Auditory Training for Children with Deficits in Auditory Processing: An Exploratory Study

Rachel Anne Pemberton

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(Please take note that this is a summary of the Thesis)

Summary of Findings

Auditory sound-based training interventions have become popular to remediate children’s deficits in auditory processing, which is not surprising given the link in the research between auditory processing and learning. However, these commercially available training programs are expensive and time-consuming. Furthermore, there is a paucity of research examining their effectiveness. The aim of this study was to explore the effectiveness of a currently commercially available auditory training program in Melbourne. In the current study, Hierarchical Linear Modeling (HLM) was used to assess the extent to which a music-based auditory training program, Auditory Training Program™ (ATP), directly improves auditory processing abilities and auditory short-term memory in children with deficits in auditory processing. The Cattell-Horn-Carroll (CHC) taxonomy of intelligence was used to classify auditory processing abilities (Ga) and short-term memory (Gsm). Data from sixty children (37 males and 23 females) who had previously undertaken auditory training was used for the present study. The results show that the auditory processing abilities of phonetic coding (PC), resistance to auditory stimulus distortion (UR), sound localization (UL), as well as short-term memory (Gsm) abilities were improved following the ATP intervention. A CHC taxonomy to classify specific auditory processing abilities can be used help better understand
which specific cognitive abilities auditory training improves, and compare research findings. Implications for future researchers and providers of auditory training programs are discussed.

**Auditory Processing**

Auditory processing generally refers to the processes that occur within the auditory system from when a sound reaches the ear until it reaches the auditory cortex in the brain, where the acoustic sound is consciously experienced (Dawes & Bishop, 2009; Sloan, 1991). The acoustic properties of a sound are characterised by frequency (pitch), intensity (loudness), and duration (Boatman, 2006). Individuals are typically able to hear sounds between 20Hz and 20,000Hz, although the speech sounds of a language generally range from 100Hz to 4000Hz (Boatman, 2006). The listener experiences a representation of an acoustic event as it is transformed, coded, and recorded by the auditory system (Boatman, 2006; Sloan, 1991). The auditory system comprises the peripheral and central auditory system (Boatman, 2006; Dawes & Bishop, 2009). This peripheral auditory system is associated with hearing. A sound reaches the inner hair cells along the basilar membrane in the cochlea. The inner hair cells selectively respond to the frequency of the sound, and the pattern of responses is organised and represented tonotopically, that is, according to their frequency. (Boatman, 2006). The central auditory processing system comprises the brainstem, thalamus, and cortex (Boatman, 2006; Dawes & Bishop, 2009). With the view of Auditory Processing Disorder (APD) being a dysfunction in the central auditory nervous system, deficits in auditory processing are indicative of a disturbance in the path between the cochlea and the auditory cortex (Dawes & Bishop, 2009).

**Auditory Processing Disorder**

APD is typically understood as deficits in processing and interpreting auditory information, despite normal hearing sensitivity, and not due to higher order language, or cognitive factors such as auditory memory (American Speech-Language-Hearing Association [ASHA], 2005; Dawes & Bishop, 2009; Jerger & Musiek, 2000; Lovett, 2011). On the one hand, APD is argued to be a dysfunction
in the central auditory nervous system, as research indicates that individuals with APD have normal peripheral hearing sensitivity (American Academy of Audiology [AAA], 2010; Jerger & Musiek, 2000). For this reason, APD has often been referred to as Central Auditory Processing Disorder (CAPD). While peripheral hearing disorders are associated with reduced auditory sensitivity, central hearing disorders are associated with speech discrimination or speech perception difficulties. However, this distinction is not clear cut, as reduced auditory acuity resulting from peripheral hearing difficulties may also result in speech discrimination difficulties (Sloan, 1991).

The Cattell-Horn-Carroll (CHC) Model of Auditory Processing

The Cattell-Horn-Carroll (CHC) taxonomy of intelligence is a theory that has aimed to deal with the issue of inconsistent definitions of cognitive abilities (McGrew, 2009). Although behavioural manifestations and symptoms differ between individuals, difficulties typically reported include: processing auditory information in challenging acoustic environments, following directions, understanding rapid speech, appreciating music, locating where a sound has come from, and auditory memory (AAA, 2010; Dawes & Bishop, 2009; Lovett, 2011; Ross-Swain, 2007).

The CHC taxonomy is described as the most empirically supported, and psychometrically based contemporary description of the structure of human cognitive abilities available to date (McGrew, 2009). Auditory processing (Ga) as a broad ability, is defined in this model as 'the ability to detect and process meaningful nonverbal information in sound' (Flanagan, Ortiz, & Alfonso, 2013). Taking the view that auditory processing can be impacted by higher auditory processes, such as short-term memory and language, it is important to take these processes into account. Classified according to the CHC taxonomy, as a broad cognitive ability, short-term memory (Gsm) refers to the ability to maintain and manipulate information in immediate awareness (Flanagan et al., 2013). As a broad cognitive ability, reading and writing (Grw) is an acquired skill that refers to the depth and breadth of knowledge and skills related to written language (Flanagan et al., 2013). These cognitive abilities are related to a child's literacy achievement in the classroom (Flanagan & Alfonso, 2011).
Auditory Processing and Academic Outcomes

A large body of research has provided convincing evidence that auditory processing deficits specifically, are related to language and academic difficulties (Chermak, Silva, Nye, Hasbrouck, & Musiek, 2007; Dawes & Bishop, 2009; Wallach, 2011; Whitton, 2010). Indeed, research into APD began in 1954 with Helmer Myklebust describing children with language delays, despite apparent normal hearing sensitivity (Lovett, 2011). More recently, researchers have suggested that although auditory processing difficulties are not linguistic, they have a negative impact on language development (Dawes & Bishop, 2009; Sloan, 1991). Research has provided evidence that deficits in auditory processing; in particular speech sound discrimination (US), phonetic coding (PC), and resistance to auditory stimulus distortion (UR), are linked to poor literacy outcomes (McGrew, 2009; McGrew & Wendling, 2010 provide a detailed review). For example, segmenting sounds for spelling requires phonetic coding (PC) (Flanagan & Alfonso, 2011). For example, a child who has difficulty detecting differences in speech sounds (US) when the teacher is talking may mishear or misinterpret the words being said, and meaning will be lost. Given the similarities in behavioural presentation, an over-inclusive definition of APD may lead to no difference between APD and other diagnoses such as Specific Language Impairment (SLI) (Dawes & Bishop, 2009; Jerger & Musiek, 2000). Although there appears to be insufficient clinical and theoretical support differentiating APD from other disorders, there is a clear link between deficits in auditory processing and learning difficulties (ASHA, 2005; Moore, 2006).

Remediating Auditory Processing Disorder

One point of view in the literature is that regardless of whether APD exists as a disorder in its own right, remediating auditory processing deficits is important because of their link with academic outcomes (Dawes & Bishop, 2009). The other view is that given insufficient evidence supporting APD as a disorder, interventions should target the related academic abilities with which students have difficulty (Dawes & Bishop, 2009). Research into brain plasticity has reignited interest in whether interventions that target auditory processing abilities specifically are
effective for remediating related learning difficulties (Strait, Parbery-Clark, Hittner & Kraus, 2012). However, there appears to be a research-practice gap because of the lack of peer-reviewed published research to support the theoretical basis and claims of auditory training programs. Therefore, this study focuses on the efficacy of interventions that aim to improve auditory processing (Ga) and auditory short-term memory (Gsm) abilities using music-based auditory training.

**Music-Based Auditory Training**

Support for the underlying theory of music-based training programs comes from neuroscientific research suggesting that musical experience is associated with enhanced brain neuroplasticity, and that this is related to years of music training (Kraus & Chandrasekaran, 2010; Strait et al., 2012). Neuroscientific research has shown that in response to pitch changes during speech, musicians show heightened auditory evoked potentials in the cortex and brainstem relative to their non-musician counterparts (Kraus & Chandrasekaran, 2010). Processing of pitch during speech is important to recognise the identity, emotion, and intention of the speaker (Kraus & Chandrasekaran, 2010). Strait et al. (2012) found that musically trained children showed faster auditory brainstem response and decreased response delays (Strait et al., 2012). Musical training relies on learning to associate slight acoustic discrepancies with behavioural significance. The findings of Strait et al. (2012) suggest that when combined with behavioural reward, activation of the primary auditory cortex induces a change in subcortical response properties. To further support this theoretical underpinning, a study by Strait, Parbery-Clark, O'Connell, and Kraus (2013) found that musically trained children performed better on auditory working memory and auditory attention tasks, but not in visual memory or visual attention, relative to their non-musician counterparts. Despite these findings it cannot necessarily be inferred that musicians have better 'classroom skills'.
Current Auditory Training Programs

The major auditory training programs that have been used in research include: The Tomatis Method (TM), Auditory Integration Training (AIT), The Listening Program (TLP), and Integrated Listening Systems (iLs). The research behind these programs will be briefly discussed below. The use of music-based interventions began with Alfred Tomatis in the 1950’s. Tomatis proposed three fundamental assumptions of sound-based interventions: an individual can only reproduce sounds that the ear can hear, the voice is able to identify and reproduce new frequencies when retrained to integrate frequencies previously unperceived, and with sufficient retraining, this change in perception can be permanent (Nicoloff, 2011; Papagiannopoulou, 2015). The TM is a music-based auditory training program based on research demonstrating that the auditory system is connected with the cortex and subcortical structures which are stimulated during normal auditory perceptions (Ross-Swain, 2007). The TM of auditory training aims to stimulate listening and processing, rather than hearing (Ross-Swain, 2007). Where hearing refers to the passive reception of sound, listening refers to the active, tuning into sound (Papagiannopoulou, 2015; Thompson & Andrews, 2000). Tomatis developed the Electronic Ear (EE) which is a device that delivers sound stimulation through special earphones containing filters, which regulate sound to alter or modify information (Thompson & Andrews, 2000; Tomatis, 1996). Tomatis posited that enhanced auditory perception is achieved through the combination of filtered music through the EE, and auditory feedback that stimulates middle ear hair cells, leading to alterations in the central nervous system (Corbett, Shickman, & Ferrer, 2008; Tomatis, 1996). Guy Berard, a student of Tomatis, developed the AIT program (Berard, 1993; Nwora & Gee, 2009). Like the TM, AIT involves listening to electronically processed music through a specialised device. Whereas the TM aims to improve listening and processing, the AIT aims to reduce hypersensitivity to certain frequencies and improve attention or awareness of the stimuli (Yencer, 1998). Advanced Brain Technologies ([ABT], 2016) further built upon the work of Tomatis and Berard, and developed TLP. As with its predecessors, TLP uses electronically processed music in certain frequency zones. However, TLP differs from the TM and AIT in that it is a therapy that can be delivered at home, and participants listen to the modified music using commercially available equipment rather than in the clinical setting with specialised devices. It is
claimed that TLP improves performance in executive functioning, communication, auditory processing, social and emotional functioning, stress response, motor coordination, and creativity (ABT, 2016). The iLs program was developed in 2008 in the United States, and even more recently has been used in Australia (Integrated Listening Systems Australia [ILSA], 2015). iLs is a multi-sensory program that loads specific classical music selections onto an Apple iPod. These music selections are then delivered through a mini amplifier emphasising frequencies at 750Hz and lower (ILSA, 2015). Based on claims that music improves brain plasticity, iLs is purported to improve global brain functioning, and address key aspects of language and cognitive processes including, but not limited to, auditory processing (ILSA, 2015).

Limitations of Current Research

Commercially available music-based auditory training programs may be attractive to parents whose children have deficits in auditory processing and are struggling at school. However, there appears to be a research-practice gap because of the lack of peer reviewed published studies to support the theoretical basis of many of the claims of these programs. It is clear that there is a lack of consistency in the definition of auditory processing, and a lack of consistent diagnostic criteria. Several other issues with the current research are also apparent: insufficient sample sizes, the lack of a control group, and limited measures of auditory processing specifically. An extensive, systematic review of the literature was conducted to identify relevant research to inform the current study.

Research on the effectiveness of auditory training programs is limited by small sample sizes. Although some studies have found positive effects of music-based auditory training, with the small sample sizes used in these studies it would be imprudent to generalise the results to the wider population. For example, Corbett et al. (2008) found no benefits of the TM in a group of 11 children, while Gerritsen (2010) used the dataset from the Corbett et al. (2008) study and analysed the participants at the individual level as separate case studies. Although several individual participants in the study showed significant improvements following
intervention, these results should not be generalised to the wider population. This highlights the lack of research using adequate sample sizes in the area of music-based interventions for deficits in auditory processing.

Research on the effectiveness of auditory training programs is also limited by a lack of studies using a control group. In reviewing the literature only two studies were identified that found improvements in auditory processing (Ga), following music-based auditory training, that could not be accounted for by the placebo treatment (Edelson et al., 1999; Rimland & Edelson, 1995). In both studies, narrow auditory processing abilities (Ga) resistance to auditory stimulus distortion (UR) and speech sound discrimination (US), were found to improve following AIT (Edelson et al., 1999; Rimland & Edelson, 1995). In measuring the narrow ability of phonetic coding (PC), one study found positive effects using the Phonemic Synthesis Test, although this was also found for the placebo and control groups (Yencer, 1998). Therefore, although there has been some research using a control group that indicates the possibility that music-based auditory training can improve certain narrow auditory processing (Ga) abilities, the evidence is inconsistent.

A further major limitation of research in this area is that rather than testing auditory processing abilities directly, many studies test learning and behavioural outcomes, assuming auditory processing abilities have improved in the intermediary. Two studies assessing the efficacy of the TM used language based and behaviour outcome measures (Corbett et al., 2008; Gerritsen, 2010), despite the aim of the TM being improved auditory processing (Corbett et al., 2008). Two studies assessing the efficacy of TLP showed improvements in behavioural and learning outcomes, however, neither examined auditory processing specifically. Only one pilot study has been conducted to test the iLS therapeutic claims, with positive results including sensory and auditory deficits. However does not give support for the iLs program as an evidence-based intervention for specifically improving auditory processing abilities (Schoen et al., 2007). By testing behavioural or language outcomes, these studies are not testing the specific processes the auditory training programs aim to improve. Four studies, however have reported using outcome measures of auditory processing or short-term memory (Edelson et al., 1999; Rimland & Edelson, 1995; Ross-Swain, 2007; Yencer, 1998). One study reported positive effects of the TM on
one narrow measure of auditory processing (Ga), phonetic coding (PC) and on four measures of short-term memory (Gsm) (Ross-Swain, 2007). However, this study was limited in that although it reported improvement in percentile ranks, the statistical significance was not reported. Furthermore, it is not clear what measures were used to assess the outcome variables. The lack of specificity makes it difficult to replicate the study or interpret its results. Three studies have measured the effects of AIT in children diagnosed with APD specifically, or at least identify narrow auditory processing (Ga) deficits (Edelson et al., 1999; Rimland & Edelson, 1995; Yencer, 1998). The studies tested the effects of AIT on phonetic coding (PC), speech-sound discrimination (US), and resistance to auditory stimulus distortion (UR), however, the findings were inconsistent. Both Rimland and Edelson (1995) measured resistance to auditory stimulus distortion (UR) using the Figure-Ground subtest of Fishers Auditory Problems Checklist. Rimland and Edelson (1995) found significant improvement in following AIT, Edelson et al. (1999). Additionally, where Yencer (1998) found significant improvement in speech-sound discrimination (US), Edelson et al. (1999) did not. As such, there is currently insufficient and inconsistent evidence for the efficacy of these music-based auditory training programs in general.

The Current Study

There is a gap in the research evaluating the effectiveness of music-based interventions, and whether they remediate auditory processing abilities (Ga) specifically. Therefore, the current study will address some of the limitations of previous research by attempting to use an adequate sample size of individuals who present with auditory processing deficits, and directly measuring auditory processing (Ga) abilities as an outcome variable.

The current study contributes to the research in this area by examining whether existing auditory training programs are directly improving auditory processing abilities (Ga) and auditory short-term memory (Gsm) specifically.
Aims and Hypotheses.

The aim of the current study is to assess whether a selected commercially available music-based auditory training program, Auditory Training Program™ (ATP), improves auditory processing (Ga) and short-term (Gsm) memory abilities in individuals with deficits in auditory processing. This study is exploratory as it is using a retrospective database from the selected auditory training program.

The ATP is delivered by trained psychologists at the Listen and Learn Centre®, a private psychology practice in Balwyn, Melbourne, Australia. The ATP is a clinic-based auditory stimulation intervention, aimed at assisting the development or enhancement of auditory processing skills and receptive language abilities. It is premised on the theoretical framework of neuroplasticity, ‘the brain’s ability to reorganize by forming or refining neural connections via specific stimulus over a sustained period of time’.

The research questions that have guided this study are:

1) For school-aged children presenting with deficits in auditory processing abilities, does the ATP improve auditory processing abilities (Ga)?
2) For school-aged children presenting with deficits in auditory processing abilities, does the ATP improve short-term memory (Gsm)?

It is hypothesised that following auditory training using the ATP, significant improvement will be found in:

1. phonetic coding (PC), the ability to hear phonemes distinctly;
2. sound localization (UL), the ability localize heard sounds in space;
3. resistance to auditory stimulus distortion (UR), the ability to hear words correctly even under conditions of distortion or loud background noise; and,
4. short-term memory (Gsm).
Method

Participants
Participants were recruited from the Listen and Learn Centre®. A total of 60 participants were included, 37 males and 23 females, aged 5 years 2 months to 16 years 7 months (M = 9.12 years) who had completed the ATP. Thirty-four participants had a diagnosis (from a registered health practitioner e.g., audiologist or psychologist) of Auditory APD, fifty two had a diagnosis of Specific Learning Disorder, eighteen with Attention Deficit Hyperactivity Disorder (ADHD), four with Global developmental delay, six with Intellectual Disability, eight with Autism Spectrum Disorder (ASD), twenty-two with Speech and Language Delay, two with Verbal Dyspraxia. Sixteen participants presented with APD alone. Ninety percent of the participants lived in metropolitan Victoria and 10 percent lived in regional Victoria or metropolitan areas of low population growth, as specified by the Australian Government Department of Immigration and Border Protection (2016). In terms of education, 37 participants attended a public school (61.7%) and 23 attended a private school (38.3%). Only 32 participants had recorded Full Scale Intelligence Quotient (FSIQ) scores; 50% of these participants had a FSIQ score in the average range.

Materials
The following measures were used as part of the regular pre and post intervention assessment at the Listen and Learn Centre®. Data was collected by a registered Psychologist at the Listen and Learn Centre®.

Test for Auditory Processing Disorders in Children - Third Edition (SCAN-3). The Test for Auditory Processing Disorders in Children (SCAN-3) is a measure of auditory processing skills in children aged 5 to 12 years old (Keith, 2009). The SCAN-3 includes four diagnostic subtests: Filtered Words, Auditory Figure-Ground+8dB, Competing Words, and Competing Sentences. The Filtered Words subtest presents twenty monosyllabic words separately to each ear via a compact disk player and headphones. The words are filtered at1000Hz based on research separating children with deficits in auditory processing better at 1000Hz than 500Hz or 750Hz filters (Keith, 2009). This subtest assesses the ability to understand
distorted speech and lower scores reflect deficits in auditory closure. The Auditory Figure-Ground+8dB presents forty stimulus words separately to each ear at an intensity 8dB greater than the background noise. This assesses the ability to interpret speech in the presence of extraneous noise. Lower scores reflect deficits with blocking out extraneous noise. The Competing Words subtest presents thirty monosyllabic word pairs to each ear simultaneously. The child is required to repeat the word heard in one ear followed by the word heard in the other ear. Lower scores reflect deficits in the ability to process auditory information binaurally, that is, make sense of competing speech sounds. The Competing Sentences subtest presents unrelated sentences to each ear simultaneously. The child is required to repeat the sentence heard in a prescribed ear only and ignore the sentence heard in the other ear. This test also assesses the ability to interpret competing speech sounds, and lower scores reflect deficits in auditory separation (Geffner & Ross-Swain, 2007). Classified according to the CHC taxonomy, the SCAN-3 subtests measure three narrow auditory processing (Ga) abilities. Filtered Words measures phonetic coding (PC), Competing Words and Competing Sentences measure sound localization (UL), and Auditory Figure-Ground+8dB measures resistance to auditory stimulus distortion (UR) (Flanagan et al, 2013).

**Time Compressed Sentence Test (TCST).**
The Time Compressed Sentence Test (TCST) measures the response to meaningful sentences presented at increasingly rapid rates in children aged 6 years to 11 years and 11 months (Keith, 2002). The TCST comprises three subtests and is presented at 55dBHL if hearing is normal, or at the most comfortable listening level. The first subtest is a screening test that presents ten sentences with 0% time compression. The second subtest presents ten sentences separately to each ear at 40% time compression. The third subtest presents ten sentences separately to each ear at 60% time compression (Keith, 2002). Lower scores indicate that the child has difficulty following rapid speech during conversation. The TCST is a measurement of resistance to auditory stimulus distortion (UR). Resistance to auditory stimulus distortion (UR) requires participants to identify words whilst listening to increasing levels of distortion (Flanagan et al, 2013). The TCST presents sentences at progressively faster rates, thus increasing distortion.
**Dichotic Digits.**
The Dichotic Digits test is a widely used screening tool for auditory processing disorders that does not have a high linguistic loading (Rosenberg, 2011). Participants are presented with 20 pairs of spoken digits between one and ten. Participants hear two different numbers presented simultaneously in each ear and are required to repeat back all four numbers (Rosenberg, 2011). Dichotic Digits measures auditory performance in competing acoustic signals which indicates measurement of the narrow auditory processing (Ga) ability resistance to auditory stimulus distortion (UR).

**Test of Auditory Processing Skills - Third Edition (TAPS-3).**
The Test of Auditory Processing Skills - Third Edition (TAPS-3; Martin & Brownell, 2005) assesses auditory processing abilities related to the communication and cognitive aspects of language in individuals aged 4 to 18 years old. The TAPS-3 comprises nine subtests that assess three broad areas: Phonological Skills, Auditory Memory, and Auditory Cohesion. One subtest also screens for Auditory Attention. Using the CHC model, the TAPS-3 subtests Phonological Blending, Phonological Segmentations, and Word Discrimination, measure the narrow auditory processing (Ga) ability phonetic coding (PC) (Flanagan et al, 2013). In addition, the TAPS-3 subtests also measure the CHC broad ability of short-term memory (Gsm). The subtests, Numbers Forward, Sentence Memory, and Word Memory, measure the narrow short-term memory (Gsm) ability memory span (MS). The Numbers Reversed subtest measures the narrow short-term memory (Gsm) ability working memory capacity (MW) (Flanagan et al, 2013).

**Macquarie Staggered Spondaic Word Test (MSSW).**
The Macquarie Staggered Spondaic Word Test (MSSW; Golding, Lilly, & Lay, 1996) assesses dichotic listening abilities; that is, the ability to process different information presented to each ear simultaneously (Rosenberg, 2011), in children aged 5 years to 12 years, 11 months. The MSSW is a re-recording of the original American English Staggered Spondaic Word Test, one of the most widely used tests to assess for APD in the United States, into Australian English (Wilson, Katz, Dalgleish, & Rix, 2007). The MSSW comprises forty pairs of spondaic words recorded and presented binaurally. The words are presented such that the second syllable of the first spondaic word overlaps with the first syllable of the second
spondaic word. To balance the syllable overlap, odd numbered items are presented first to the left ear and even numbered items are presented first to the right ear. The child is required to say all four words in the order they are presented from the recording. Lower scores indicate deficits in binaural integration. This results in the following four conditions: Right Ear Non-Competing, Right Ear Competing, Left Ear Competing, and Left Ear Non-Competing. Total scores above the critical value are considered average, and total scores below the critical value are considered below average. The MSSW measures auditory performance in competing acoustic signals which indicates measurements of the narrow auditory processing (Ga) ability resistance to auditory stimulus distortion (UR).

**Comprehensive Test of Phonological Processing - Second Edition (CTOPP-2).**
The Comprehensive Test of Phonological Processing - Second Edition (CTOPP-2; Wagner, Torgesen, Rashotte, & Pearson, 2013) is an individually administered measure of reading-related phonological processing skills. The CTOPP-2 includes test versions for 4 to 6 year olds and 7 to 24 year olds. The CTOPP-2 comprises 12 subtests that make four composites: (1) Phonological Awareness, (2) Phonological Memory, (3) Rapid Symbolic Naming, and (4) Rapid Nonsymbolic Naming for the 4 to 6 year olds and Alternate Phonological Awareness for the 7 to 24 year olds. Several of the C-TOPP-2 subtests provide a measure of the CHC narrow auditory processing (Ga) ability phonetic coding (PC): Blending Nonwords, Blending Words, Elision, Phoneme Isolation, Segmenting Nonwords, and Sound Matching (Flanagan, Ortiz, & Alfonso, 2015).

**Integrated Visual and Auditory Continuous Performance Test (IVA).**
The Integrated Visual and Auditory Continuous Performance Test (IVA; Sandford & Turner, 1995) is a test of attention for children aged 6 years to 12 years and 11 months. The IVA is a computer-based task that measures the child's ability to maintain attention for approximately 15 minutes. Two types of continuous performance tests are combined; visual and auditory. The task measures responses to a random combination of 500 visual and auditory stimuli spaced 1.5 seconds apart. The child is required to click the mouse when the target stimulus is seen or heard, and refrain from clicking when a non-target stimulus is seen or heard. The IVA is
reported to have moderate to good reliability (Cronbach’s $\alpha = .37 \text{ to } .75$) (Sandford & Turner, 1995).

**Procedure**

Over 100 individuals were invited and 63 agreed to participate in the study. Children identified as having deficits in auditory processing abilities, as assessed by a registered psychologist or speech pathologist at the Listen and Learn Centre®, were offered auditory training at a cost. The auditory training program was explained in plain English to those who booked in to take part in the training. Pre and post testing of the child’s auditory processing abilities was conducted as part of the training program, and is part of the clinic’s usual protocol of pre and post testing of the interventions they offer. Only the data of the participants who returned the signed consent form was used in the research project. Three participants were excluded from this research as they had a cold at the time of assessment post intervention (as per the file case notes), and so their auditory processing results were considered invalid.

**Intervention Program Individualization**

The ATP was designed by the director of the Listen and Learn Centre® using a combination of programs and clinical experience. The main objective of the ATP, as defined in the user manual, is to challenge and prepare the auditory system to deal with changes in sound intensity (volume), frequency (pitch), time delays (pause, order and sequence), pattern differences (intervals between sounds), auditory figure-ground differentiation, and to assist in encoding and decoding of speech sounds in order to address the skills of auditory processing. There is a major emphasis on auditory performance in competing acoustic signals, dichotic listening (auditory separation and integration), temporal processing, auditory closure (when the information is incomplete or degraded), sound localization, auditory memory and auditory attention skills. The program incorporates four distinct techniques:

1. **Besson Auditory Training System (BATS)** technology developed by Christophe Besson and his company “Besson of Switzerland”. The technology is based on the pioneering auditory stimulation work of Dr. Alfred Tomatis, a French Ear Nose and Throat Specialist. The BATS modifies and
enhances the elements of sound, ‘frequency, timing and volume’, using the medium of high fidelity orchestral music by Mozart, vocal tones such as Gregorian Chant (vocal pieces sung with the timing of the breath rather than a strict and counted tempo, availing the qualities of the human voice); and finally, the individual’s voice and other voices (e.g., in the case of children, their parents’ voices), to imprint the intrinsic characteristics and properties of the voice and spoken language (specifically the mother tongue).

The BATS technology incorporates amplifiers, filters, multiple channels, switches and timers to amplify selected frequencies and attenuate or cut non-requisite frequencies to treat the sound in real time. Variation of these sound treatments reduces the potential for auditory habituation (the non-response to auditory stimulus) by the random and frequent interchange of acoustic filtration bands, to the full spectrum music or vocals, thereby maintaining auditory novelty. The modified sound is provided to the individual through both air and bone conduction by means of specially manufactured headphones (Listen And Learn Centre®, 2015).

2. Dichotic Listening Training developed by Annette Hurley and Bradley Davis (2011), also known as Constraint Induced Auditory Therapy (CIAT), and based on Dichotic Interaural Intensity Difference (DIID) training (Musiek & Schochat, 1998), is used to remediate dichotic listening difficulties. In this training, the listener attends to and then recalls competing auditory stimuli (e.g., numbers, words and sentences), presented simultaneously to the left and right ears. The skill involved in dichotic listening is binaural separation and integration. This technique furthermore aims to improve inter-hemispheric transfer of auditory information via the Corpus Collosum, strengthening attentional orientation (both in the left and right ears), intended to remediate atypical left or right ear auditory processing weakness.

3. Listening ShadowTM Auditory Training (LSAT) was developed by Martha Mack and George Mack with Christophe Besson (LSAT Manual, 2014). This is a special technique of time and intensity (volume) altered music and speech exercises designed to develop:
• Auditory timing discrimination between the left and right ears. Timing discrimination is achieved by the presentation of the same stimulus arriving at the left and right ears at differing times, with timing differences ranging from 10,000 milliseconds [10 seconds] down to 1 millisecond. The timing delay is similar to an echo. This technique aims to promote interhemispheric discrimination and separation, sound localization and attentional direction.
• Auditory sound intensity (volume) discrimination. Sound volume discrimination is achieved by the presentation of the same stimulus to the left and right ears at differing volume levels. The intent is to train the weaker ear at normal sound levels while reducing the sound intensity level to the stronger ear thereby allowing the auditory system to learn to prioritize processing of auditory information in the weak ear. The combination of a timing delay and sound intensity difference gives rise to a spatial “shadow” effect that mimics the skills required for an individual to determine the direction and distance of a sound source. The co-training of timing and intensity differences between the left and right ears is the Shadow Listening effect.
• Audio-vocal time expanded biofeedback. This technique is also used to promote self-listening via audio-vocal time expanded biofeedback exercises, allowing for a feedback loop between self-produced speech, and milliseconds later hearing the same content, aimed at speech awareness and self-correction.

4. Auditory Short-Term and Auditory Working Memory Training. This part of the program incorporates a number of exercises where the individual is asked to repeat information such as numbers, words, and sentences of various length and complexity, which address auditory short-term and auditory working memory skills. Auditory Working Memory Training is conducted while using the BATS.

The ATP is based on the delivery of individualized auditory exercises following an auditory processing skills assessment using standardized tests, which determines the listening protocol to integrate the four distinct techniques into one program of
auditory training. The training is delivered in a controlled, systematic, and cumulative manner over an intense period of time (an intensive), typically undertaken as 1-2 hours of training per session, five days per week over a period of 2 to 4 weeks. A re-evaluation of the auditory skills is undertaken approximately 8 weeks after the completion of a block of intensive therapy, to measure the degree of auditory processing skill change.

Table 1

Demographic Descriptive Frequencies and Percentages

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<th>Variable</th>
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<tr>
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<tr>
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<td>3.3</td>
</tr>
<tr>
<td>Mild Intellectual Disability</td>
<td>2</td>
<td>1.7</td>
</tr>
<tr>
<td>Autism Spectrum Disorder</td>
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<td>5</td>
</tr>
<tr>
<td>Attention Deficit Hyperactivity Disorder AND Specific Learning Disorder</td>
<td>4</td>
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<tr>
<td>Speech and Language Delay</td>
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<td>11.7</td>
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<tr>
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<tr>
<td>AND Speech and Language Delay</td>
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<tr>
<td>Autism Spectrum Disorder</td>
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<td>3.3</td>
</tr>
<tr>
<td>AND Speech and Language Delay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention Deficit Hyperactivity Disorder AND Autism Spectrum Disorder</td>
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<td>26.7</td>
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<tr>
<td>High Average</td>
<td>1</td>
<td>1.6</td>
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</table>
Participants completed either one, two, or three intensive sessions. The majority of participants in the current study completed one intensive (n = 36) session, or two intensive sessions (n = 21), and a few participants completed three intensive sessions (n = 3). The number of total hours spent completing intensive sessions also varied between participants.

**Data Analysis**

Hierarchical Linear Modeling (HLM) was used to evaluate whether the ATP was predictive of changes in auditory processing (Ga) abilities using the Hierarchical Linear Modeling (HLM7) software (Raudenbush & Bryke, 2002). The objective of HLM is twofold: to assess individual change over time, and to examine the effects of treatment on group differences, and is, therefore, an appropriate approach for the current study. HLM offers several advantages over traditional repeated measures analysis of variance often used in longitudinal designs. First, HLM treats time as a continuous variable to estimate individual change over time. Second, HLM is particularly useful when there is missing data as HLM is able to retain a participant's data when there are missing entries. Third, HLM is better at handling violations of assumptions than standard linear regressions (West, 2009). For example, in simple linear regression models, there is the assumption of independence; that is, observations in the dependent variable are assumed to be independent of one another. In this study multiple dependent variable observations come from the same individual and as such are related; therefore HLM is advantageous as it allows the models to have some non-zero covariance (West, 2009).

**Results**

**Preliminary Analysis**

Data was screened for missing data, non-normality, and outliers. Expectation Maximization (EM) was used to manage missing data as a Missing Values Analysis (MVA), which indicated a large percentage of missing values for several variables. Data was only imputed for the participants who had completed one of the CTOPP-2 subtests related to auditory processing (Ga) - Elision, Blending Words, and Phoneme Isolation - during at least one assessment time point. In this case. No patterns existed in the missing data; therefore analyses performed are unbiased.
The data was then examined for deviations from normality. The Kolmogorov-Smirnov test showed that scores on the SCAN-3 (Filtered Words, Competing Words, Competing Sentences, and Auditory Figure-Ground+0), TCST (Right Ear 40%, Right Ear 60% pre, and Left Ear 60%), and TAPS-3 (Working Memory post, and Sentence Memory pre) were abnormal. However, given that a clinical sample was sought for this study (i.e., those with deficits in auditory processing) this was not unexpected; therefore these variables were not transformed for further analysis.

Finally, the data was screened for outliers to assess for any impact of extreme values on the distribution of the variables. Three cases were found to be above the critical value and were manually re-coded to one point higher than the next closest score, six cases that were found to be below the critical value and were manually re-coded to one point lower than the next closest score (Tabachnick & Fidell, 2007).

**Descriptive Statistics**

The means and standard deviations for each subtest at pre-intervention and post-intervention and shown in Table 2, below.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Means and Standard Deviations at Pre-and Post-Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Pre-Intervention M (n=60)</td>
</tr>
<tr>
<td><strong>SCAN-3</strong></td>
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<tr>
<td>Filtered Words</td>
<td>8.93</td>
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<tr>
<td>Auditory Figure Ground +8</td>
<td>7.81</td>
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<tr>
<td>Competing Words</td>
<td>5.34</td>
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<tr>
<td>Competing Sentences</td>
<td>6.97</td>
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<tr>
<td>Auditory Figure Ground +0</td>
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<tr>
<td><strong>TCST</strong></td>
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<tr>
<td>Right Ear 40%</td>
<td>83.25</td>
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<tr>
<td>Right Ear 60%</td>
<td>64.56</td>
</tr>
<tr>
<td>Left Ear 40%</td>
<td>81.91</td>
</tr>
<tr>
<td>Left Ear 60%</td>
<td>67.33</td>
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<tr>
<td><strong>Dichotic Digits</strong></td>
<td></td>
</tr>
<tr>
<td>Left Ear</td>
<td>72.22</td>
</tr>
</tbody>
</table>
Hypothesis Testing

To test the hypotheses a series of hierarchical linear models were conducted. This involved two levels of analysis. At the first level, the outcome variable was entered into the model to determine the amount of variance between individual participants. HLM is useful in analyzing change over time where the difference between participants is high (approximately 20% or more). This level provides the final estimates of variance components coefficients for the random effects between children (the intercept, $r_o$), and within children (level 1, $e$). These coefficients are then used to calculate the intercluster criterion (ICC) representing the amount of variance between participants. This percentage provides support for the use of HLM over other analyses when the percentage is high.

$$ICC = \frac{r_o}{r_o + e} = x$$

The fixed components at Level 1 (i.e., individual test scores at each time point) were then entered into the model. Finally, the predictor variable (auditory training) was entered into the model to determine whether intervention significantly influenced the rate of change in auditory test scores between pre and post intervention. As a repeated measures design was being implemented predictor variables at Level 1 were group-mean centred rather than grand-mean centred. This means that the
intercept, $\beta_{00}$, equals the group mean score on the dependent variable controlling for time. The coefficients for the mean group score ($\text{INTRCPT2}, \beta_{00}$) and the slope ($\text{INTRCPT2}, \beta_{10}$) with robust standard errors provide an estimate of the change in scores following auditory training ($Y$) and was calculated using the equation below:

$$Y = \beta_{00} + \beta_{10}$$

Separate models were run to test each hypothesis. The following figures show the estimated improvement in standard scores over the time points recorded.

![Graph showing change in standard scores in measures of phonetic coding](image)

**Figure 1.** Change in standard scores in measures of phonetic coding, at pre- and post- auditory training. Higher scores indicate improvements on auditory processing skills.
Figure 2. Change in standard scores in measures of sound localization (UL), at pre- and post- auditory training. Higher scores indicate improvements on auditory processing skills.

Figure 3. Change in standard scores in SCAN-3 measures of resistance to auditory stimulus distortion (UR), at pre- and post- auditory training. Higher scores indicate improvements on auditory processing skills.
Figure 4. Change in standard scores in TCST and Dichotic Digits measures of resistance to auditory stimulus distortion (UR), at pre- and post- auditory training. Higher scores indicate improvements on auditory processing skills.

Figure 5. Change in standard scores in measures of short-term memory, pre- and post- auditory training. Higher scores indicate improvements in measures of memory.
Discussion

This study aimed to examine whether improvements were found in auditory processing abilities (Ga) and short-term memory (Gsm) following the ATP, a specialised auditory training program. The assessment measures used in this study were classified according to the CHC taxonomy. Specifically, the current study assessed whether, for school-aged children presenting with deficits in auditory processing abilities, the ATP improved the narrow auditory processing (Ga) abilities, phonetic coding (PC), sound localization (UL), and resistance to auditory stimulus distortion (UR). Additionally, it was assessed whether, for school-aged children presenting with deficits in auditory processing abilities, the ATP improved short-term memory (Gsm).

The results of the study supported the hypothesis that improvements would be found in phonetic coding (PC) abilities. Scores were found to significantly improve on all four measure of phonetic coding (PC) following auditory training. The findings of the present study support and extend previous research, and suggest that phonetic coding (PC) isa specific narrow auditory processing ability (Ga) that can be improved as a result of auditory training.

The results of the current study supported the hypothesis that improvements would be found in sound localization (UL) abilities following auditory training. There were no previous studies found to have measured improvement in sound localization (UL) directly, as the only study identified that used a measure of sound localization (UL) did not perform statistical analysis on that subtest (Edelson et al., 1999). Therefore, the current findings extend current research and indicate that sound localization (UL) is one narrow auditory processing ability that may be improved as a result of auditory training.

The results of the current study supported the hypothesis that improvements would be found in resistance to auditory stimulus distortion (UR) following auditory training. The results are consistent with the findings of one previous study which found significant improvement in resistance to auditory stimulus distortion (UR) following AIT (Rimland & Edelson, 1995). As significant improvements were found in six of the measures following auditory training, this provides support for the
findings in the Rimland and Edelson (1995) study and indicates that the narrow auditory processing (Ga) ability, resistance to auditory stimulus distortion (UR), can be improved following auditory training.

The results of the study supported the hypothesis that improvements would be found in short-term memory (Gsm) following auditory training. This is consistent with the findings of previous research that found significant improvement in short-term memory (Gsm), as measured by the TAPS-3, following the TM of auditory training (Ross-Swain, 2007). In the current study, significant improvement was found on three of the four measures of short-term memory (Gsm) assessed by the TAPS-3 subtests: Numbers Forward, Numbers Reversed, and Sentence Memory.

Limitations and Implications

The current exploratory study provides some optimism for the efficacy of auditory training to improve auditory weaknesses. However, there are several limitations which must be considered. First, although compared to previous research the sample size in the present study was a relative strength, there was a large percentage of missing data for many of the outcome variables. This was due to the data being collected retrospectively, so not all participants had completed the same tests at all time points. Consequently, some variables were unable to be tested due to an insufficient sample size. This highlights the need for a consistent set of assessment measures to be administered to all participants.

Second, the short-term memory (Gsm) and narrow auditory processing (Ga) abilities assessed were limited to those measured by the specific assessments at the Listen and Learn Centre®. Another strength of the current study is that, unlike previous studies, the measures employed assessed the specific abilities that the ATP aims to improve, rather than changes in behaviour or language. However, only the TAPS-3 subtests measuring short-term memory (Gsm), not those assessing phonetic coding (PC), were administered. These additional measures of phonetic coding (PC) would have been useful to further verify the findings that phonetic coding (PC) improved following the ATP. Future research might consider investigating whether improvements are found in other narrow auditory (Ga) abilities following auditory training.
A third limitation is that the current study did not employ a control group as a retrospective database was used. Without a no-treatment or placebo group, it cannot necessarily be concluded that the improvements are not due to factors other than the ATP intervention. There is a need for planned intervention studies that employ a control group in order to provide validity evidence for auditory training interventions and confirm that any positive changes are a result of the auditory training itself.

Fourth, not all the measures used in the current study have been theoretically classified according to the CHC model (Flanagan et al., 2013, Flanagan et al., 2015 researchers). In this study, some of the measures were matched by the researchers of this project, by comparing the descriptions of each narrow auditory processing ability (Ga) with the description of a given subtest. However, it would be helpful for future researchers to use a robust method to formally classify measures of auditory processing according to the CHC taxonomy.

Finally, the results of the current study may be contaminated by possible practice effects from using the same measures at pre and post testing. Additionally, some participants undertook a number of intensives (one, two, or three) and were tested using the same measures following each intensive, thus creating the possibility for further practice effects. In order to address this issue, future researchers evaluating auditory training programs could use different measures of the same narrow ability, as classified according to the CHC taxonomy, pre and post intervention, and change the order of these tests between individuals to control for order effects.

Despite these limitations, the current study provides preliminary evidence for the efficacy of auditory training programs. The findings of this exploratory study, suggesting that auditory training may improve auditory processing abilities in children, are encouraging and provide support for further research in this area. Importantly, significant improvements were found on measures of auditory processing (Ga) abilities and short-term memory (Gsm) that are linked to reading and writing abilities in the classroom (Flanagan & Alfonso, 2011; McGrew, 2009; McGrew & Wendling, 2010).
The ATP targets: encoding and decoding of speech sounds (i.e., PC); auditory performance in competing acoustic signals, dichotic listening (auditory separation and integration), temporal processing, and auditory closure (i.e., UR); sound localization (UL); and auditory memory (Gsm). Improvements in these areas were expected based on the theoretical framework of neuroplasticity, and the ATP emphasis on improving these specific areas of cognitive ability. Clearly defining and testing the specific auditory processing abilities that the intervention claims to improve is important as it allows research to test whether claims are supported.

**Conclusion**

This study provides preliminary evidence supporting the ATP as an auditory training intervention, for children aged 5 years 2 months to 16 years 7 months, with deficits in auditory processing. Auditory training programs are expensive, time-consuming, and lack research supporting their efficacy. Findings suggest that auditory training targeting auditory processing abilities (Ga), and working memory (Gsm) directly is an area of research worth pursuing. This study classified measures of auditory processing according to the CHC taxonomy, an empirically validated measure of intelligence. This was useful in providing clarity in the definition of the variables being measured, underpinned by a well-validated theoretical model. Future research in the field of auditory processing, by employing the CHC taxonomy of intelligence to identify changes in specific auditory processing (Ga) abilities, will allow for comparisons to be made between studies. Importantly, studies are needed that employ a research design that includes a large sample size, a control group, an empirically supported theoretical underpinning such as neuroplasticity, and the use of the CHC taxonomy to classify measures so results can be compared to other studies. Research showing which specific auditory processing abilities (Ga), and other related cognitive processes, such as short-term memory (Gsm), can be improved by auditory training will lead to a better understanding of the underlying deficits that may contribute to learning difficulties in the classroom, and ultimately inform intervention.
References


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