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Review Article

Systematic Review of Auditory Training in Pediatric Cochlear Implant Recipients

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Objective: The purpose of this systematic review is to evaluate the published research in auditory training (AT) for pediatric cochlear implant (CI) recipients. This review investigates whether AT in children with CIs leads to improvements in speech and language development, cognition, and/or quality of life and whether improvements, if any, remain over time post AT intervention.
Method: A systematic search of 7 databases identified 96 review articles published up until January 2017, 9 of which met the inclusion criteria. Data were extracted and independently assessed for risk of bias and quality of study against a PICOS (participants, intervention, control, outcomes, and study) framework.
Results: All studies reported improvements in trained AT tasks, including speech discrimination/identification and working memory. Retention of improvements over time was found whenever it was assessed. Transfer of learning was measured in 4 of 6 studies, which assessed generalization. Quality of life was not assessed. Overall, evidence for the included studies was deemed to be of low quality.
Conclusion: Benefits of AT were illustrated through the improvement in trained tasks, and this was observed in all reviewed studies. Transfer of improvement to other domains and also retention of benefits post AT were evident when assessed, although rarely done. However, higher quality evidence to further examine outcomes of AT in pediatric CI recipients is needed.

Audibility or access to sound is only the first step of many that results in effective communication for hearing device users (Sweetow & Palmer, 2005). Kiessling et al. (2003) noted that audition is an essential component in aural communication, but it does not guarantee effective interaction. Instead, they suggested sequential stages that lead to successful communication, namely, hearing, listening, comprehension, and finally communication.

Cochlear implants (CIs) have been an extremely successful intervention for children with severe-to-profound hearing loss, helping to restore access to sound (Markman et al., 2011; Pulsifer, Salorio, & Niparko, 2003). However, large variability in auditory, speech, and language outcomes postimplantation has been observed (Kane, Schopmeyer, Mellon, Wang, & Niparko, 2004; Niparko & Blankenhorn, 2003; Niparko et al., 2010). Average speech recognition outcomes are reported to be similar across different CI systems; however, within-device variation can be large across individuals (Firszt et al., 2004), suggesting that observed variation is recipient dependent (Blamey et al., 2015; Finley et al., 2008). There are various factors that affect speech and language outcomes postimplantation. The main factors that have been identified for predicting word recognition scores in adult CI recipients are duration of deafness and duration of CI device use, where the shortest duration of deafness and longest CI device use lead to highest word recognition scores (Blamey et al., 1996; Friedland, Venick, & Niparko, 2003; J. T. Rubinstein, Parkinson, Tyler, & Gantz, 1999). For pediatric CI recipients, the main factors predicting CI outcomes are age of implantation, residual hearing before implantation, parent–child interactions, socioeconomic status (Niparko et al., 2010), and language acquisition status prior to cochlear implantation (prelingual or postlingual; Kane et al., 2004). Children with CI progressed exceptionally well when they were postlingualy deaf, implanted at younger age, had residual hearing before implantation, and belonged to supportive and highly motivated parents who were among the higher socioeconomic families. Other general factors predicting CI recipients' speech or language performance postimplantation include electrode coupling (Mens & Berenstein, 2005; Pfingst, Franck, Xu, Bauer, & Zwolan,

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2001), signal processing approach (Nogueira, Litvak, Saoji, & Buchner, 2015; Skinner et al., 2002; Wilson et al., 1988), quality of CI fitting (Holden, Vandali, Skinner, Fourakis, & Holden, 2005; Skinner, 2003), and age at implantation (Blamey et al., 1996; Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006). Other factors, known to vary across subjects but not yet shown to influence speech recognition ability significantly, include spiral ganglion cell survival (Khan et al., 2005; Nadol, Young, & Glynn, 1989; Seyyedi, Viana, & Nadol, 2014) or morphological changes in surviving ganglion cells (Briaire & Frijns, 2006), and compromised central pathways (Kral, Kronenberger, Pisoni, & O'Donoghue, 2016; Shepherd & Hardie, 2001; Shepherd, Hartmann, Heid, Hardie, & Klinke, 1997).

Some of these factors, such as CI-fitting approach and parameters for the sound-processing strategy, have the potential to be improved; however, other factors are out of the control of the clinician, for example, home language and family engagement. In addition, in some cases, the sound may be delivered through the auditory system, but the individual needs support to make effective use of the sound—and to this end, auditory training (AT) programs may help.

AT

AT is a sound-based habilitative intervention aimed at improving individuals' speech and hearing skills through varied listening exercises (Sweetow & Sabes, 2006). AT aims to teach the brain to make sense of sound contrasts through repetition and variation of stimuli together with effective feedback. In this way, the listener habitually learns to distinguish between sound contrasts (Schow & Nerbonne, 2007).

AT is a potential intervention that can be used to maximize benefit from hearing devices. Although hearing devices may help people with hearing loss to access sound, it cannot enhance their ability to listen and comprehend what they hear. Changes in brain organization to some extent can lead to improvements over time, but the rate of change and potentially the maximum level of performance achieved can be modified with AT (M. Sharma, Purdy, & Kelly, 2009). Outcomes of AT have been assessed by measuring improvement in trained tasks and by improvement in different tasks that were not included in the training session. A review of AT research in adult CI users reported improvements in trained tasks; however, generalization of the trained tasks to other learning domains that were not targeted within an intervention and retention of any benefits thereafter remain unproven (Henshaw & Ferguson, 2013).

Analytic (Bottom-Up) and Synthetic (Top-Down)

Approaches of AT are mainly divided into two types, bottom-up (analytic) and top-down (synthetic). The analytic approach uses a context-free acoustic–phonetic signal (it trains the listener to decode the speech signal without any context, such as syllabic structure, vowels, and initial consonant difference), whereas the synthetic approach relies on the listeners' linguistic knowledge (e.g., semantic, syntactic, lexical, and phonological) to fill in the gaps in the sensory information provided by their hearing device. An example of synthetic AT includes connected discourse tracking (De Filippo & Scott, 1978).

One of the earliest studies in AT (A. Rubinstein & Boothroyd, 1987) where a group of adults with mild–moderate sensorineural hearing loss received only synthetic training and another group received both synthetic and analytic training reported that the inclusion of analytical training did not lead to further improvement in listening skills since a significant improvement was found with synthetic training alone. Furthermore, Sweetow and Palmer (2005) reviewed studies between 1970 and 1996 to evaluate AT in adults with hearing loss and assessed its effectiveness in improving communication and concluded that synthetic training could enhance speech recognition abilities, whereas the effectiveness of analytic training was not clear. Contrary to such views, Fu and colleagues (Fu & Galvin, 2008; Fu, Galvin, Wang, & Nogaki, 2004; Galvin, Fu, & Shannon, 2009; Zhang, Dorman, Fu, & Spahr, 2012) conducted many experiments using analytic training approaches with adults with CIs and demonstrated significant improvements in the subjects' phonemic contrast scores and word recognition after training. Recent evidence recommends combining the two approaches to achieve maximum benefit (Amitay, Irwin, & Moore, 2006). Tye-Murray et al. (2012) used both approaches for AT with stimuli ranging from basic phonemic discrimination to comprehension of extended passages, and they reported significant improvement in all trained tasks. Overall, a trend toward combining analytic and synthetic training is evolving throughout the literature as a means to achieve maximum benefit from this intervention.

Trained Task Performance and Generalization of Benefits

Reports of improvement in trained tasks post AT intervention in both hearing aid and CI users are positive. Henshaw and Ferguson (2013) systematically reviewed AT studies published from 1996 up to 2011 for adults with hearing loss. Their review stated that improvement in trained tasks was consistently reported whenever they were assessed. However, only one study, which trained adult CI recipients, reported a trend in improvement for one of their trained tasks, and no significant improvement for the other (Stacey et al., 2010).

Reports of learning transfer or generalization of benefits post AT are varied. Henshaw and Ferguson (2013) reported a significant but small improvement in generalization of learning to untrained measures, including speech intelligibility, cognition, and self-reported hearing abilities. For example, Burk, Humes, Amos, and Strauser (2006) reported that word training programs generalized to improvements in untrained words and to untrained speakers of trained words but did not generalize to trained words used in sentences. Zhang et al. (2012) also reported posttraining improvements in the intelligibility of untrained vowels, consonants, and words, but not in untrained sentences; the degree of improvement was larger in subjects with normal hearing compared to those with hearing loss. When training communication strategies along with syllable recognition, Kricos and Holmes (1996) observed improved performance post active listening training, and skills were transferred to speech-in-noise conditions that were not included in the training. Communication strategies that were included in the training program include encouraging active listening, showing interest while others are talking, using eye contact and body language, filling in the gaps for words not heard clearly based on the context of the conversation, replying with a statement summarizing whatever the speaker said, and accepting corrections readily.

Retention of Benefits Post AT

Retention of benefits or maintaining improvements over time is measured by comparing the performance of the subjects at baseline and after the training regimen has ceased on trained tasks and/or nontrained tasks. Henshaw and Ferguson (2013) indicated that eight of the 13 articles that were reviewed assessed retention at follow-up assessments ranging from 4 days to 7 months posttraining. For instance, Burk et al. (2006) reported that word recognition performance was significantly improved 6 months after training compared to baseline, whereas Oba, Fu, and Galvin (2011) reported sustained performance on digit recognition up to 1 month posttraining. In addition, Stecker et al. (2006) and Burk and Humes (2008) reported significant improvements on the Nonsense Syllable Test (Dubno & Levitt, 1981) and both easy and hard real-word recognition tests up to 7 weeks post AT.

Retention was not only limited to trained tasks; it was also measured in other tasks that were not included in the training intervention. For example, Sweetow and Sabes (2007) reported that posttraining improvements were maintained for all measures including Quick Speech-in-Noise Test (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004), Hearing-in-Noise Test (Nilsson, Soli, & Sullivan, 1994), Hearing Handicap Inventory for the Elderly (Ventry & Weinstein, 1982), Hearing Handicap Inventory for Adults (Newman, Weinstein, Jacobson, & Hug, 1990), and the Communication Scale for Older Adults (Kaplan, Bally, Brandt, Busacco, & Pray, 1997) questionnaires up to 4 weeks posttraining. However, this improvement can be attributed to test–retest effect as alluded to by the authors. In a different study, Oba et al. (2011) controlled for this confound by comparing subjects' performance immediately posttraining and at 4 weeks follow-up and reported no significant change. Therefore, Oba et al. suggested that subjects improved performance in the Hearing-in-Noise Test, and Institute of Electrical and Electronics Engineers (1969) sentences in steady noise and in a multitalker babble were a clear evidence of AT retention.

Brain Plasticity as Evidence of AT

Neuroplasticity changes have been investigated as evidence of AT and have shown that neural pathways and synapses can be affected by training. In fact, studies have shown that neural responses to sound change through rigorous listening (Tremblay, Kraus, McGee, Ponton, & Otis, 2001; Tremblay, Shahin, Picton, & Ross, 2009), suggesting that AT may optimize neural activation and, in turn, improve auditory perception and listening skills and reduce functional deficits (Kraus & Chandrasekaran, 2010).

The question is which parts of the brain are being affected by AT? Electroencephalography and magnetoencephalography have been used to explain how AT exercises might affect the brain. These techniques determine the time course and the occurrence of cortical and subcortical modulations as a response to a stimulus, which is related to the particular AT goal (Barrett, Ashley, Strait, & Kraus, 2013; Brattico, Tervaniemi, & Picton, 2003; Shahin, 2011; Tremblay, Inoue, McClannahan, & Ross, 2010; Tremblay et al., 2009).

The P1–N1–P2 waves of the cortical auditory evoked potential response measured with electroencephalography consistently showed increased gain in P2 amplitude post AT (Kühnis, Elmer, Meyer, & Jäncke, 2013; Kuriki, Ohta, & Koyama, 2007; Seppänen, Hämäläinen, Pesonen, & Tervaniemi, 2012; Shahin, Bosnyak, Trainor, & Roberts, 2003). Despite the emerging evidence that improved perception is reflected by increased amplitude of the P2 wave of the P1–N1–P2 complex, not much is known about the neural generators of the auditory P2 response. Ross and Tremblay (2009) showed that the center of activity for P2 to be in the anterior auditory cortex, but how it relates to learning is still unidentified (Tremblay, Ross, Inoue, McClannahan, & Collet, 2014).

Other studies have examined P1 cortical auditory evoked potential latencies in relation to cortical maturation in response to sound (Bauer, Sharma, Martin, & Dorman, 2006; Ponton, Don, Eggermont, Waring, & Masuda, 1996). The auditory thalamic and cortical sources generate P1 responses that vary with chronological age. Accordingly, P1 latency has been used to infer the maturational status of auditory pathways (Bauer et al., 2006; A. Sharma et al., 2005). The rapid decrease in P1 latency post cochlear implantation is speculated to reflect central auditory plasticity (A. Sharma, Dorman, & Spahr, 2002; A. Sharma, Dorman, Spahr, & Todd, 2002; A. Sharma et al., 2004).

Anderson and Kraus (2013) established that there are brain plasticity changes in two distinct ways: short- and long-term plasticity. Language reflects long-term plasticity, whereas AT exercises relate to short-term plasticity. Jeng et al.'s (2011) study investigated the difference between Chinese and American speakers' pitch representation at the level of the brainstem. The study revealed that brainstem encoding of linguistic pitch contours was enhanced in Chinese adults compared to American adults reflecting the outcome of long-term linguistic experience in each group. The study also suggested that tuning features of neurons along the pitch axis with enhanced sensitivity to linguistically relevant variations in pitch are sharpened by long-term experience (Krishnan, Xu, Gandour, & Cariani, 2005). Another example of neuroplasticity is bilingualism. Krizman, Marian, Shook, Skoe, and Kraus (2012) showed that a greater brainstem encoding of the fundamental frequency (F0), a feature known to underlie pitch perception and grouping of auditory objects, was greater in bilinguals compared to monolinguals.

An example of short-term brain plasticity has been observed in musical training programs. Growing evidence, especially for listeners with normal hearing, suggests that intersecting networks in the brain process acoustic features heard in music and speech. This suggests that musical training may generalize to neural encoding of speech, language, and music (Anvari, Trainor, Woodside, & Levy, 2002; Besson, Schön, Moreno, Santos, & Magne, 2007; Herholz & Zatorre, 2012; Kraus, Skoe, Parbery-Clark, & Ashley, 2009; Patel, 2011). In deaf children, a recent study showed evidence of improvements in executive function following a 5-week music training intervention (Manson, 2017). Further evidence confirmed that music skills significantly correlate with phonological awareness and reading (Anvari et al., 2002; Culp, 2017). It was proposed that actively listening to music by utilizing greater perceptual demands might further fine-tune the auditory system (Herholz & Zatorre, 2012; Ingvalson & Wong, 2013; Patel, 2011). Not only listening to music but also exploration of sound and singing was linked to improved pitch discrimination, speech perception in noise, and singing competency in children with normal hearing and children with hearing loss (Welch et al., 2015).

Research Aims

The primary aim of this systematic review was to investigate whether AT is effective at improving performance scores for pediatric CI recipients. Performance measures were considered for speech and language, cognition, and quality of life abilities. Secondary aims were to evaluate the impact of different AT approaches (analytic vs. synthetic) and to determine if improvements generalize to untrained tasks and assess the retention of benefit post AT. Ultimately, outcomes of this review will potentially help clinicians to make informed decisions related to AT with pediatric patients using CIs and provide researchers with the latest AT findings for pediatric CI recipients (see Appendix A).

Method

A systematic review protocol was prepared and registered with PROSPERO (2017: CRD42017057346), the international prospective register of systematic reviews. Inclusion and exclusion criteria were established based on the PICOS (participants, intervention, control, outcomes, and study) designs strategy (Richardson, Wilson, Nishikawa, & Hayward, 1995; see Appendix B).

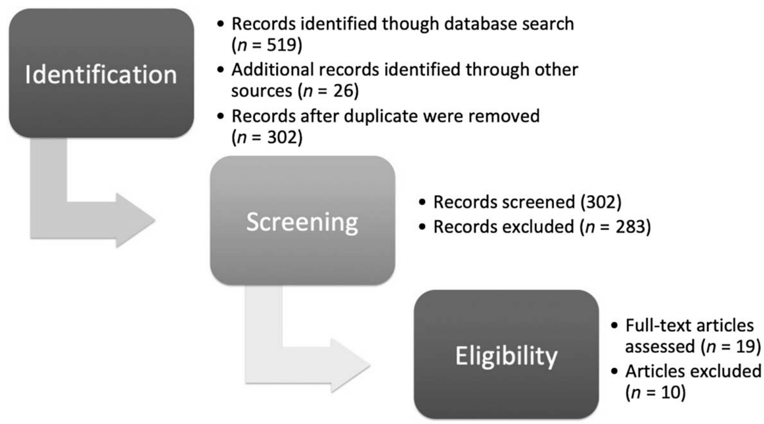
Methods for the review were clearly stated in advance of the review and followed to ensure transparency and to avoid bias. The search was conducted using seven electronicbibliographic databases: MEDLINE, EMBASE, The Cochrane Library (Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Cochrane Methodology Register), CINAHL, Scopus, PubMed, and Web of Science (Science and Social Science Citation Index). Only studies published in English were included with no publication period restrictions. Study designs that were included in this review were randomized controlled trials (RCTs), non-RCTs, cohort studies with control, or repeated measures. All AT interventions involving human or computer-based delivery in clinic, home, school, or laboratory were included. Keywords used included *cochlear implant*, *cochlear prosthesis*, *auditory training*, *auditory learning*, and *rehabilitation*.

To minimize the risk of bias, two of the authors independently extracted and analyzed the data based on several measures, including randomization, blinding, controls, power calculation, selective reporting of outcome measures, training feedback, participants' self-assessment, and generalization of improvements if any. The third author was the moderator who reviewed the extracted and analyzed data and discussed any inconsistencies or concerns. All retrieved review articles went through three main stages: identification, screening, and eligibility assessment. A total of 96 articles were extracted from the selected databases and from references therein. After removing duplicates, review articles, and studies addressing different outcomes, only 19 remained. The 19 articles were carefully reviewed, and only nine matched the PICOS criteria and were included in the review. The other 10 articles (Barton & Robbins, 2015; Chen et al. 2010; De Bruyn et al., 2011; Fu, Galvin, Wang, Wu, 2015; Kant & Adhyaru, 2009; Perin da Siliva, Comerlatto Junior, Andreoli Balen, & Bevilacqua, 2012; Rochette & Bigand, 2009; Rochette, Moussard, & Bigand, 2014; Vongpaisal, Caruso, & Yuan, 2016; Zhou, Chai Sim, Tan, & Wang, 2012) were not included in this review due to failing to meet the inclusion criteria, including irrelevant outcome measure, study design, or lack of controls. The articles were further evaluated and graded to assess their levels of evidence and control for bias (see Figure 1).

Quality of the Articles

All the selected studies were evaluated and graded to assess their levels of evidence following the guidelines from the 2004 Grading of Recommendations Assessment, Development and Evaluation Working Group guide (see Appendix C; Atkins et al., 2004). Measures and criteria used in assessing the quality of the studies were adopted from Henshaw and Ferguson (2013). The level of evidence of each study was established based on a sum of scores that was given to each category within the general scientific measures and AT-specific measures. General scientific measures include looking at the approaches for randomization and control groups and explanation of the power calculation,

Figure 1. Process of review articles selection.



blinding, and outcome measure reporting. AT-specific measures include looking at the applicability of outcome measures selection, providing training feedback, assessing ecological validity (i.e., the location where AT was conducted, e.g., in the home, which better represents normal listening environment compared to an unnatural laboratory setting), complying with training protocols, and assessing retention of improvements. The score for each measure is either 0, 1, or 2. A score of 0 indicates faulty or lack of information to make an informed judgment, a score of 1 indicates weak information or absence of detail, and a score of 2 refers to proper use and comprehensive reporting. Scores for each study were summed to produce an individual study quality score, which is used to convey the level of evidence credited to each study. A low level of evidence indicates that the results of the study are not repeatable, whereas a high level of evidence suggests greater confidence in the findings (Henshaw & Ferguson, 2013).

Synthesis of Results

All the extracted data, including study design, participant details, training protocol, outcome measures, and main findings, were tabulated; then, a summarized table was produced to answer the research questions, assess levels of evidence, quality of research, and bias. Ideally, combined data would be subjected to a meta-analysis, but as there was no commonality across studies for training stimuli, training protocols, and outcome measures, it meant that this was not possible.

Results

The analyzed studies and their findings were summarized in two tables. Table 1 describes the study design (design, number of subjects, participants' age, and training location), training stimuli, frequency of training sessions, outcome measures, and main findings. Table 2 summarizes the main findings, including improvement, retention, generalization of learning, and compliance.

Characteristics of the Studies

The participants in all of the studies were children with severe-to-profound hearing loss. Seven of the nine studies included only children with CIs or bimodal devices (CI and hearing aid), and only two studies (Welch et al., 2015; Wu, Yang, Lin, & Fu, 2007) included both children with CIs and bimodal devices and children using hearing aids. Overall, the studies represented results from 89 CI and bimodal users and six hearing aid users. Although our initial inclusion criteria were restricted to studies with CI users, it was necessary to relax this criterion to include a larger group of review articles for analysis.

Participant sample sizes ranged from nine subjects (Kronenberger, Pisoni, Henning, Colson, & Hazzard, 2011) to 29 subjects (Welch et al., 2015; M = 19.67, SD = 7.03). Only three studies utilized a repeated-measures design (Kronenberger et al., 2011; Welch et al., 2015; Wu et al., 2007), and only one study (Welch et al., 2015) included children with normal hearing as a control group. The remaining studies utilized non–repeated-measures design that used two independent groups, one as an experimental group and the other as a control group. There were two RCTs (Ingvalson, Young, & Wong, 2014; Roman, Rochette, Triglia, Schön, & Bigand, 2016), four non-RCTs (Good et al., 2017; Hagr et al., 2016; Mishra, Boddupally, & Rayapati, 2015; Yucel, Sennaroglu, & Belgin, 2009), and three repeated measures (Kronenberger et al., 2011; Wu et al., 2007; Welch et al., 2015).

Quality of the Studies

Quality of the studies in addition to their level of evidence is listed in Table 3. Scores for each study were calculated based on a number of scientific measures and AT-specific measures. The scientific measures include randomization, controls, power calculation, blinding, and

Table 1. Summary of the extracted data from the nine included studies.

Study		Participants		Training					Findings		
References	Design	*n*	Age	Stimuli	Skills trained	Frequency and duration	Place of training	Outcome measures	Improved?	Retention	Generalization
Good et al. (2017)	Non-RCT	9 CI EG/ 9 CI CG	6–15 years	Piano training (musical theory and technical exercises and learning a song)	Music theory and technical exercises scales (bilateral finger control and hand positions; learning a song)	24 Sessions; private half an hour lesson per week for 24 weeks for 6 months	Lab	– Montréal Battery for Evaluation of Musical Abilities (Peretz et al., 2013) – Perceived Emotional Prosody Based on Diagnostic Analysis of Nonverbal Accuracy Scale (Nowicki & Duke, 1994)	Not assessed (purpose was to investigate generalization not trained task)	Not assessed	Yes
Hagr et al. (2016)	Non-RCT	13 CI EG/ 13 CI CG	3–7 years	Detection of Ling sounds, environmental sounds, and phrases; discrimination between intensity, duration, pitch, or intonation stress; rhythm and rate; discrimination of vowels, consonants, and number of syllables in words	Sound detection and discrimination using Rannan software	1 hr of weakly speech therapy + extra 1 hr of AT using Rannan weekly (in a different day) for 12 months	PC based in clinic	– Listening Progress Profile (Nikolopoulos et al., 2000) – The Infant–Toddler Meaningful Auditory Integration Scale (Zimmerman-Phillips et al., 2001)	Yes	Not assessed	Not assessed

(*table continues*)

Table 1. *(Continued)*.

Study		Participants		Training					Findings		
References	Design	*n*	Age	Stimuli	Skills trained	Frequency and duration	Place of training	Outcome measures	Improved?	Retention	Generalization
Ingvalson et al. (2014)	RCT	10 CI EG/ 9 CI CG	4–7 years	Recalling and sequencing environmental and speech sounds in quiet and noise; matching phonemes to graphemes; identifying and discriminating between phonemes; recalling sequence of drumbeats, speech sounds, syllables, and phonemes; blending words, syllable	Phonological awareness skills and auditory working memory	Interactive exercises, 75 min of training per week for 4 weeks	PC based in school	– Expressive One-Word Picture Vocabulary Test (Martin & Brownell, 2011) – Receptive One-Word Picture Vocabulary Test (Martin & Brownell, 2011) - Oral Written Language Scales (OWLS; Carrow-Woolfolk, 2008)	Yes	Not assessed	Not assessed
Kronenberger et al. (2011)	Repeated measures	9 CI	7–15 years	Cogmed working memory involving auditory, visuospatial, or combined short-term and working memory skills	Working memory	30–40 min per day for 5 days a week for 5 weeks	PC based at home	– Digits forward and backward – Spatial span forward and backward BRIEF: – Sentence repetition	Yes	yes (all working memory and Language for 1 month and language only up to 6 months)	Yes (working memory to language processing)
Mishra et al. (2015)	Non-RCT	13 CI EG/ 14 CI CG	5–12 years	Adaptive speech (numbers) in noise recognition in a white/ speech noise (Angel Sound)	Speech in noise	2 sessions 40 min per day for 6 days a week for 5 weeks	PC based at home	– Numbers in white noise – Number in speech-shaped noise (trained) – Digit triplets in speech-shaped noise (untrained)	Yes	Yes for up to 3 weeks	Near transfer but not far transfer

(*table continues*)

Table 1. *(Continued)*.

Study		Participants		Training					Findings		
References	**Design**	***n***	**Age**	**Stimuli**	**Skills trained**	**Frequency and duration**	**Place of training**	**Outcome measures**	**Improved?**	**Retention**	**Generalization**
Roman et al. (2016)	RCT	10 CI EG/ 9 CI CG	4–10 years	Environmental sound, music, voices, and abstract	Auditory cognitive processing (identification, discrimination, ASA, and auditory memory)	30 min per 1 session per week for 20 weeks	Sound in hand instrument; in clinic/lab	– Same as training stimuli but different sets used only as outcome measures	Yes in all except ASA	Yes	Yes (phoneme discrimination)
Welch et al. (2015)	Non-RCT	12 9 CI/3 HA/ 17 NH	5–7 years	Singing exercises vocal explorations; tongue twisters; explorations in visual imagery for sound, sound imagery, and metaphor	Singing and vocal exploration	Once a week for 20 weeks	School	– Singing competency profile *Sing Up* (Welch et al., 2014) – Chord pitch discrimination test – Speech perception in noise	Yes, but not speech in noise	Not assessed	Not assessed
Wu et al. (2007)	Repeated measures	7 CI/3 HA	5–11 years	Discrimination task, trained to identify final vowels. Discriminating between phonemes. For vowels, acoustic speech features included (F1 and F2) and duration	Identification and discrimination of speech sound	30 min per 1 session 5 days a week for 10 weeks	PC based at home	– Vowel and consonants discrimination – Chinese tone recognition	Yes	Yes for 2 months	Not assessed

(*table continues*)

Table 1. *(Continued)*.

Study		Participants		Training					Findings		
References	Design	*n*	Age	Stimuli	Skills trained	Frequency and duration	Place of training	Outcome measures	Improved?	Retention	Generalization
Yucel et al. (2009)	Non-RCT	9 CI EG/ 9 CI CG	36–96 months	Pitch discrimination task; rhythm discrimination and sequence repetition	Child listening to different pairs of notes using electronic keyboard	10 minutes daily for 2 years post CI activation	Keyboard at home	– Music: developed questionnaire – Meaningful Auditory Integration Scale (MAIS; Robbins, Renshaw, & Berry, 1991) and Meaningful Use of Speech Scale (MUSS; Robbins & Osberger, 1994) – Phonetic discrimination – Word identification – Comprehension of simple auditory instructions – Sentence repetition	Yes	Yes	No (no transfer to speech)

Note. RCT = randomized controlled trial; EG = Experimental group; CG = Control group; AT = auditory training; CI = cochlear implant; ASA = auditory scene analysis.

Table 2. Summary of the main research findings.

Study	Findings				
Authors	**Outcome measures**	**Improved trained skills**	**Retention**	**Generalization**	**Reporting compliance**
Good et al. (2017)	– Montréal Battery for Evaluation of Musical Abilities (Peretz et al., 2013) – Perceived Emotional Prosody Based on Diagnostic Analysis of Nonverbal Accuracy Scale (Nowicki & Duke, 1994)	The purpose of the study was to investigate generalization not trained task	Not assessed	Yes	Not explicitly reported but can be deduced
Hagr et al. (2016)	– Listening Progress Profile (Nikolopoulos et al., 2000); – The Infant–Toddler Meaningful Auditory Integration Scale (Zimmerman-Phillips et al., 2001)	Yes	Not assessed	Not assessed	Not reported
Ingvalson et al. (2014)	– Expressive One-Word Picture Vocabulary Test (Martin & Brownell, 2011) – Receptive One-Word Picture Vocabulary Test (Martin & Brownell, 2011) – Oral Written Language Scales (Carrow-Woolfolk, 2008)	Yes	Not assessed	Not assessed	Not explicitly reported but can be deduced
Kronenberger et al. (2011)	– Digits forward and backward – Spatial span forward and backward BRIEF: – Sentence repetition	Yes	Yes (all working memory and Language for 1 month and language only up to 6 months)	Yes (working memory to language processing)	Not explicitly reported but can be deduced
Mishra et al. (2015)	– Numbers in white noise – Number in speech-shaped noise (trained) – Digit triplets in speech-shaped noise (untrained)	Yes	Yes for up to 3 weeks	Near transfer but not far transfer	Explicitly reported
Roman et al. (2016)	– Same as training stimuli but different sets used only as outcome measures	Yes, in all except auditory scene analysis	Not assessed	Yes (phoneme discrimination)	Not explicitly reported but can be deduced
Welch et al. (2015)	– Singing competency profile Sing *Up* (Welch et al., 2014) – Chord pitch discrimination – Speech perception in noise	Yes, but not speech in noise	Not assessed	No transfer to speech	Not explicitly reported but can be deduced
Wu et al. (2007)	– Vowel and consonants discrimination – Chinese tone recognition	Yes	Yes for 2 months	Not assessed	Not reported
Yucel et al. (2009)	– Music: developed questionnaire – Meaningful Auditory Integration Scale (MAIS; Robbins et al., 1991) and Meaningful Use of Speech Scale (MUSS; Robbins & Osberger, 1994) – Phonetic discrimination – Word identification – Comprehension of simple auditory instructions – Sentence repetition	Yes (only trained)	Not assessed	No transfer to speech	Not reported

Table 3. Level of evidence and quality of studies.

	Scientific study validity criteria					Training-specific study validity criteria						
Article	**Randomization**	**Control group**	**Power calculation**	**Blinding**	**Outcome measure reporting**	**Outcome measure selection**	**Training feedback**	**Ecological validity**	**Reporting of compliance**	**Follow-up**	**Study quality score**	**Level of evidence**
Good et al. (2017)	1	2	0	0	2	1	0	1	1	0	8	Low
Hagr et al. (2016)	0	1	0	1	2	1	2	1	0	0	8	Low
Ingvalson et al. (2014)	1	1	0	0	2	2	2	1	1	0	10	Low
Kronenberger et al. (2011)	0	0	0	0	2	2	0	2	1	2	9	Low
Mishra et al. (2015)	1	1	0	1	2	1	2	2	2	1	13	Moderate
Roman et al. (2016)	1	1	0	0	2	1	0	1	1	0	7	Low
Welch et al. (2015)	0	1	0	0	2	2	1	1	1	0	8	Low
Wu et al. (2007)	0	0	1	0	2	1	2	2	0	2	10	Low
Yucel et al. (2009)	0	1	0	0	2	2	0	2	0	0	7	Low

outcome measure reporting, whereas AT-related measures include generalization of learning, outcomes used, evaluation of functional benefit in real-world listening, training feedback, ecological validity measurement of compliance with training protocols, and long-term follow-up of improvements. This rigorous evaluation revealed that the level of evidence of all studies but one (Mishra et al., 2015) were low. A major factor affecting the quality of the studies was failing to meet the requirements for randomization, power calculation, and/or blinding. An attempt to randomize was evident in four studies (Good et al., 2017; Ingvalson et al., 2014; Mishra et al., 2015; Roman et al., 2016), blinding in two studies (Hagr et al., 2016; Mishra et al., 2015), and power calculation in one study (Wu et al., 2007). In addition, lack of follow-ups post AT program (Hagr et al., 2016; Ingvalson et al., 2014; Roman et al., 2016; Welch et al., 2015; Yucel et al., 2009), report of compliance (Hagr et al., 2016; Wu et al., 2007; Yucel et al., 2009), and training feedback (Good et al., 2017; Kronenberger et al., 2011; Roman et al., 2016; Yucel et al., 2009), which were evident across the studies, further reduced the overall quality score. Moreover, the lower scores of the quality of studies increased the risk of bias; such findings may degrade the confidence of clinicians when recommending AT to their patients.

Trained Skills and Outcomes of AT

Trained skills included working memory, speech perception, music, pitch and rhythm discrimination, and environmental sounds. Benefits of AT were clearly illustrated through the improvement of all trained tasks across all nine studies regardless of the duration of training, which ranged from 4 weeks (Ingvalson et al., 2014) up to 2 years (Yucel et al., 2009), or type of training.

Working Memory With or Without AT

Two studies used auditory and/or cognitive training materials, where AT focused on phonological awareness skills (Ingvalson et al., 2014) and cognitive training focused on training working memory skills (Ingvalson et al., 2014; Kronenberger et al., 2011). Kronenberger et al. (2011) used Cogmed Working Memory Training (Klingberg et al., 2005; http://www.cogmed.com) to assess its effectiveness for improving memory and language skills in children with CIs. Cogmed is a computer-based program that exercises auditory and visuospatial memory or combined auditory–visuospatial short-term and working memory. The training led to an improved performance on most training exercises, including verbal and nonverbal working memory tasks. Even though improvement in working memory decreased after 1 month at follow-up, sentence repetition continued to show improvement up to 6 months. Such improvement that remained over a period of time post AT intervention led the authors to suggest that working memory training might improve aspects of memory and language in children with CIs, but of course, it is hard to tease apart the specific effects due to working memory and visuospatial awareness.

Ingvalson and Wong (2013) used Earobics (Cognitive Concepts, 1997), which trains both phonological awareness and working memory skills simultaneously through exercises for matching phonemes to graphemes; identifying target phonemes as initial, medial, or final; recalling a sequence of drumbeats; identifying sound, phoneme, syllable, and rhyme; and recognizing speech perception in noise. The group of children who received the training showed significant gains on language measures postintervention, whereas the control group did not. The authors suggested that phonological and working memory training in children with CIs may lead to improved language performance, but it is hard to determine which aspects of the training were most influential.

Speech Stimuli and Environmental Sounds

Three of the nine studies used speech stimuli (in quiet and/or noise) to improve speech perception skills. Tasks were focused on detection, discrimination, and identification of speech sounds/words (Hagr et al., 2016); identification and discrimination of phonemes, vowels, and constants (Wu et al., 2007); and recognition of digits in noise (Mishra et al., 2015).

Wu et al. (2007) investigated the impact of computer-assisted speech training on speech recognition performance of Mandarin-speaking children with hearing impairment. Training stimuli included discriminating between phonemes and acoustic speech features in vowels (first and second formant frequencies and duration) and consonants (e.g., voice, manner, and place of articulation). Children receiving the intervention showed significant improvements in vowel, consonant, and tone recognition. The authors suggested that moderate amounts of AT led to improvements in speech understanding in children with hearing loss.

Mishra et al. (2015) evaluated training speech-in-noise skills in children with CIs in which training used adaptive speech (mainly numbers) in a white/speech-shaped noise. The speech-in-noise recognition training used a customized version of “Angel Sounds” (Version 5.08.01, Emily, Shannon, Fu Foundation). Speech-in-noise performance improved in the group that received the intervention compared to the control group. The authors concluded that AT improves speech-in-noise performance in children with CIs.

In another group of children, Hagr et al. (2016) assessed the effectiveness of “Rannan,” an AT program developed for Arabic-speaking children with CIs. The software provides computer-based exercises for sound detection and discrimination skills. Namely, sound detection exercises use Ling sounds, environmental sounds, and phrases. In addition, suprasegmental discrimination exercises include stimuli that differ in intensity, duration, pitch, or intonation/stress/rhythm and rate, whereas segmental discrimination and association exercises include discrimination of words that differed in vowels, consonants, and number of syllables and similar words were also available. The study showed that the group who received the Rannan computerized training intervention, in addition to the basic aural rehabilitation program, scored significantly higher on the Infant–Toddler Meaningful Auditory Integration Scale parent questionnaire

(Zimmerman-Phillips, Osberger, & Robbins, 2001) and Listening Progress Profile (Nikolopoulos, Wells, & Archbold, 2000) compared to control.

Music, Pitch and Rhythm Discrimination, and Environmental Sounds

Four studies used nonspeech stimuli such as environmental sounds and music. Roman et al. (2016) assessed the impact of training on four main areas of auditory cognitive processing, namely, identification, discrimination, auditory memory, and auditory scene analysis (ASA) in children with CI using "sound-in-hand" apparatus (Rochette & Bigand, 2009). Sound in hand is a tool that looks like a mini keyboard but was specifically developed to assess different auditory cognitive skills. In the identification task, the subject listens to one sound and has to find the key that corresponds to it. In the discrimination task, the subject listened to a continuous sound that can be modified by changing its pitch or duration, and the subject determined if it is the same or different. In the auditory memory task, the subject is asked to imitate or recall a sequence of sound. In the ASA task, the subject is familiarized with elements of the auditory scene and then listened to a continuous auditory scene consisting of two or three different sources. Surreptitiously, removing one or two elements modifies the auditory scene, and the subject has to identify the change that occurred. The authors reported a significant improvement in the identification, discrimination, and auditory memory tasks, but not in the ASA task in the experimental group compared to the control group. In addition, improved performance was also transferred to phonetic discrimination skills.

Good et al. (2017) assessed the impact of music training (individual piano lessons) on various aspects of auditory processing in children with CIs. The study aimed to assess generalization of music training to other learning domains rather than assessing improvements of trained tasks. The children received individual piano lessons, which involved music theory and hands-on techniques such as playing musical scales, learning finger control, and hand position. In addition, subjects learnt a new song and rehearsed it. The authors reported improved scores on discrimination of melodic contour, rhythm, and memory for melodies in the experimental group compared to the control group. These improved skills were also transferred to improved emotional speech prosody perception.

In a slightly younger group of children, Yucel et al. (2009) trained pitch and rhythm perception and assessed the impact of training on speech perception. The musical training program used electronic keyboards to improve pitch and rhythm discrimination and familiar melody recognition. By the end of the 2-year follow-up, the experimental group had developed more rapidly than the control group in all aspects of musical skills assessed; a positive trend was noted for an improvement in open-set speech perception scores for the experimental group, but the difference between the groups did not reach significance.

Finally, Welch et al. (2015) offered 20 weekly sessions of singing and vocal exploration training. Normal hearing children and children with hearing impairment participated together in training exercises, which aimed to teach them simple songs with actions, descending/ascending pitch glides, contrasting vocal timbres, explorations in visual imagery for sound, and mimicry of vocal patterns. The training had a positive impact on participants' singing skills in terms of accuracy of singing simple songs as measured using the England National Singing Scale (Welch, Saunders, Papageorgi, & Himonides, 2012). Overall, pitch perception also improved measurably over time for children, particularly for those with hearing loss. Findings imply that sustained age-appropriate musical activities can benefit all children, regardless of hearing status.

Retention of Improved Performance

Retention of benefits or sustaining of improvements is measured by comparing the performance of the subjects at baseline and after the training regimen has ceased on trained tasks and/or nontrained tasks. Mishra et al. (2015) investigated retention of improvements after training children with CI to recognize numbers in white noise and in speech-shaped noise, and subjects showed retained improvements up to 3 weeks post AT intervention. Kronenberger et al. (2011) also assessed the benefits of retention post working memory training in children with CI. Although language was not the focus of the training, retention of improvement in speech measures was retrained for up to 6 months, whereas retention in working memory measure was retained for up to 1 month posttraining. Wu et al. (2007) trained discrimination of phonemes and acoustic speech features in vowels (first and second formant frequencies and duration) and consonants (e.g., voice, manner, and place of articulation). The authors reported retention of improvement in all measures assessed (vowel, consonants, and Chinese tone recognition) for up to 2 months posttraining.

Generalization and Transfer of Learning

Four of the six studies, which assessed generalization, reported transfer of learning to other skills. Good et al. (2017) demonstrated a transfer of learning from music training to emotional speech prosody perception. Accordingly, the authors concluded that music training can be an effective tool to be integrated in auditory rehabilitation plan post cochlear implantation. Roman et al. (2016) showed a transfer of learning from identification and discrimination of nonspeech stimuli such as environmental sounds and music to phonetic discrimination skills. Mishra et al. (2015) reported "near transfer" as learning effects were established and generalized to similar but untrained conditions. The trained tasks included number recognition in white noise, whereas the untrained task consisted of digit triplets in speech-shaped noise. Kronenberger et al. (2011) also observed generalization of learning from improved working memory skills to improved language processing skills post working memory training. The two studies that did not observe generalization of learning from music training to speech perception (Welch et al., 2015; Yucel et al., 2009) were both pilot studies. Yucel et al. (2009) observed a transfer of learning in one of the speech measures but not in the other. Welch et al. (2015) did not report any transfer of learning, but the authors acknowledged that resources were insufficient to allow focused singing training with children with hearing loss, and participants were a heterogeneous mix of CI users, hearing aid users, and children with normal hearing.

AT Approaches

Analytic (bottom-up) and synthetic (top-down). When assessing the approaches of AT across the studies, we found that four studies used both analytic and synthetic approaches, and others used either one or the other. For instance, Mishra et al. (2015) used a combination of both analytic and synthetic approaches in their training program. Detection and discrimination of acoustic differences between several speech tokens in noise reflect the analytic element of learning, whereas the synthetic component involved listening to an accented speech that requires more attention and a higher level of language processing. Roman et al. (2016) also utilized both approaches training auditory memory, identification, and discrimination of sound and ASA. Furthermore, Ingvalson et al. (2014) trained both phonological awareness skills and auditory working memory; phonological awareness exercises train mostly bottom-up skills, whereas working memory exercises train top-down skills. Finally, Yucel et al. (2009) used both approaches training pitch discrimination, rhythm discrimination, and sequence repetition. All four studies reported improved skills on trained tasks.

Synthetic (top-down) versus analytic (bottom-up). Five studies used just one approach, two studies used an analytic training approach, and three studies used a synthetic approach. Wu et al. (2007) trained discrimination using vowels and acoustic speech features, such as formant frequencies and duration, in addition to discriminating between phonemes. Hagr et al. (2016) trained for detection of Ling and environmental sounds; discrimination between intensity, duration, pitch, or intonation stress; rhythm and rate; and discrimination between vowels, consonants, and number of syllables in words. Both studies reported improved skills on trained tasks.

On the other hand, Good et al. (2017) utilized synthetic training in private piano lessons, including musical theory, technical exercises, eventually learning a song. Welch et al. (2015) also opted to use a synthetic training approach where the training stimuli were singing exercises, vocal explorations, and explorations in visual imagery for sound. Finally, Kronenberger et al. (2011) trained working memory using Cogmed training software, which involved auditory, visuospatial, and combined short-term and working memory skills. All approaches resulted in an overall improvement in performance, and no advantage of either approach over another was evident.

Risk of Bias Across Studies

The level of evidence is generally considered to be low except for one study (Mishra et al., 2015), which reached a moderate level of evidence. A low level of evidence is claimed to be indicative of unrepeatable results and lower confidence in the research. Such an issue could increase bias when interpreting the evidence in favor of AT. For some of the articles, the reported research outlined the proof of concept in a pilot study and stated that larger scale studies were intended (Kronenberger et al., 2011; Welch et al., 2015; Yucel et al., 2009). For many of the studies, one of the main issues related to the small sample size (average of 10.33 subjects for studies that used repeated-measures design and 22.83 subjects for studies that included controls), which potentially resulted in an underpowered study.

Discussion

Summary and Recommendations

This systematic review assessed the literature on the benefits of AT with pediatric CI users. For two of the studies, the study group contained children with other hearing devices, as well; however, the focus was on CIs. Trained tasks included working memory phonological awareness, speech perception, music perception, singing, pitch and rhythm discrimination, and environmental sound identification. Benefits of AT were illustrated through improvement on trained tasks in all nine studies regardless of the duration or type of training. In addition, four of six studies, which assessed generalization of training, demonstrated a transfer of improvement to other learning domains, such as working memory training that led to improved language processing skills along with improved working memory skills (Kronenberger et al., 2011), and music training that lead to improved emotional speech prosody perception (Good et al., 2017). Although these results are encouraging for clinicians when considering whether to incorporate AT in the rehabilitation pathway of pediatric CI users, clinicians have to bear in mind that the evidence supporting such claims are not solid. In fact a recent meta-analysis (Melby-Lervåg, Redick, & Hulme, 2016) demonstrated that working memory training does not improve other skills that are not working memory specific, including speech perception. However, there is no evidence either that such findings apply to CI users because the number of working memory training studies with CI is extremely limited.

The findings also suggest that the type of AT should be determined based on individual needs, since both analytic and synthetic approaches led to improvements with no definite benefits of one approach over another. Further work is required to understand if there are specific reasons to use different techniques or whether any AT approach will suffice.

Interestingly, it was observed that almost all studies that used synthetic training, independently or along with analytical exercises, assessed the benefits of generalization of learning to untrained tasks or other auditory perceptual domains. Namely, Good et al. (2017), Kronenberger et al. (2011), Mishra et al. (2015), and Roman et al. (2016) reported benefits in untrained tasks, whereas studies by Hagr et al. (2016) and Wu et al. (2007) used only analytic tasks and did not assess the benefit of generalization to untrained tasks, perhaps because training stimuli were targeting basic discernible skills that were not expected to influence untrained skills. Although there was no clear evidence for benefits of using one training approach over another, a trend emerged to suggest that adding synthetic training tasks to analytic training might be optimal because it combines higher language and/or cognitive processing with the more basic perceptual discrimination abilities. This trend supports the recommendation by Amitay et al. (2006), who also suggested combining the two approaches to achieve maximum benefit.

An essential measure when assessing the benefits of AT is retention of benefit and is measured in follow-up assessments after AT is completed. Such factors can influence the clinicians' decisions when offering AT in clinical settings; if the retention is low, the motivation for utilizing AT will be low, and vice versa. Hence, retention of improvement was assessed in this review. Surprisingly, only three studies (Kronenberger et al., 2011; Mishra et al., 2015; Wu et al., 2007) investigated retention post AT and revealed that improvements were sustained for a period ranging from 2 weeks up to 2 months post AT intervention. Such great variation in retention periods could also be reflective of subjects' compliance to training programs, yet another essential measure for the effectiveness of AT. Unfortunately, only one study (Mishra et al., 2015) assessed compliance to AT programs, which illustrated its importance as a sign of children's and their families' interest in AT, and ultimately as an indicator of the intervention's success. Therefore, we recommend investigating these two AT-specific measures to demonstrate the effectiveness of AT in future studies.

Another factor that was not investigated in the studies is quality of life. Quality of life is an essential outcome, which may also influence clinicians' and service providers' decisions to offer AT in their practice. The only study to include self-report or parent report questionnaires as an outcome measure was Yucel et al. (2009). Such tools are valuable when assessing the outcome of AT, as it directly determines the attitude of the end users to the intervention and highlights if they observed changes in speech perception and production and how the training affects everyday life.

The categorization of the articles indicated that quality of the studies was low to moderate. This is in line with Henshaw and Ferguson (2013), who assessed the AT literature for adults with hearing loss and found that the level of evidence was very low to moderate. In other medical fields such as plastic surgery, there is an agreement that the grading system should not dismiss lower quality evidence when deciding on recommendations if the results are consistent (Burns, Rohrich, & Chung, 2011), a pattern that was observed here. When looking at the specific studies in this review, factors contributing to lower overall quality scores are mainly lack of randomization, lack of a power calculation, and lack of blinding, which can all be practically difficult to achieve in studies dealing with populations such as children with CI because of the size of the population and constraints due to delivery approaches for the intervention, such as within a school, which can make randomization very difficult. Future AT research with this population should attempt to overcome some of these limitations by using greater control in the participant recruitment and intervention delivery. The population size available now is far larger than had been previously the case for some of the earlier studies, and there are many outcome measures that have published reliability values to be able to conduct power calculations, so some issues can readily be overcome. Future studies should be careful to report participant compliance, and appropriate outcome measures were selected to reflect direct, generalized, and real-life listening situations. For assessing generalization, the use of outcome measures should be both specific and general and include periods without intervention to assess retention. Even though meta-analysis of the benefits of AT is not feasible due to the diversity of the outcome measures used across studies, generalization and retention of benefits can be the focus of future studies as a primary AT outcomes, regardless of the measures used in the studies, and eventually be investigated in a meta-analysis.

Limitations of This Review

There were three main limitations in this review. First, CI and hearing aid users were followed in two of the studies (Welch et al., 2015; Wu et al., 2007), which could be considered as inconsistency in the targeted population in the analysis because the intention was to only explore studies using children with implants. Because of the small number of studies available investigating outcomes purely with children with CIs, it was decided to include them. Furthermore, as more present-day CI users have greater degrees of residual hearing, the distinction between these two populations becomes less clear. The second limitation occurred because it was not possible to conduct a meta-analysis because of lack of commonality among outcome measures. Finally, this analysis did not consider the impact of duration and frequency of the intervention on the outcome of AT, which could have a large impact on outcomes; this aspect is not clearly reported in the literature.

Conclusion

The literature on the benefits of AT in pediatric CI recipients was systematically reviewed. Benefits of AT were demonstrated through the improvement of all trained tasks in the studies analyzed, regardless of the duration or type of training. Transfer of improvement to untrained tasks was measured in number of the studies (six out of nine). Retention of benefits after a period without training, following the intervention, was evident in the cases where it was assessed (three out of nine), but time periods for evaluation varied. None of the studies assessed changes in quality of life despite its value when assessing the effectiveness of interventions. In agreement with previous reviews, a higher quality of evidence for examining outcomes of AT in pediatric CI recipients is still required. The lack of higher quality studies should not be associated with the effectiveness of AT intervention. It is important not to draw the conclusion that the current level of evidence infers lack of benefit especially because the studies reviewed consistently reported benefit.

To ensure that future AT studies achieve a higher level of evidence when graded and to minimize the potential bias, general measures such as randomization, power calculation, blinding, and control groups should be used. Other outcome measures such as quality of life, retention of benefit, and compliance to AT program should also be incorporated and be considered as key indicators to the success of any AT program.

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Appendix A

Research Questions

This research aimed to answer the following questions:

- Does auditory training lead to improvements in speech and language, cognition, and/or quality of life in children with cochlear implants?
- Is analytic or synthetic auditory training more effective for improving outcomes in implanted children?
- Do improvements in speech and language, cognition, and/or quality of life remain over a period of time post auditory training intervention?
- Do improvements in trained tasks generalize to other domains or transfer to untrained tasks?

Appendix B

Inclusion and Exclusion Criteria According to PICOS

Inclusion and exclusion criteria were defined as follows:

- **Participants:** Children (< 18 years old) with cochlear implants.
- **Intervention(s):** All auditory training for cochlear implant users including human or computer-based delivery in clinic, home, school, or laboratory.
- **Comparator(s)/Control:** Comparison with a control group (with placebo intervention or a nonexposed control group) and repeated-measures design (pretraining and posttraining comparisons).
- **Outcome(s):** Improvements in speech perception (words and sentences recognition in quiet and noise), cognitive abilities (working memory, executive function, and attention), and/or quality of life (family or self-reported feedback related to improved communication, if any). Retention of benefits when AT ceases and generalization of learning.
- **S (Study Design):** Randomized control trials, nonrandomized control trials, repeated measures, or cohort studies with controls.

Appendix C

Guidelines for Level of Evidence

Henshaw and Ferguson (2013) developed guidelines for evaluation auditory training studies, which categorize the level of evidence according to study quality scores (a sum of graded predefined measures) as follows:

- Scores between 0 and 5 are deemed very low, indicating that the estimation of effect is unreliable.
- Scores between 6 and 10 are deemed low, indicating that further evidence is very likely to impact on our confidence in the estimation of effect and are likely to alter the estimate.
- Scores between 11 and 15 are deemed moderate, indicating further evidence is likely to impact on our confidence in the estimation of effect and may alter the estimate.
- Scores between 16 and 20 are deemed high, indicating further evidence is very unlikely to alter our confidence in the estimation of effect.