients will have better rated self-efficacy and will improve the greatest in speech perception abilities because the findings from Bennett et al., (2018) revealed better speech perception and self-rated outcomes for those under the age of 76.

Pre-measured self-reported comfort with technology should correlate with better overall improvement in speech perception ability, quality of life, and depression post-training program.

Conclusion

What is effective self-directed auditory training for adults with cochlear implants? To classify training as effective, it must accomplish a purpose or produce the intended result. Five auditory training programs can currently be classified as self-directed including: computer-based auditory training (CBAT), listening and communication enhancement (LACE), speech tracking (CASPER), Hearing Rehabilitation for Older Adults (HeRO), and an interactive music awareness program (IMAP). Speech perception abilities were shown to increase, and measures of quality of life were shown to improve as a result of self-directed auditory training.

The evidence of the efficacy of self-directed auditory training for adult cochlear is currently deemed weak because few studies have been conducted and those that have have weaknesses including small sample sizes, and lack of controls. To overcome this lack of evidence, a self-directed auditory training effectiveness study has been proposed that could be carried out at The University of Arizona Hearing Clinic.

The data collected in this review suggest that Angel Sound Training is currently the most effective evidence based auditory training program currently available for adult cochlear implant users. This recommendation has been chosen because the program promotes self-efficacy, is easily accessible, utilizes automatic adaptation and provides progress measurements throughout training. The effectiveness of the program should be further explored through the proposed study.

Appendix A- Search Strategies

Database: Arizona Libraries

Search date: 1/19/2021

Search strategy:

Any field contains “cochlear implant” AND any field contains “aural rehabilitation” AND any field contains “auditory training” AND any field contains “adult” NOT any field contains “children” NOT any field contains “prelingual”

Material type: All items

Language: Any language

Publication Date: Any year

“Adjust my results”: peer reviewed/scholarly resources

Database: Cochrane Library

Search date: 1/19/2021

Search strategy:

All text “cochlear implant” AND all text “aural rehabilitation” AND all text “auditory rehabilitation” AND all text “auditory training” AND all text “adult”

Database: Medline

Search date: 1/19/2021

Search strategy:

“cochlear implant” AND “aural rehabilitation” AND “auditory rehabilitation” AND “auditory training” AND “adult” NOT “children” NOT “prelingual”

Database: PsycINFO

Search date: 1/19/2021

Search strategy:

“cochlear implant” AND “aural rehabilitation” AND “auditory rehabilitation” AND “auditory training” AND “adult” NOT “children” NOT “prelingual”

Appendix B- The Measure of Audiologic Rehabilitation Self-Efficacy for Hearing Aids

Item #	*Item content*
Factor 1 (aided listening)	
17	I could understand a one-on-one conversation in a quiet place if I wore hearing aids.
18	I could understand conversation in a small group in a quiet place if I wore hearing aids.
19	I could understand conversation on a standard telephone if I wore hearing aids.
20	I could understand television if I wore hearing aids.
21	I could understand the speaker/lecturer at a meeting or presentation if I wore hearing aids.
22	I could understand a one-on-one conversation in a noisy place if I wore hearing aids.
23	I could understand conversation in a small group while in a noisy place if I wore hearing aids.
24	I could understand a public service announcement over the loudspeaker in a public building if I wore hearing aids.
25	I could understand conversation in a car if I wore hearing aids.
Factor 2 (basic handling)	
1	I can insert a battery into a hearing aid with ease.
2	I can remove a battery from a hearing aid with ease.
3	I can tell a right hearing aid from a left hearing aid.
4	I can insert hearing aids into my ears accurately.
5	I can remove hearing aids from my ears with ease.
7	I can operate all the controls on a particular hearing aid (knobs, switches, and/or remote control) appropriately.
11	I can clean and care for a hearing aid regularly.
Factor 3 (adjustment)	
14	I could get used to the sound quality of hearing aids.
15	I could get used to how a hearing aid feels in my ear.
16	I could get used to the sound of my own voice if I wore hearing aids.
Factor 4 (advanced handling)	
6	I can identify the different components of a particular hearing aid (i.e. microphone, battery door, vent, etc.).
9	I can stop a hearing aid from squealing.
10	I can troubleshoot a hearing aid when it stops working.
12	I can name the make or model of a particular hearing aid.
13	I can name the battery size needed for a specific hearing aid.
omitted item	
8	I can adjust a specific hearing aid in each ear so that I feel the hearing aids are balanced.

Appendix C- The Nijmegen Cochlear Implant Questionnaire (NCIQ)

Otolaryngology–
Head and Neck Surgery
Volume 123 Number 6

APPENDIX: NIJMEGEN COCHLEAR IMPLANT QUESTIONNAIRE*

*A native English speaker using forward-backward translation translated the NCIQ questionnaire.

Please answer the following 60 questions regarding the CI situation (use "not applicable" [N/A] only if none of the possibilities is applicable).

	Never	Sometimes	Regularly	Usually	Always	N/A
1. Can you hear background noises (toilet flushing, vacuum cleaner)?	☐	☐	☐	☐	☐	☐
2. Does your hearing impairment present a serious obstacle in your contact with persons with normal hearing?	☐	☐	☐	☐	☐	☐
3. Are you able to whisper if you have to?	☐	☐	☐	☐	☐	☐
4. Do you feel at ease in company despite your hearing impairment?	☐	☐	☐	☐	☐	☐
5. Can you hold a conversation in a quiet environment (with or without lip-reading) with one person?	☐	☐	☐	☐	☐	☐
6. Does your hearing impairment present a serious problem during your work or studies?	☐	☐	☐	☐	☐	☐
7. Can you hear the footsteps of other persons in your house (eg, in the hall or on the stairs)?	☐	☐	☐	☐	☐	☐
8. Does your hearing impairment present a serious problem in your contact with deaf persons?	☐	☐	☐	☐	☐	☐
9. Are you able to shout if you need to?	☐	☐	☐	☐	☐	☐
10. Does it bother you that you are hard of hearing?	☐	☐	☐	☐	☐	☐
11. Are you able to hold a conversation with 2 or more persons in a quiet environment (with or without lip reading)?	☐	☐	☐	☐	☐	☐
12. Does your hearing impairment present a serious problem in traffic?	☐	☐	☐	☐	☐	☐
13. Can you hear your own telephone or doorbell ringing?	☐	☐	☐	☐	☐	☐
14. Does your hearing impairment present a serious problem when you are with a group of persons (hobbies, sport, holidays)?	☐	☐	☐	☐	☐	☐
15. Are you able to make yourself understood to strangers without using hand gestures?	☐	☐	☐	☐	☐	☐
16. Do you become irritated if you cannot follow a conversation?	☐	☐	☐	☐	☐	☐
17. When you are in a busy shop, can you understand the shop assistant?	☐	☐	☐	☐	☐	☐
18. Does your hearing impairment present a serious problem during leisure-time activities?	☐	☐	☐	☐	☐	☐
19. Can you hear (not feel) the front door slam when you are busy at home?	☐	☐	☐	☐	☐	☐
20. Does your hearing impairment present a serious problem in your contact with the persons you live with (family/partner)?	☐	☐	☐	☐	☐	☐
21. Are you able to adapt your voice to different situations (noisy environment, quiet environment)?	☐	☐	☐	☐	☐	☐
22. Do you avoid speaking to strangers?	☐	☐	☐	☐	☐	☐
23. Are you able to enjoy music?	☐	☐	☐	☐	☐	☐
24. Does your hearing impairment present a serious problem for functioning in the home?	☐	☐	☐	☐	☐	☐
25. Are you able to hear cars approaching in traffic?	☐	☐	☐	☐	☐	☐

	Never	Sometimes	Regularly	Usually	Always	N/A
26. Are you left aside in company because of your hearing impairment?	☐	☐	☐	☐	☐	☐
27. Can strangers hear from your voice that you are deaf or hearing-impaired?	☐	☐	☐	☐	☐	☐
28. Do you ask other persons to speak more loudly or clearly if they are speaking too softly or unclearly?	☐	☐	☐	☐	☐	☐
29. Are you able to recognize certain melodies in music?	☐	☐	☐	☐	☐	☐
30. Does your hearing impairment present a serious problem when you are shopping?	☐	☐	☐	☐	☐	☐
31. Can you hear soft noises (key falling, microwave beeping)?	☐	☐	☐	☐	☐	☐
32. Do you go places where your hearing impairment might present a serious handicap?	☐	☐	☐	☐	☐	☐
33. Can you make yourself understood to acquaintances without using hand gestures?	☐	☐	☐	☐	☐	☐
34. Do you feel anxious when talking to strangers?	☐	☐	☐	☐	☐	☐
35. Are you able to recognize certain rhythms in music?	☐	☐	☐	☐	☐	☐
36. Does your hearing impairment present a serious problem when watching television?	☐	☐	☐	☐	☐	☐
37. Can you hear (not feel) someone approaching you from behind?	☐	☐	☐	☐	☐	☐
38. Does your hearing impairment present a serious hindrance in your contact with persons who live in your neighborhood?	☐	☐	☐	☐	☐	☐
39. How often does it annoy you that persons can hear from your voice/speech that you have a hearing problem?	☐	☐	☐	☐	☐	☐
40. Can you understand strangers without lip-reading?	☐	☐	☐	☐	☐	☐
41. Does your hearing impairment present a serious problem at parties (eg, birthday)?	☐	☐	☐	☐	☐	☐
42. Can you hear (not necessarily understand) persons talking on the radio?	☐	☐	☐	☐	☐	☐
43. Does your hearing impairment present a serious problem when you are with friends?	☐	☐	☐	☐	☐	☐
44. Can you make contact easily with other persons despite your hearing problem?	☐	☐	☐	☐	☐	☐
45. Can you hear the difference between a man's voice, a woman's voice, and a child's voice?	☐	☐	☐	☐	☐	☐
46. Does your hearing impairment present a serious problem when dealing with formal matters (insurance, solicitor, municipal office)?	☐	☐	☐	☐	☐	☐
47. Can you hear when someone calls you?	☐	☐	☐	☐	☐	☐
48. Does your hearing impairment present a serious problem in your contacts with family members?	☐	☐	☐	☐	☐	☐
49. Are there situations in which you would feel happier if you were not hearing-impaired?	☐	☐	☐	☐	☐	☐
50. Do you feel it tiring to listen (with or without lip-reading)?	☐	☐	☐	☐	☐	☐
51. Does your hearing impairment present a serious problem when you go out or go on trips?	☐	☐	☐	☐	☐	☐
52. Can you hear voices from another room (eg, children playing, baby crying)?	☐	☐	☐	☐	☐	☐
53. When you are in a group, do you feel that your hearing impairment keeps persons from taking you seriously?	☐	☐	☐	☐	☐	☐
54. Does your hearing impairment undermine your self-confidence?	☐	☐	☐	☐	☐	☐

	Never	Sometimes	Regularly	Usually	Always	N/A
55. Does your hearing impairment prevent you from sticking up for yourself (at work, in relationships)?	☐	☐	☐	☐	☐	☐

Please note: the answer categories for the following 5 questions are changed

	No	Poor	Fair	Good	Quite Well	N/A
56. Are you able to make your voice sound angry, friendly, or sad?	☐	☐	☐	☐	☐	☐
57. Can you control the pitch of your voice (high, low)?,	☐	☐	☐	☐	☐	☐
58. Can you control the volume of your voice?	☐	☐	☐	☐	☐	☐
59. Can you make your voice sound “natural” (so that is does, not sound like a deaf person’s voice)?	☐	☐	☐	☐	☐	☐
60. Are you able to hold a simple telephone conversation?	☐	☐	☐	☐	☐	☐

Code book

Domain	Question	Recoding (6 score)
Physical		
Basic sound perception	1, 7, 13, 19, 25, 31, 37, 42, 47, 52	
Advanced sound perception	3, 9, 15, 21, 27, 33, 56, 57, 58, 59	27
Speech production	5, 11, 17, 23, 29, 35, 40, 45, 50, 60	50
Psychological		
Self-esteem	4, 10, 16, 22, 28, 34, 39, 44, 49, 54	10, 16, 22, 34, 39, 49, 54
Social		
Activity limitations	6, 12, 18, 24, 30, 36, 41, 46, 51, 55	6, 12, 18, 24, 30, 36, 41, 46, 51, 55
Social interactions	2, 8, 14, 20, 26, 32, 38, 43, 48, 53	2, 8, 14, 20, 26, 38, 43, 48

References

Abdrabbou, Marwa F, Tucker, Denise A, Compton, Mary V, & Mankoff, Lyn. (2018). Quality of life and speech perception in two late deafened adults with cochlear implants. *Audiology Research, 8*(1).

Bennett, Rebecca J, Meyer, Carly J, Eikelboom, Robert H, Atlas, Julian D, & Atlas, Marcus D. (2018). Factors associated with self-reported hearing aid management skills and knowledge. *American Journal of Audiology, 27*(4), 604-613.

Boothroyd, Arthur. (2007). Adult aural rehabilitation: what is it and does it work? *Trends in Amplification, 11*(2), 63-71.

Castiglione, A., Benatti, A., Velardita, C., Favaro, D., Padoan, E., Severi, D., Pagliaro, M., Bovo, R., Vallesi, A., Gabelli, C., & Martini, A. (2016). Aging, cognitive decline and hearing loss: effects of auditory rehabilitation and training with hearing aids and cochlear implants on cognitive function and depression among older adults. *Audiology & Neuro-Otology, 21*(1), 21–28.

Fu, Q.J., & Galvin, J. J., 3rd. (2007). Perceptual learning and auditory training in cochlear implant recipients. *Trends in Amplification, 11*(3), 193–205.

Kwak, Chanbeom, Kim, Saea, You, Sunghwa, & Han, Woojae. (2020). Development of the hearing rehabilitation for older adults (hero) healthcare mobile application and its likely utility for elderly users. *International Journal of Environmental Research and Public Health, 17*(11), 3998.

LaRocque, Margaret, Hassan, Rajaa, Vidas, Silvia, Gagne, Jean-Pierre, & Parnes, Lorne S. (1991). Effectiveness of an intensive speech perception training program for adult cochlear implant recipients. *Annals of Otology, Rhinology & Laryngology, 100*(9).

Miller, Sharon, Zhang, Yang, & Nelson, Peggy. (2016). Neural correlates of phonetic learning in postlingually deafened cochlear implant listeners. *Ear and Hearing, 37*(5), 514-528.

Moberly, A., Vasil, K., Baxter, J., & Ray, C. (2018). What to do when cochlear implant users plateau in performance: A pilot study of clinician-guided aural rehabilitation. *Otology & Neurology, Inc., 39*(9), 794-802.

Moberly, A., Vasil, K., Baxter, J., Klamer, B., Kline, D., & Ray, C. (2020). Comprehensive auditory rehabilitation in adults receiving cochlear implants: A pilot study. *Laryngoscope Investigative Otolaryngology, 5(*5), 911-918.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLOS Medicine, 6*(7).

Moradi, Shahram, Wahlin, Anna, Hällgren, Mathias, Rönnberg, Jerker, & Lidestam, Björn. (2017). The efficacy of short-term gated audiovisual speech training for improving auditory sentence identification in noise in elderly hearing aid users. *Frontiers in Psychology, 8*, 368.

Okell, Elise, & Lind, Christopher. (2012). A conversation analytic view of continuous discourse tracking as a rehabilitative tool. *International Journal of Audiology, 51*(1), 43-53.

Plant, G., Bernstein, C., & Levitt, H. (2015). Optimizing performance in adult cochlear implant users through clinician directed auditory training. *Seminars in Hearing, 36*(4), 296-310.

Reis, M., Boisvert, I., Beedell, E., & Mumford, V. (2019). Auditory training for adult cochlear implant users: A survey and cost analysis study. *Ear and Hearing, 40*(6), 1445-1456.

Schumann, A., Liebscher, T., & Hoppe, U. (2015).Computer-based auditory phoneme discrimination training improves speech recognition in noise in experienced adult cochlear implant users. *International Journal of Audiology, 54*(3)*,* 190-198.

Shafiro, V. (2008). Development of a large-item environmental sound test and the effects of short-term training with spectrally-degraded stimuli. *Ear and Hearing, 29*(5), 775–790.

Smith, Sherri L, Saunders, Gabrielle H, Chisolm, Theresa H, Frederick, Melissa, & Bailey, Beth A. (2016). Examination of individual differences in outcomes from a randomized controlled clinical trial comparing formal and informal individual auditory training programs. *Journal of Speech, Language, and Hearing Research, 59*(4), 876-886.

Smith, Sherri L, & West, Robin Lea. (2006). The application of self-efficacy principles to audiologic rehabilitation: A tutorial. *American Journal of Audiology, 15*(1), 46-56.

Sweetow, Robert W, & Sabes, Jennifer Henderson. (2007). Technologic advances in aural rehabilitation: Applications and innovative methods of service delivery. *Trends in Amplification, 11*(2), 101-111.

van Besouw, Rachel M, Oliver, Benjamin R, Hodkinson, Sarah M, Polfreman, Richard, & Grasmeder, Mary L. (2015). Participatory design of a music aural rehabilitation programme. *Cochlear Implants International, 16*(3), 39-50.

West, R. L., & Smith, S. L., (2007) Development of a hearing-aid self-efficacy questionnaire. *International Journal of Audiology, 46,* 759-771. PMID: 18049965

Yu, Luodi, Rao, Aparna, Zhang, Yang, Burton, Philip C, Rishiq, Dania, & Abrams, Harvey. (2017). Neuromodulatory effects of auditory training and hearing aid use on audiovisual speech perception in elderly individuals. *Frontiers in Aging Neuroscience, 9*(30).

Zhang, M., Miller, A., & McNutt Campbell, M. (2014) Overview of nine computerized, home-based auditory-training programs for adult cochlear implant recipients. *Journal of the American Academy of Audiology, 25*(4).