The impact of an auditory training programme (The Listening Programme®) on the auditory processing and reading skills of mainstream school children

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Content

Tables and Figures:

Abstract

The impact on listening difficulties in children due to impaired central auditory processing is currently a topic of considerable interest. This is due to the high reported incidence of deficits in auditory processing ability (the main deficit reported being poor speech discrimination ability in background noise in the classroom setting (Witton, 2010), and potential impact on reading deficits, through poor auditory temporal processing skills impacting on phonological awareness and reading abilities (Tallal et al, 1980; Stein et al, 1997; Goswami, 2011). There is currently a lack of consensus regarding the underlying cause of these listening difficulties, including the impact of higher order cognitive function (attention) and test materials used to diagnose impaired auditory processing function. Despite this lack of consensus, there are currently several commercially available systems claiming to improve reading and listening skills. These include the use of spectrally filtered classical music to reportedly improve neural synchrony of the central auditory system, an example is that of "The Listening Programme® (TLP)" produced by Advanced Brain Technologies. The British Society of Audiology and American Speech and Hearing Association currently report these interventions as experimental with little high quality scientific evidence.

The aim of this study to investigate whether TLP® could affect an advance in auditory processing and reading skills in typically developing school age children (aged 8-9 years) compared to non-filtered classical music and a non-music control group.

This study used a pseudo-random control trial design involving 21 participants. A series of auditory processing tasks including speech discrimination in noise, auditory attention and Backward Masking (a test of auditory temporal resolution) and reading tasks (including task of phonemic decoding; a test of a participant's phonological awareness) were performed at pre and post intervention stages. All subjects were of average/above average readers. This study

was underpowered and therefore concrete conclusions regarding the efficacy of the use of TLP® to improve auditory processing and reading skills in typically-developing children cannot be made. Correlations between temporal resolution and reading ability were not seen, as had previously been suggested (Tallal et al, 1980). The development of further research is discussed.

Declaration

No work referred to in this thesis has been submitted in support of another degree or qualification at this or any other university or institute of learning.

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CHAPTER 1

INTRODUCTION

Communication is a key aspect of human existence, of which spoken language is the most used form of communication. The development of spoken language is a continuous process from birth, for which the earliest years are of most importance (Jackendorf, 1993). Before speech is processed at a linguistic level, it must be processed by the auditory system. Such transference through the peripheral and central auditory systems results in transformation, divergence and convergence of varying perceptually salient cues in speech prior to the involvement by linguistic levels of processing. This results in the need for a functioning peripheral and central auditory system as a prerequisite for the development of speech. This chapter aims to offer a synopsis of the subsequent chapters:

Chapter 2 offers a rationale for the need of the current investigation. It starts with an overview of the auditory system, in particular the central auditory nervous system (CANS) and its role in the transduction and processing of sound. The focus of the chapter is on the effects of subtle deficits in the CANS and its impact in the development of reading skill. Finally this chapter will examine the current evidence regarding remediation methods for such difficulties, focussing on the role of music in these interventions; in particular new commercially available systems. It concludes with a discussion of a gap in current knowledge which this investigation attempts to answer.

Chapter 3 presents details of the methodology of the current study, including the rationale for each experimental measure performed, as well as a discussion of the methods used and information regarding participant selection and recruitment.

Chapter 4 aims to disclose the results of the current. Statistical analyses of these results are highlighted.

Chapter 5 is a detailed examination of the results obtained during data collection in relation to current evidence, drawing conclusions and suggesting requirements of future work.

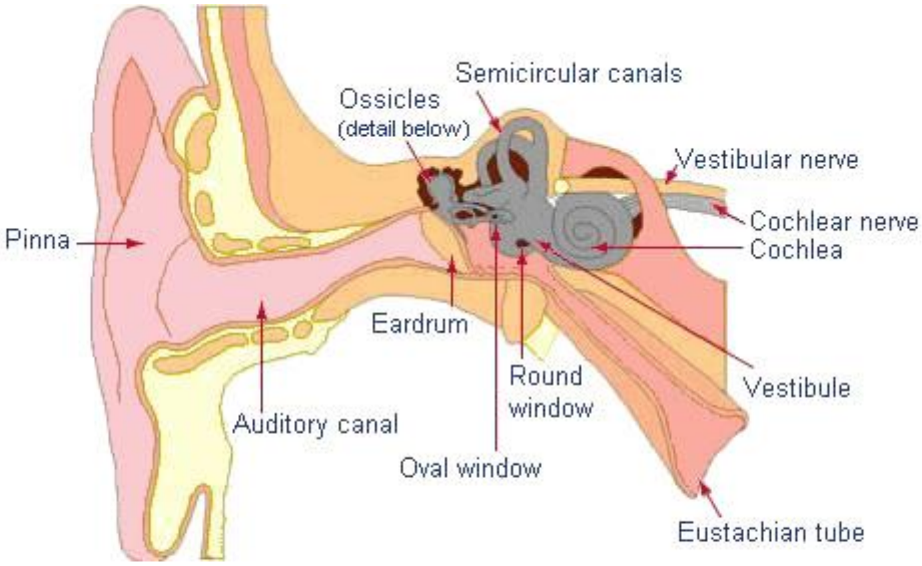
CHAPTER 2

BACKGROUND INFORMATION

2.1 *Overview of anatomy and physiology of peripheral auditory system*

The peripheral auditory system (Fig 2.1) is comprised of the structures of the ear prior to the Auditory Nerve (Cranial Nerve VIII). These structures act as a sound collection and transducer system converting the acoustic energy of the incoming signal into electrical impulses that are then conveyed by the Auditory nerve to the Central Auditory Nervous System (CANS). The peripheral system consists of the external, middle and inner ear.

Fig 2.1 Diagram of the Peripheral Auditory System



www.listenandlearn.com.au (accessed 7/3/13)

The external ear, or pinna, acts as a sound collection device, funnelling acoustic energy towards the Tympanic Membrane and middle ear system via the external auditory meatus (Pickles, 1988). This funnelling effect has two main consequences on the incoming signal. Firstly, natural resonances of the pinna, concha and meatus produce an increase in sound pressure of 15-20 dB between approximately 2000 and 7000 Hz (Yost, 2000). The second effect is caused by the angle of reflection of incoming acoustic signal by the external ear, resulting in the modification of the acoustic signal by the pinna and concha (Yost, 2000). These modifications create differences between time and intensity of the signal at both ears and play an important role in the ability of the auditory system to localise sound in the horizontal plane (Pickles, 1988).

The middle ear acts as a first phase transduction device converting acoustic energy in the air into mechanical energy in the cochlea overcoming the impedance mismatch between the low impedance medium of air and the high impedance medium of the cochlea fluids (Yost, 2000). This is achieved through a number of specific mechanical functions of the middle ear system which produce a force multiplier effect to overcome the impedance mismatch (Pickles, 1988).

The middle ear transfer function also has an effect on the spectral properties of the transferred system by essentially acting as a band pass filter, reducing transmission of sound at low and high frequency (<100 Hz and >10,000 Hz). This however has very little impact on the spectral content of speech, which lies within this band pass filter, but rather minimises the effect of unwanted noise outside this filter band (Yost, 2000).

The transmission of mechanical energy through the stapes footplate into the oval window occurs in a complex piston-like movement which is dependent on intensity and frequency of the incoming signal. The piston-like movement creates a travelling wave throughout the cochlea (Yost, 2000)

The Cochlea acts as the second stage transducer converted mechanical energy into electrical impulses which can be decoded by the CANS. It is comprised of three passages; the Scala Vestibuli, Scala media and Scala Tympani. The Scala Vestibuli extends from the oval window to the apex of cochlea where it connects with the Scala Tympani which run parallel to the Scala Vestibuli to the round window. The Scala media is a completely enclosed membranous duct that separates the Scala Vestibuli and Tympani. It is separated by the Scala Vestibuli by

Reissener's membrane and from the scale Tympani by the Basilar membrane, along which the auditory sensory organ known as the Organ of Corti lies (Yost, 2000)

Cochlear fluids are virtually incompressible (Pickles, 1988), therefore as the travelling wave conducts up the Scala Vestibuli and through the Scala Tympani the round window bulges into the middle ear space allowing pressure to be relieved (Pickles, 1988). The actions of the travelling wave cause displacement of the basilar membrane, with the rate of displacement altering along the membrane in accordance with frequency of the travelling wave. The basilar membrane is not a uniform shape or thickness therefore each region of the membrane responds best to a specific frequency known as its characteristic frequency (Pickles, 1988).

Within the organ of Corti reside two types of hair cell structure; Inner and Outer hair cells (IHC and OHC) with OHC being more numerous by a ratio of approximately 3:1 (Demanez and Demanez, 2004). As the travelling wave passes along the Basilar membrane, the hairs, or cilia, of the IHC are displaced creating action potentials within the cells, which cause the connected auditory neurones to fire. Basilar membrane displacement is not a purely passive system but includes active amplification due to the movement of the OHC (Kim et al, 1986).

In summary, the peripheral auditory system provides a transduction system from acoustic (air-borne) energy to electro-chemical energy seen in the Auditory Nerve. The Cochlea also provides a primary auditory processing stage prior to the CANS which is important for frequency selectivity and sound localisation. The following section will discuss the anatomy and physiology of the CANS, and its ability to process the auditory information received from the Auditory Nerve.

2.2 *Introduction to the anatomy and physiology of Central Auditory Nervous System*

The anatomy and physiology of the CANS is far less well understood than that of the Peripheral Auditory System. Despite this, there has been a dramatic increase in knowledge over the last 50 years.

The anatomical limits of the CANS (Fig 2.2) start at the Cochlea Nucleus and end at the Primary Auditory Cortex (AI). Between the two limits of the CANS several relay stations located within the Brainstem and midbrain conduct information both up (afferent) and down (efferent) throughout the CANS. The Auditory Nerve is the primary innervation from the peripheral auditory system to the CANS, as such it will be discussed with CANS.

Figure 2.2: Schematic diagram of the CANS (Yost, 2000; fig 7.10, p121)

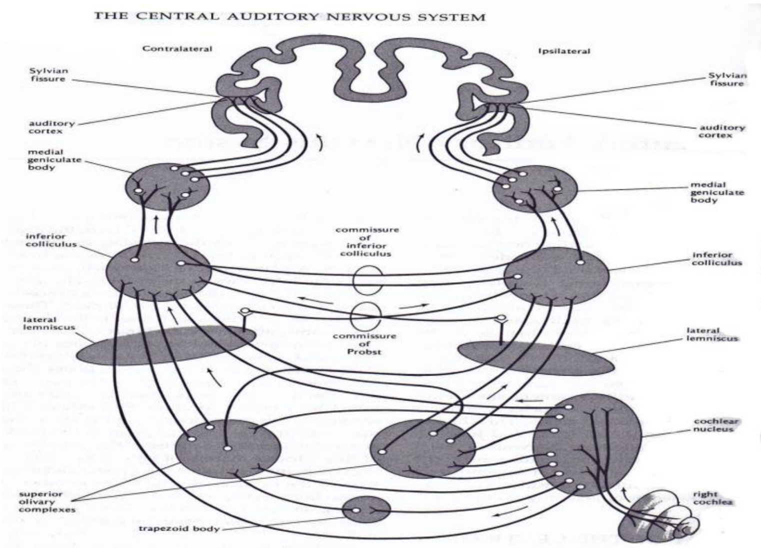


Figure 2.2 shows the complexity of the ascending CANS, including the 3 main relay centres prior to cortical involvemnt; the Cochlear Nucleus (CN), Inferior Colliculus (IC) and Medial Geniculate Body (MGB) between the Cochlea Nerve and AI. Further to these main afferent relay centres, numerous neurones also connect to the Superior Olivary Complexes (SOC) and

Lateral Lemiscus (LL) (Yost, 2000). There is a bilateral projection of ascending neurones (primarly through the SOC and LL within the lower CANS and through the Corpus Callosum at the cortical level, with a significant contralateral dominance (Demanez and Demanez, 2004).

The detailed analysis of the anatomy and physiology of the subsections of the CANS is beyond the remit of this dialog, as such the discussion will focus on a brief overview of each subsection's key contribution to auditory processing.

The Human Auditory Nerve contains approximately 30,000 individual neurones (Harrison & Howe, 1974), which provide the direct synaptic connection between the Inner, and Outer Hair Cells located within the Cochlea (Peripheral Auditory System) and the Cochlea Nucleus (CANS). There are two types of neurone within the Auditory Nerve; Type I and Type II, with Type I being myelinated exclusively innervating IHC and compromising 95% of the overall number of Auditory Nerve neurones (Morrison, 1975). Each IHC is innervated by approximately 20 Type I fibres (Pickles, 1988) thus creating a high degree of redundancy, and thus are shown to be the primary afferent pathway to the CANS (Demanez and Demanez, 2004).

As well as acting as the transmission path (afferent and efferent) from peripheral to central auditory systems, the Auditory Nerve acts as the first level of auditory processing of the signal. At the level of the Auditory Nerve, the incoming electro-chemical signal from the Cochlea is broken down into constituent components via phase-locking (entrainment of the neural firing of the auditory neurones to the frequency of the signal), and tonotopic organisation (Bamiou et al, 2001). The efferent role of Type II neurones allow for the adaptation and suppression of the afferent auditory signal due to their involvement in regulating cochlea mechanical response (Demanez and Demanez, 2004).

The Cochlear Nucleus is the primary site for all afferent connections of the Auditory Nerve to the CANS, and is divided into 3 main areas: the Anterior Ventral Cochlear Nucleus, the

Posterior Ventral Cochlear Nucleus and the Dorsal Cochlear Nucleus (Yost, 2000). The multiple interconnectivity of Auditory Nerve and Cochlea Nuclei neurones create a high degree of redundancy of signal, and concept of convergence/divergence seen throughout the rest of the CANS (Demanez and Demanez, 2004). The Cochlear Nuclei contain multiple cell types with differing neuronal response patterns. These are localised to specific areas of the Cochlear Nucleus (Yost, 2000) and are hypothesised to relate individual specialities of the sub-nuclei (Musiek et al, 2000).

The structure of the Cochlea Nuclei allows for the enhancement of modulations and transient structures of the incoming signal via the role of multiple cell responses and the convergence/divergence of the innervation between Auditory Nerve and Cochlear Nuclei (Musiek et al, 2000). These roles also allow for a preliminary feature extraction process (Masterton, 1992).

The afferent projections from the Cochlear Nuclei to the Superior Olivary Complex occur from all subsections of the Cochlear Nuclei, with afferent innervations occurring bilaterally (Yost, 2000). The bilateral innervations result in the Superior Olivary Complex becoming the first level of the auditory system for binaural input and a pivotal input for the detection of interaural time and intensity differences the basis of spatial mapping of the acoustic environment and a key contributor to auditory processing (Moore, 1994). The tonotopicity of the afferent signal is also preserved at this level (Demanez and Demanez, 2004), as well as playing a feedback control mechanism for cochlear mechanics via the efferent auditory pathway (Yost, 2000).

The afferent projections from the Superior Olivary Complex innervate bilaterally to the Inferior Colliculus via the Lateral Lemniscus, resulting in the Inferior Colliculus being a major relay station of the central auditory system (Pickles, 1988). These bilateral afferent innervations allow the Inferior Colliculus to continue the coding of binaural cues (Litovsky et al, 2002; Skotun et al, 2001), as well as providing sensitivity to amplitude modulation of incoming stimuli (Krishna and Semple, 2000).

The Inferior Colliculus is split into three main nuclei; the central, external and dorsal (Yost, 2000). The central nuclei are shown as the primary auditory nuclei within the Inferior Colliculus and have a high degree of tonotopicity (Merzenich and Reid, 1974). The external and dorsal nuclei do not hold the higher degree of tonotopicity seen at the lower levels of the CANS, but rather receive inputs from other sensory and cognitive processes (Chermak et al, 1997; Bellis, 1996). These inputs result in the Inferior Colliculus providing the first-stage of multi-modal integration to other somato-sensory systems, dividing the afferent pathway into the primary and diffuse auditory systems (Demanez and Demanez, 2004).

The afferent pathways of the Inferior Colliculus innervates the Medial Geniculate Body, which provides the last of the three obligatory relay stations of Brainstem CANS prior to cortical involvement (Yost, 2000), of which all afferent fibres of the Inferior Colliculus synapse (Yost, 2000). As with the Inferior Colliculus, the Medial Geniculate Body contains several subsections;

The ventral region is characterised as the primary auditory relay station (containing a high degree of tonotopicity) which is particularly sensitive to slowly changing temporal structure, important for syllable contrasts (von Kriegstein, Patterson and Griffiths, 2008). In comparison, the medial and dorsal regions act as multi-modal integration centres, and are innervated by both the ventral region and other somatosensory systems. The Medial Geniculate Body is thought to play an important function in auditory attention (Demanez and Demanez, 2004).

The afferent connections of the Medial Geniculate Body to the Auditory Cortex arise from each subdivision. Projections from the ventral Medial Geniculate Body provide the primary afferent auditory pathway and synapse solely with the Primary Auditory Cortex providing a “core” afferent pathway. In contrast, secondary afferent pathways are seen to arise from the medial and dorsal MGB providing multi-modal afferent input to the Auditory Cortices (Demanez and Demanez, 2004; Yost, 2000, Pickles, 1988).

The Auditory Cortex is a series of subsections within the temporal lobe of the brain that responds to auditory information, and represents the principal site of cortical processing of sound with inter-hemispheric communication provided through the Corpus Callosum. The Auditory Cortex is represented by a three tier hierarchical system involving the three individual subsections of the Auditory Cortex: the primary (AI), secondary (AII) and tertiary cortices (AIII). In addition to temporal lobe activation, both the frontal and parietal lobes are also responsive to auditory stimulation (Demanez and Demanez, 2004).

The AI represents the “core” region of tonotopic processing of sound within the Auditory Cortex building on the high degree of frequency specific information received from the ventral Medial Geniculate Body (Demanez and Demanez, 2004). In addition to the frequency selectivity seen within the AI, there are several subsections that code specifically for other dimensions such as amplitude and temporal characteristics of sound (Musiek et al, 2000).

The AII region represents the second tier of cortical auditory processing, and obtains the majority of afferent information from the AI and the medial and dorsal Medial Geniculate Body (the latter via a secondary afferent auditory pathway from the brainstem), as well as lesser innervation from the ventral Medial Geniculate Body (Pickles, 1988).

The AII also shows evidence of tonotopic organisation, but to a lesser extent than that seen in the AI for pure tones (Pickles, 1988). Neural excitation has been shown to be greater for complex sound and also for speech vocalisations in this region (Patterson et al, 2002; Zatorre, Berlin and Penhune (2002). The greater excitation of the AII region to more complex tones of multiple frequencies suggests a convergence of frequency based information from the AI (Pickles, 1988; Demanez and Demanez, 2004)

The AIII represents the third stage of cortical auditory processing within the AC and is the least tonotopically organised. It is supplied primarily by the AII, as well as from the dorsal and medial nuclei of Medial Geniculate Body. This allows for both AII and thalmic input to be processed in parallel (Bellis, 1996). Further to its innervations from within the CANS, the AIII region also synapses with several non-auditory sites in the frontal and parietal lobes. It is through these synaptic connections that auditory processing continues outside the AC, thus acting as the primary multimodal cortical relay station resulting in the influence on the Auditory Cortex from arousal, general attention, auditory attention and task demand. (Bellis, 1996; Chermak, 1997).

2.3 Hemispheric Asymmetry of Auditory Cortex

While both the left and right Auditory Cortices respond to both temporal and spectral acoustic information (Berlin, 1998), there is considerable evidence supporting the role of hemispheric specialisation of Auditory Cortices. These findings come from anatomical, pyscho-acoustic and imaging investigations.

Anatomically, Geschwind and Levitsky (1968) showed that the planum temporale was larger on the left hemisphere. Musiek and Reeves (1990) reported on a relationship between the length of planum temporale and the sylvian fissure, showing a significant difference in size between the left and right in all specimens studied. In addition, Musiek and Reeves (1990) also showed that the length of Heschl’s gyrus was longer on the left. The implications of this prove significant when discussing theories on hemispheric specialisation of the cortical auditory system (Chermak, 1997).

With the introduction of improved imagery techniques, numerous studies have reported a difference in functional output between the two hemispheres dependent on the auditory stimuli used. Berlin et al (1998) used Positron Emission Topography to investigate the role of temporal processing in language lateralisation. Good temporal resolution has been previously shown to play a key role for speech recognition (Shannon et al, 1995). The results from Berlin et al (1998) showed an increased activation in the left Auditory Cortex for temporal cues, and the high activation of the right for spectral cues.

These findings complement results from behavioural studies of individuals with damaged auditory cortices, with left temporal lobe damage related to impairment in temporal processing manifested as speech disorders (Tallal, 1993; Efron, 1963). In contrast, lesions of the right Auditory Cortex caused deficits in spectral processing and pitch perception (Johnsrude et al, 2000). Kimura (1962) provided evidence of a right ear advantage for speech in a behavioural dichotic listening paradigm, suggesting that due to the contralateral dominance of the CANS, the left auditory cortex was responsible for speech.

The right sided specialisation for pitch is supported by imaging studies (Griffiths et al, 1999; Hugdahl et al, 1999) showing increased activation of the right temporal lobe in response to pitch perception. These findings are also supported by electrophysiological evidence showing left cortical involvement for the encoding of rapid temporal changes in Voice-onset Time required for consonant perception (Liegeois-Chauvel et al, 1999). These rapid temporal changes having been theorised to be the underlying mechanism behind Specific Language Impairment and Dyslexia (Tallal et al, 1974; Tallal et al, 1980). Auditory Evoked Potentials were shown to be sharply tuned to frequency in right temporal lobe (Liegeois-Chauvel, 2001), providing further evidence for the role of the right auditory cortex in spectral perception.

These investigations highlight auditory hemispheric asymmetry with regards to speech, however further inferences can be made by investigations of auditory hemispheric asymmetry with regards to music. Koelsch (2005) showed that the right hemisphere is more responsive to pitch recognition and melody (rhythm) as a response to musical stimuli. This has specific relevance to recent developments in theories in reading deficits, particularly with regards to role of rhythm perception on the perception of the speech envelope and problems with prosody as the underlying cause of reading deficits (Goswami et al, 2011).

Complementary evidence investigating phonemic contrasts in neonates using imaging techniques (Arimitsu et al 2011) has revealed a right hemispheric advantage for prosodic processing, suggesting that while rapid transient changes in acoustic signal (important for sub-syllabic speech perception) are processed by the left auditory cortex, rhythmic perception (linked to modulations of the speech amplitude envelope) important to prosody are processed primarily by the right hemisphere. (For further discussion regarding the role of rapid auditory temporal cues and amplitude modulations of the speech envelope, see section 2.7.6).

2.4 Neuro-maturation of the Central Auditory Nervous System

The structures of the of the peripheral and central auditory systems are present at relatively early gestational age, with evidence of primitive hearing being possible from approximately 20 weeks gestational age (Hall, 2000). By birth, a full-term neonate possesses a highly functional peripheral auditory system that is adult like within the first four months of life (Graven, 2008).

The maturation of the CANS is more complex. There are numerous morphological changes within the central nervous system that influence the CANS. The most prominent of these changes is that of myelination. Myelin provides a multi-layered sheath around a neurone in order to protect and insulate the fibre allowing for efficient conduction of the electrical impulse (Counter, 2010). Electrophysiological evidence of the presence of adult-like myelination at the level of the AN within the first three months of birth (full-term), however myelination of the higher CANS continues for a considerable time (Moore, 2002; Demanez and Demanez, 2004). Within the CANS, myelination is a complex process but generally follows a progressive pattern that shows increased myelination from periphery to central structures, with higher order central structures not being fully mature until the second decade of life (Bellis, 2003).

A second prominent factor in the neuro-maturation of the CANS is that of arborisation (dendrite branching). Dendrites are extensions of individual nerve fibres that form the synapses between neurone cell bodies allowing transfer of electro-chemical information (Moore, 2002). These dendrites synapse with a multiple of the other cell bodies, however not all synapses provide an efficient progression of signal. Throughout maturation, activity of the individual neurones along the CANS allows for dendrite “pruning”, resulting in inefficient synapses being discarded, thus allowing for effective transfer of information through highly myelinated synapses between neurones. While this effect occurs throughout time (and in some situations continues indefinitely), it is based upon regular activation of that neurone. This fact is extremely important when discussing the effects of hearing loss on the ability of CANS to efficiently transmit stimuli. The lack of regular activation (as with hearing impairment, even transient hearing impairment) creates a deprivational effect, resulting in a reduction of effective arborisation and reduced efficiency of the auditory system (Bellis, 2003; 1996; Chermak, 1997)

2.5 Summary of CANS

This chapter has attempted to describe the anatomy and physiology of the CANS. The CANS is a complex system involving both afferent and efferent pathways both of which are shown to have a highly complicated system of ipsilateral and contralateral innervations. In addition, there is a plethora of individual neurone responses to specific stimuli throughout and within each level of the CANS, allowing for complex analysis of acoustic stimuli.

The tonotopic arrangement seen in the Auditory Nerve, is preserved throughout the entirety of the CANS via a core ascending pathway. At higher levels of the CANS (Inferior Colliculus, Medial Geniculate Body and Auditory Cortex) the development of a diffuse/secondary pathway allows for multimodal integration with auditory analysis and has been shown to have an important implication on higher cognitive involvement (attention and memory) in the CANS. The descending pathway offers the higher levels of the CANS the ability to some extent control input into the lower levels of the CANS.

2.6 Perception of Speech

Spoken language is the primary measure of communication for humans (Diehl, 2004). It is a highly complex process that not only involves the role of the peripheral ear as a spectro-temporal analyser and CANS as a complex neural auditory processing unit, but also a higher order language processing system. There is still much debate regarding how speech is decoded and processed to give it's final percept to the listener (Samuel, 2011). The detailed examination of speech perception theories is beyond the remit of this discussion (for recent review, see Samuel (2011) and Diehl (2004). This discussion will rather focus on the acoustic-phonetic properties of speech and their impact on speech perception.

There are numerous acoustic percepts of speech that are used as perceptual cues by the listener. These include spectral and temporal information.

Speech is produced by the modification of pulmonary air pressure by the vocal tract system, including the temporal and spectral changes to the output signal (Pisoni and Remez, 2008). While the source of energy is created by the release of pulmonary air pressure, major modifications to the sound energy are the result of the physical changes of the structures of the larynx (Fant, 1960). Within the larynx lay the vocal folds, with the space between the folds known as the glottis (Gick et al, 2012). For voiced sounds, the vocal folds are adducted (brought together), temporarily block the flow of air from the lungs. This leads to an increase in subglottal air pressure which builds until it overcomes the resistance offered by the vocal folds, forcing the folds open. These then close due to the reduced subglottal air pressure, vocal cord tension and elasticity. This occurs repeatedly modulating the air flow creating pulses of air. The frequency of these air flow pulses determines the fundamental frequency of the speech sound (FØ). For voiceless sounds, the vocal folds do not adduct, creating little resistance to the air pressure. This results in voiceless sounds having no FØ.

Following its passage through the larynx, the air pulse passes through the supralaryngeal vocal tract, consisting of the oral and nasal airways. The role of the supralaryngeal vocal tract is to act as an acoustic filter and resonator of the incoming air pulses from the lower vocal tract. The supralaryngeal tract modifies the vocal note due to the effect of resonances and anti-resonances, creating concentrations of acoustic energy known as formants, thus modifying the utterance. There are multiple formants present in a single spoken utterance as a result of the effect of the acoustic-filter mechanism of the supralaryngeal tract created by the alteration of the shape of the supralaryngeal tract.

The alteration of the supralaryngeal vocal tract by movement of structures within the tract (known as articulators) allows for changes in formants and therefore of the overall utterance, with the articulation pattern of an utterance used to classify consonants in English (Table 2.1 Cawley, 1996).

Table 2.1 showing manner and place of articulation of consonant sounds in English.

place / manner	labial	labio-dental	dental	alveolar	palate-alveoral	palatal	velar	glottal
plosive	p b			t d			k g	
fricative		f v	q ð	s z	ʒ ʃ			h
nasal	m			n			ŋ	
liquid				r l				
semivowel	w					j		

(Cawley, 1996).

An utterance can be visualised using a speech spectrogram. This is a visual recording of the utterance as a function of frequency versus time as a function of intensity. An example can be shown below for the two-phoneme utterances /ba/ /da/ /ga/ below (figure 2.3).

Fig 2.3 Diagram showing actual and schematic spectrograms of formants

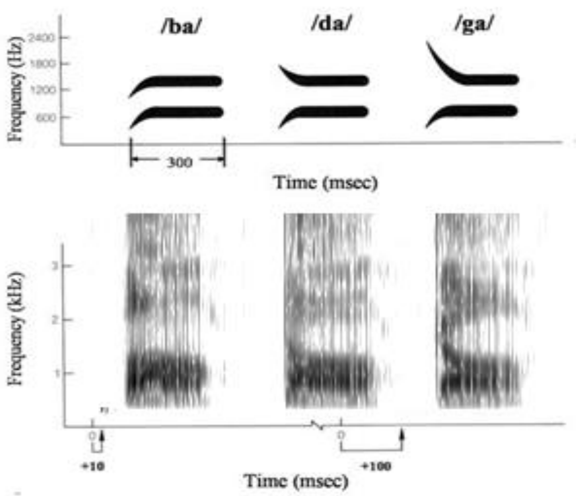


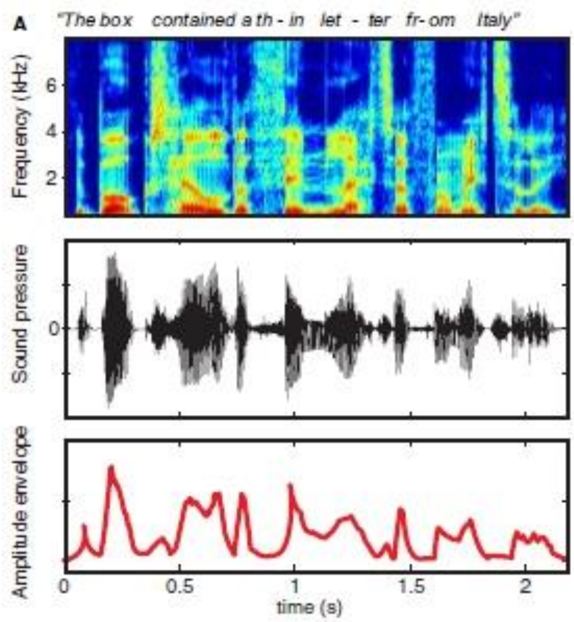
Fig 2.3 shows examples of spectrograms for two phoneme utterances. The top spectrogram shows an artificial spectrogram for the utterances of /ba/ /da/ /ga/. The bottom spectrogram shows a realistic recording of a spectrogram for the same utterances. Each horizontal shaded line represents a formant. Formants are classified by number based on their frequency. The lowest frequency formant is known as F1, with further frequencies numbered accordingly as frequency increases. In this case, all the formants (minus the initial transient shift) have the same values in relation to the fundamental for the sound "ah". Formant frequencies have been shown to be crucial in vowel characterisation, with vowel perception shown to be reliant on F1 and F2 (Fox, 1982; 1983; Rakerd & Verbrugge, 1985).

The spectrogram also offers temporal information of an utterance. Speech is a complex acoustic signal that does not run as a simple succession of individual sounds but rather individual sounds overlap producing a entity that does not just run in series (i.e. one sound follows the previous, as can be seen in written language) but also in parallel. The ability of the speech production system to articulate the following sound while completing the previous allows humans to produce a high number of sounds in very quick succession, This phenomenon is known as co-articulation (Diehl et al, 2004).

In the case of this example, all vowels are preceded by a stop consonant/ plosive. The transition between the consonant and following vowel are shown by the slopes on Fig 2.3. These slopes are known as formant transitions. Formant transitions have been shown to important acoustic cues to place the articulation of stop-vowel syllables (Kewley-Port, 1982), with their coding reliant on the rapid temporal processing of the auditory system. Deficits in rapid temporal processing in the auditory system has been suggested as the possible underlying deficit in both Specific Language Impairment and Dyslexia (Tallal, 1974;1975; 1980).

While the spectrogram offers an important representation of rapid acoustic cues required for consonant-vowel perception, it does not represent the rhythmic information of the speech signal. Rhythm is the property of the amplitude envelope of the speech signal (Rosen, 1992). In contrast to rapid acoustic cues, the amplitude envelopes of speech relate to low frequency fluctuations that arise from cyclical opening of the jaw coupled with voicing (Peelle and Davis, 2012) that are associated with physical events that occur once every syllable. This results in syllabic information dominating the amplitude envelope of speech (Greenberg, 1999).

Figure 2.4 Multiple representation of acoustic and linguistic information of a single sentence



At top is a spectrogram, showing power in different frequency ranges over the course of a sentence. The middle row shows the changes in sound pressure over time, as occur at the Tympanic membrane. The bottom row shows the amplitude envelope of the sentence, corresponding approximately to the syllable rate, and created by half-wave rectifying and low-pass filtering the speech signal (Peelle and Davis (2012) p2).

The importance of low frequency rhythmic structures in speech has been shown to be relied upon heavily by listeners. Disrupted amplitude modulation of a speech signal caused by the deletion of short segments of the signal at regular intervals has been shown to have significant impact on syllabic perception (Nelson and Jin, 2004; Wang and Humes, 2010). The removal of different speech modulation frequencies have also shown to have also offered an insight in the perception of spoken language, with listeners able to show remarkable speech recognition in the presence of low frequency temporal cues (even when all spectral cues were removed) (Van Tassel et al, 1987).

The amplitude modulations in speech that code for the low amplitude modulation rhythm perception has recently been shown to have an important role for the neural entrainment within the cognitive system (Lakatos et al 2008, 2005). Impaired neural entrainment has been suggested as the underlying cause for poor phonological ability and Dyslexia (Goswami, 2011) (see section 2.7.6.2 for further discussion of the role of neural entrainment on phonological and reading abilities).

The role of amplitude modulation on speech recognition was also revealed by Zeng et al (1999) who used a temporal smearing technique in order to distort the amplitude modulation of an incoming speech signal. The smearing technique used was based on the temporal modulation transfer function of a cohort of patients with Auditory Neuropathy[1]. A cohort of normal-hearing listeners was presented with the temporal envelope smeared signal, resulting in the cohort showing reduced speech recognition scores. In addition, performance on speech recognition of the normal hearing cohort listening to temporally smeared speech predicted the speech recognition scores of patients with Auditory Neuropathy.

This discussion has focussed primarily on the temporal and spectral changes in speech required for speech perception showing that the auditory and linguistic systems use the

[1] An umbrella term for a cohort of central auditory disorders characterised by dyssynchrony of the CANS in the transmission of an auditory signal, in the presence of a functional peripheral auditory system (BSA, 2008)

complex acoustic properties of the incoming signal to provide an accurate recognition of the signal. Despite this complexity, evidence has suggested that despite auditory speech perception continuing to develop throughout childhood it is well developed within early infancy (Cunningham et al, 2000).

Prior to birth, a foetus has been shown to be able to able to recognise familiar speech patterns. DeCasper et al (1994) showed that when pregnant women recited nursery rhymes daily between gestational weeks 33 and 37, their unborn child was able to discriminate between the recited nursery rhyme and novel control rhyme. The recited nursery rhyme elicited a decreased foetal heartrate, whereas the control rhyme did not. This suggests that prior to birth a foetal already has awareness and auditory memory of the speech rhythm of their mothers native language (note that the fetal acoustic environment is dominated by low frequency information (Armitage, 1980).

Kuhl (1993) suggests that when born, infants are “citizens of the world”, and have the ability to learn any language rather than be predisposed to that of their parental language. Eimas et al (1971) revealed that by 4 weeks, infants were able to discriminate speech sounds on a phonetic level. Lasky (1975) showed that infants were also able to discriminate speech sounds that are absent in the native language of their environment. This suggests that although an infant is able to percieve phonetic contrasts, they are not perceiving the signal as a linguistic token (as an adult does) but rather as auditory tokens (Gerkin and Aslin, 2005).

The development of infant speech perception from a generic acoustic percept into a linguistically meaningful percept is driven by statistical learning (Curtin and Hufnagel, 2009) with acoustic percepts of the speech signal that are statistically more recurrent forming linguistic percepts relevant for speech, and also for music (Hanon and Trehub, 2005b).

By 4 months, infants are able to perceive phonemic boundaries in their native langauge (Eimas, 1971) with infants at this age eliciting preferences for rhythmically structured speech, specifically to the rhythmical structure of their native language (Cutler et al, 1994). By the age of 7 months Infants able to cluster syllabic structures that tend to occur together, and are able to use syllabic stress patterns of their native language to guide lexical segmentation (Swingley, 2000). Curtin (2010) using a word-object association paradigm found that infants aged 14 months were able to store stress information of the speech signal to form prosodically rich lexical representations. By the age 4 years, children are typically able to produce and understand large, complex sentences, making use of a vocabulary of thousands of words (Bishop and Leonard, 2000).

For spoken language development to progress, it is clear that an infant requires the ability to efficient relay and analyse auditory information prior to any analysis from language processing centres. In recent years, the role of subtle deficits in the ability of the auditory system to process incoming acoustic information has become a topic of interest. The following sections will examine these deficits and their relationship with other neurodevelopmental deficits, specifically reading ability and finally describe methods suggested to remediate these auditory deficits.

2.7 Auditory Processing Disorder (APD)

2.7.1 Definition

APD is generally described as “persistent difficulties in sound perception despite normal peripheral hearing” (Kimura, 1962. Hinchcliffe, 1992). Initially this term was confined to adults who presented with known lesions of the CANS. In later years, this definition has been widened included all those who presented with listening difficulties despite normal peripheral hearing (Jerger, 1998).

This broad definition has raised several concerns regarding its suitability due to the potential application to other developmental conditions, leading to professional bodies proposing an alternative, more restrictive definition of APD. In 1996, the American Speech-Language-Hearing Association (ASHA) offered a more restrictive definition. By first defining “auditory processing” as the auditory mechanism responsible for the following processes:

- Sound localization and lateralization
- Auditory discrimination
- Temporal aspects of audition including: temporal resolution, temporal masking, temporal integration and temporal ordering.
- Auditory performance with competing acoustic signals
- Auditory performance with degraded signals

Therefore deficits in one or more of those behavioural phenomena seen above can be categorised as an indicator for APD.

The definition of APD by ASHA has been criticised for several failings: Firstly, the definition states a list of possible behavioural auditory dysfunctions that critics have argued does not present APD as a coherent syndrome (Chermak, 2001). This criticism has been expanded stating that the definition lacks suitable refinement that would separate APD from other more generalised higher order cognitive deficits (involving attention and memory), which would result in a multi-modal deficit rather than a specific auditory deficit (Cacace and Macfarland, 2005).

Cacace and Macfarland (2005) argue that the ASHA definition would result in over-inclusion of multiple deficiencies that were not auditory in cause. The authors further suggest that any definition must be modality specific, resulting from impairment in auditory processes only.

However, higher order structures of the CANS also interact with other modalities (such as attention, working memory and language) and therefore it is unlikely that deficits in auditory processing can be truly labelled as “pure” APD.

The second criticism of the ASHA produced APD definition involves the use of speech stimuli. The rationale behind this criticism is similar to that voiced by Cacace and Macfarland (2005) in that use of speech stimuli involves higher centres of the brain and hence poor performance on speech based stimuli could be the result of a purely language based disorder. In view of the criticism received by the original definition, ASHA revised the definition of APD that aimed to focus the definition towards to the purely auditory deficit by stating that “APD may be defined as a deficit that is most pronounced in the auditory modality” (ASHA, 2005).

The British Society of Audiology (BSA) issued an alternative definition, which although similar to that from ASHA differed initially in one primary component by focusing on the ability of the subject to process non-speech sounds. This non-speech based definition aims to categorise APD as a pure processing deficit in the auditory modality, thus removing compounding effects of higher order impairments (such as language impairment, developmental delay).

However, there has also been criticism of APD definitions based purely on non-speech stimuli. These critics suggest that it is impossible to categorize APD based purely on non-speech due to the influence of higher order cognitive processes seen on the CANS (Bellis, 2003). In more recent years, BSA state that the deficit may occur using speech and non-speech stimuli as part of an overall listening disorder (BSA, 2011).

In summary, although definitions of APD share a degree of homogeneity, there are significant differences that influence the diagnosis of deficits in auditory processing. Until recently, deficits in auditory processing lacked a common definition and as such caution must be used when analysing evidence relating to “pure” APD. The following section will attempt to provide a historical perspective of deficits in AP.

2.7.2 Historical Perspectives of APD

The investigation of the effect of CANS dysfunction has been on-going since the 1950’s. Early research primarily focussed on adults with known neurological lesions involving the CANS (Bocca et al 1954, 1955). These early works on assessment strategies in adults has formed the basis of a number of auditory processing tasks used today (Chermak, 1997).

The investigation of auditory processing skills in children developed later in comparison to adult studies (Chermak & Musiek, 1997). Children have been shown to perform poorly on a myriad of auditory processing tasks compared to adults; this has been demonstrated by behavioural and electro-cortical investigation (Sans and Woolley, 2011). The umbrella term of “Auditory Processing Disorder” was coined in 1977 (Keith 1997) to describe specific listening difficulties, as such investigation into the audiological field of APD in its own right developed relatively late. This was despite the emergence of several studies linking auditory processing deficits with other neurodevelopment conditions prior to this (Tallal et al, 1973, 1974, 1975) (see sections 2.7.5 and 2.7.6 for detailed analysis).

The investigation of deficits in auditory processing can be roughly categorised as being either audiological or speech and language based, however there is some overlap between these.

Audiological investigations have focused primarily on understanding the CANS, the maturation effects that are demonstrated and listening difficulties that result from deficient auditory processing. In contrast, Speech and Language based investigations have focused on the association between auditory processing skill and language development (both written and verbal) and other neurodevelopmental social communication disorders.

Despite interest in the 1970's and 1980's, the research into the area of auditory processing difficulties gained popularity in the early 1990's, and has remained a subject of substantial investigation since. This rise in prominence can be attributed to three main factors (Witton, 2010):

Firstly, the emergence of an increased body of evidence proposing a high incidence of comorbidity of auditory processing deficits and other neurodevelopmental conditions such as Dyslexia and Specific Language Impairment (SLI) (Tallal, 1974; Tallal, 1980); secondly, the impact of the high incidence of neurodevelopmental deficits in the paediatric population, including the impact on educational and social performance (Chermak and Musiek, 1997); and finally, the development and introduction of commercially available auditory remediation programmes, such as FastForWord (Tallal, 1996) that claiming to improve auditory processing and hence remediate its associated neurodevelopmental conditions such as SLI (Tallal, 1996, Witton, 2010).

The most common reported symptom of auditory processing difficulties in children is that of poor listening skills in the presence of background noise within the classroom (Witton, 2010). The following section aims to detail the acoustic properties of the classroom environment and their links to educational performance.

2.7.3 The effect of the Acoustic Environment on listening and educational performance

Listening to speech in adverse acoustic conditions is one of the most common reports of children who have listening difficulties (Lagace et al, 2008; Bellis et al 2003) with the school classroom environment often reported as a main setting of such difficulties (Witton, 2010). The effect of adverse listening conditions on the performance of children in the educational setting is well documented, with particular focus on the effect of noise and reverberation (Shield and Dockrell, 2003).

The speech signal received by a child within a classroom is dramatically affected by the acoustic properties of the environment, principally; distance between sound source and listener, early and late reverberation and background noise (Boothroyd, 2002). This examination will first discuss these important acoustic properties prior to the investigation of their impact on children.

The distance between the listener and sound source is a primary variable affecting how well the listener perceives a signal (Boothroyd, 2002). As an acoustic signal leaves the source, its acoustical energy disperses into the environment (Yost, 2000). This reduces the intensity of the signal as distance increases. This effect is known as the 6dB rule (Madell and Flexor, 2008), whereby a doubling of distance between sound source and speaker results in deterioration of 6dB in signal intensity.

This 6dB rule applies to a direct speech signal, however as this signal disperses, it comes into contact with other physical surfaces within the room such as tables, chairs, walls, ceilings, floors, other listeners (Bradley et al, 1999). The acoustic signal is reflected back off these structures into the acoustic space of the original acoustic signal (Berg and Stark, 1982). These multiple reflections that persist within the room are referred to as Reverberation and are "relatively independent of distance" (Boothroyd, 2004).

The level of reverberation is dependent on the size of the room, acoustic properties of the reflective boundaries and direction of the sound source (Davis and Davis, 1997). When the production of the original direct acoustic signal ceases, the reverberation signal begins to decay, although it may remain audible for some time. The time taken for the reverberation to decay by 60dBSPL is known as the Reverberation Time (Boothroyd, 2004). Therefore at any point the listener will receive both a direct and reverberant input; a listener close to a sound source will detect the direct signal above that of the reverberation, whereas if the listener was further away the reverberation signal will be greater than the direct signal (Fig 2.5). The distance at which the intensity of the direct signal and reverberation signal are equal is known as the critical distance, past which the signal of the reverberation is higher than that of the direct signal input.

Fig 2.5 Diagram showing impact of direct signal and reverberation in a classroom as a function of distance

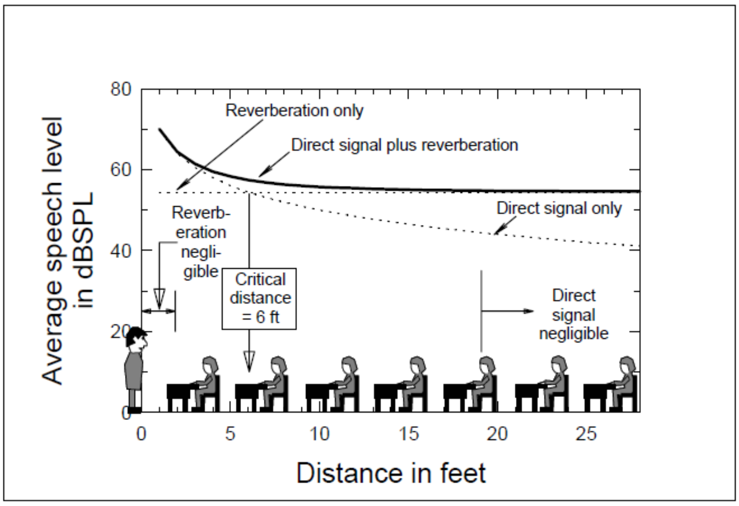


Figure 2. Predicted long-term average speech level as a function of distance from the talker in a room measuring 30x20x9 feet with a reverberation time of 0.5 seconds.

(Boothroyd, 2002; figure 2, p5)

Reverberations can be classified into two categories; early and late. Early reverberations (often referred to as "reflections") are characterised as a reflective signal that reaches the listener within 50 milliseconds of the direct signal (Bradley et al, 2003), with late reverberation characterised as any reverberation past this. Early reflections arrive at a point soon enough after the arrival of the direct signal that the listener is able to integrate them with the direct signal in order to enhance intelligibility and audibility (Bradley et al, 1999, Bradley et al, 2003). In contrast, late reverberations arrive too late for the listener to integrate them with the direct signal or early reflections (Klatte et al, 2010), and therefore effectively act as a masking noise.

The fourth primary acoustic property of a listening environment is the level of background noise. Background noise can be created internally (e.g. the hum of a radiator within a classroom) or externally (e.g. traffic noise from a nearby road) (Shield and Dockrell, 2003). It has a detrimental impact on the perception of the direct signal (Shield and Dockrell, 2003; Boothroyd, 2004; Bradley et al 2003), with particular importance on the interaction between the two demonstrated by the ratio between the intensity of the effective signal (direct signal + early reflection) and effective noise (noise + late reverberation) (Boothroyd, 2002). This ratio is known as the Signal to Noise Ratio (SNR).

Children do not have the same perceptual ability as adults with regards to listening to speech (Sussman, 1993), with poorer sensitivity to small differences in acoustic cues such as VOT (Elliot, 1986) and formant frequency transitions (Elliot and Hammer, 1988). Furthermore children assign differing perceptual weights to certain acoustic cues than adult listeners (Nittrouer and Studdert-Kennedy, 1987; Sussman, 2001; Mayo and Turk, 2005). Children are also poorer than adults in speech perception in noise (Elliot, 1979; Fallon, 2000; Hall, 2002; Picard and Bradley, 2001) and reverberation (Newman, 1983; Finitzoheber and Tiblman, 1978). Nabelek and Mason (1981) showed that the effects of reverberation and noise were worse than each condition separately, while Johnson (2000) showed that the effects of speech perception performance were correlated with age, with constant recognition maturing at approximately 13 years old for reverbatory conditions, and 13 to 15 years in noise.

Fallon (2000) suggests that difficulties in adverse conditions related to immature central auditory processing abilities in younger children, and maturation of the central auditory system resulted in improvements in speech perception in adverse listening conditions. A similar theory is proposed by Sussman (2001) with regards to the shift in perceptual weighting as a correlate of listener age. Sussman (2001) suggested that use of differing perceptual cues in speech was a result of sensory immaturities of the central auditory system resulting in children being less able to use quieter, shorter, spectrally informative cues leading to heavier use of the perceptual cues that were better defined by the auditory system at that time. However, Mayo and Turk (2005) showed that not all perceptual differences were as a result of a general auditory processing, and that its effect was only seen for certain contrasts.

Immature cognitive capacity and less well developed coping strategies have also been suggested to cause reduce performance in speech perception in adverse conditions (Stansfield and Mathesson, 2003). Cacace and Macfarland (2005) stress the role of higher order cognitive capacities such as attention on perception of speech in noise. Elliot (1979) suggests immature linguistic competencies as the overriding factor in poor speech in noise performance in children.

Boothroyd and Nittrouer (1988) proposed that an individual's speech perception abilities were also impacted by the speech material used, with recognition ability for Consonant-Vowel-Consonant syllables predicted by recognition of the constituent phonemes. This resulted in the recognition of one phoneme in the word leads to an expectation of other possible phoneme, thus increasing the probability of rapid recognition. Therefore if the word is unfamiliar, word recognition would require the correct independent perception of each phoneme. Word recognition therefore is dependent both the language knowledge of the individual and the acoustic complexity and structure of the signal. As language knowledge, acoustic-phonetic representations and sentence familiarity increases with age, less pressure is placed on the need of the auditory system to represent every individual phoneme within a sentence presented in degraded acoustic conditions, as they may be resolved using top-down processing thus resulting in adults managing with a poorer signal to noise ratio to hear adequately compared to younger children (Boothroyd, 2002).

However, this explanation does not categorise the important cognitive involvement in the task of listening in adverse acoustic conditions. Auditory Memory is important in retaining acoustic cues required for speech and language development. Presence of background noise has been shown to affect the process of committing auditory stimulus to short-term memory in young adults (Suprenant, 2007). The author argues that if such difficulty occurs in young adults then children should show greater difficulty. McCormack et al (2000) showed that short-term memory improved in typically developing school-age children from 7 years to 11 years old. However, the recall paradigm used was also sensitive to the effect of lexical knowledge (Edwards et al, 2004).

Work by Gathercole et al (2006) suggests that Auditory Working Memory plays an essential component in the process of analysing acoustic-phonetic representations and integrating them into existing phonological representations of the lexicon. Such effect is known as the “Phonological Loop” (Gathercole et al, 2006). In addition, Gathercole et al (2006) demonstrated an advantage for novel (non-word) targets with higher “phonotactic probability” or that the target words included cues with a higher relative frequency of co-occurrence of known phonemic sequences to the subject. Storkel et al (2006) also suggested that the phonotactic probability was influenced by lexical neighbourhood density (number of words similar to the target word), and suggested both phonotactic probability and lexical neighbourhood density may affect the integration of words into the mental lexicon and therefore offers a cognitive insight into the phonemic recognition effects seen in Boothroyd and Nittrouer (1988).

A further impact of noise on auditory memory was provided by Wong et al (2008). This study used a word recognition task (based on reaction time) and brain activation during functional Magnetic Resonance Imaging. Reaction time has been previously used as an index of cognitive processing (Whelan, 2008) although it is known to be linked to task complexity, sensory modality, age, arousal state and attention (Luce, 1986). The task involved acoustically presented target words at various SNRs, with the subject required to press a response button at the location of the target word that was displayed visually in one of three boxes on a monitor. Results showed that when the SNR decreased, the response time of the subjects increased, suggesting that the increased response time was due to the greater listening effort of the subject.

While the general effects of adverse acoustic conditions on learning and school attainment show that increased noise levels have a detrimental effect on learning and attainment including reading ability (Picard and Bradley, 2001; Shield and Dockrell, 2003), higher order cognitive demands such as attention and memory appear the most affected by noise exposure (Shield and Dockrell, 2003).

While this discussion has reported difficulties in speech perception and academic abilities in adverse acoustic environments including noise, it has not referred to the type of noise involved. Dockrell et al (2003) found that the type of noise had an important effect on the classroom environment and childhood educational attainment; while Nabelek and Nabelek (1994) state that the spectral characteristics of target signal and noise significantly affect the interference caused. Noise sources (as previously stated) can be external or internal to the classroom environment, with overall classroom noise consisting of both. Shield and Dockrell (2000) in a survey of London primary schools found the primary external source to be road traffic, followed by aircraft and railway noise, while Shield et al (2002) found the dominant source of internal classroom noise came from the students themselves. The intensity of the overall noise in the classroom was affected by the presence of students even if silent (Picard and Bradley, 2001), age of students (Picard and Bradley, 2001), level of activity of the class (Shield and Dockrell, 2003; Moodley, 1989) and teacher experience (Hay, 1995).

Acoustic treatment of classrooms was also shown to have a significant effect on performance in children. Bronzaft and McCarthy (1975) compared cohorts of children from within the same school but with classrooms based close to or far away from an overhead railway line. The cohort based closer to the railway line presented with significantly poorer reading scores compared to the quiet classroom cohort. This difference was not seen between the cohorts following a noise abatement programme which reduced the high intensity railway noise.

Temporary noise events such as aircraft noise resulted in a detrimental effect that was disproportionate to their overall contribution of the overall listening environment (Dockrell et al, 2003). Lundquist et al (2000) revealed a significantly stronger relationship between student annoyance caused and performance than noise level and academic performance. In addition, younger subjects (12 year olds) considered the noise to be more intrusive than older subjects (15 years old). Dockrell and Sheild (2003; 2002; 2001) also showed that annoyance caused to students was negatively correlated with age of students. Younger children were most annoyed, whereas older students showed an awareness of sound but were not reported to be annoyed by it. These findings support those of Stelmachowitz et al (2000) who showed that the greatest detrimental effect of noise and reverberation was shown by younger children, who Jamison (2004) reported to also have the noisiest classrooms.

In conclusion, the effect of classroom acoustics on children is multifactorial; dependent on acoustical properties of the room, characteristics of the wanted signal and noise (including spectral similarity), task required of the students (reading, mathematics, memory or attention), age of students and their level of irritance.

These findings illustrate that the acoustic environment of the classroom has a significant effect on the educational performance of typically developing children. For individuals with auditory processing difficulties, the situation is reported to be considerably more challenging. The following section details the attempt to assess auditory processing function within the clinical environment.

2.7.4 Assessment of Auditory Processing Deficits

The complexity of the acoustic stimuli requires the CANS to perform a wide variety of processing tasks; these include frequency, intensity and temporal coding, as well as binaural integration relating to differences in time, intensity and phase (important for sound localisation and lateralisation; Yost, 2000), binaural summation (the ability of the CANS to input stimuli binaurally and integrate them to give a total that is greater than the sum of the two individual stimuli), and dichotic listening (Chermak, 1997). The term APD therefore provides an umbrella term for numerous subtle manifestations of poor auditory processing.

There are many tests available to examine auditory processing function (Emanuel, 2002). These tests aim to examine individual sub-processes of the CANS, however there is no consensus between professionals regarding which tests should be performed, despite several attempts to do so (Bellis and Ferre, 1999; Chermak and Musiek, 1997)

There are several reasons for the lack of a consensus regarding testing. The first is the lack of a clear definition of APD creates difficulties in designing tests to examine central auditory function. The use of speech tests versus non-speech tests is an example of the impact of the lack of consensus, with speech-only test batteries theoretically allowing a subject with normal auditory function and higher order purely linguistic deficits to be diagnosed with APD (Katz and Tillery, 2005).

Secondly, it’s widely recognised that there currently lacks a “gold standard” in auditory processing tests with which to compare other auditory processing tests (BSA, 2011). The lack of a behavioural “gold standard” is unsurprising given the (until recent) lack of a coherent definition, and the compounding influence of higher order deficits on the performance on behavioural tasks (Moore, 2010). Musiek (1999) suggests the closest to a behavioural “gold standard” is the psycho-acoustic performance of subjects with well-defined CANS lesions. The use of specific electro-physiological measurements as an objective method of auditory processing investigations offers the potential to act as a reference point against which to compare other behavioural tests of auditory processing (Banai et al, 2009; 2005), however with exception of the BioMARK electrophysiological test system there are no commercially clinical systems available to test auditory processing abilities.

Finally, as APD is an umbrella term to describe a heterogeneous group of conditions and as such there are a vast number of tests available aimed to test these subtle individual deficits. There are also numerous tests available to test each specific process, with little investigation between differing tests of the same topic. It is widely recognised that many AP tests lack required normative data to make valid comparisons with appropriate control subjects (BSA, 2011), as well as not producing the required test-retest validity needed (Keith, 2009).

Despite these significant barriers to providing standardised tests of AP, the use of a test battery approach has been repeatedly recommended (Bellis and Ferre, 1999; Jerger and Musiek, 2000; ASHA, 2006; BSA, 2011). These test batteries differ in complexity but offer some degree of consensus regarding the detailed inspection of the peripheral system prior to any APD tests. However it is at the analysis of the peripheral hearing system that this consensus ends.

The vast majority of tests recommended are behavioural including non-speech tests such as measures of temporal discrimination, as well as speech based measures such as monaural low redundancy and binaural interaction (dichotic listening) tests (Emanuel, 2002) . The rationale for the repeated use of such tasks is discussed below.

Non-speech tests are reported to provide evidence of a deficit that cannot be attributed to purely linguistic deficits (Cacace and MacFarland, 2005). Of these, temporal processing tests provide the primary non-speech test in the majority of APD test batteries (Emanuel, 2002).

Despite the limitations of speech-based tests due to the influence of linguistic factors, monaural low-redundancy speech tests play an important role in recommended APD test battery (ASHA, 2004; BSA, 2011). One of the most common reports from patients with suspected APD is difficulty in listening to speech in adverse listening conditions (Dawes et 2007), therefore the use of such tests allow for functional assessment of these reported difficulties.

The CANS operates with a high degree of redundancy (Bamiou et al, 2001). This is also true of spoken language (Bellis, 1997). In situations where the incoming acoustic signal is not compromised, subjects with auditory processing deficits are not reported to function dissimilarly to typically developing listeners (Bamiou et al, 2001; Dawes et al, 2008). In adverse listening situations (e.g. speech in background noise) the speech signal may be compromised, thus creating a reduction in the available information in the signal thereby reducing the information (bottom-up) entering the higher centres of the auditory system, placing greater emphasis on the top-down processing system. Typical listeners are able to achieve auditory closure and make correct discriminations even in the presence of a degraded signal, but those with APD show significantly poorer auditory closure skills (Jerger and Jerger, 1982). There are currently several methods of reducing the redundancy of speech for clinical assessments, including frequency filtering, time compression and the addition of an unwanted signal such as background noise or reverberation (Bellis, 1997).

2.7.5 Incidence of APD and link with other neurodevelopmental conditions

The exact nature of APD remains a topic of controversy. Behavioural listening difficulties related with APD have been typically associated with other neurodevelopmental and language disorders such as Autistic Spectrum Disorder (ASD), Attention Deficit Hyper Activity Disorder (ADHD), Dyslexia, Specific Language Impairment (SLI) (Dawes and Bishop, 2009), with Chermak and Musiek, 1997 suggesting an incidence approximately 2-3% of all children will present with APD.

As well as difficulties listening in complex acoustic environment, children with APD are often described as having numerous behavioural problems, including being inattentive, easily distractible and disruptive in class situations (Dawes, 2009). Both ASHA and BSA recognise that these non-auditory behaviours are also characteristic of ADHD. Riccio et al (1994) showed that over 50% of children with APD could also be diagnosed with ADHD (cited in Dawes, 2009).

This potential co-morbidity of symptoms could be potentially explained by the effect of task demand in the classroom situation. Reiss-Jones (2000) suggested that task difficulty has an impact on attentional resource allocation, and that selective attention is modulated by the demand placed on the perceptual and cognitive systems. Therefore if a child has a deficit for listening to speech in adverse listening conditions such as a classroom, that same child would allocate greater attentional resources due to the perception of difficulty than those children who do not. Attention is theorised to have a finite capacity (Kahnerman, 1973), resulting in that capacity being drained sooner when there is a greater allocation of attention resources. In children with auditory processing difficulties, performance and behaviour will drop compared to those children who did not find the situation as perceptually taxing as their attentional capacity has been drained.

Attempts have been made by Chermak and colleagues in 1999 and 2002 to ascertain the relationship between APD and ADHD by the use of a behavioural checklist. Chermak et al (2002) argued that individuals with ADHD produced an exclusive set of behaviours compared to those with APD. Cacace and McFarland (2005) reanalysed the data from Chermak et al, concluding that the exclusive behaviours shown for subjects with ADHD and APD were far more overlapping than previously suggested, citing that Chermak et al (2002) had focused heavily on the behaviours commonly associated with the most inattentive subtype of ADHD.

Behavioural checklists have been used previously is diagnosis of APD. The development and analysis of the Children's Auditory Performance Scale (CHAPS; Smoski, Brunt and Tannerhill, 1998) previously attempted to ascertain behavioural cues to diagnose APD, however recent studies have shown that behavioural checklists (including CHAPS) do not correlate with diagnostic testing (Wilson, 2011), thus questioning the use of behavioural checklists in diagnosis of APD.

An alternative effort to separate APD and ADHD listening behaviours has been provided by use of visual attention tasks (acting as a generalised attention variable) in comparison to tests of AP function. Riccio et al (2005) showed no relationship between AP and visual variables, concluding that APD and ADHD were separate entities. This view has been recently challenged by a large scale prospective study by Moore et al (2010) who used a detailed battery of auditory and cognitive (including visual and auditory attention) tests. The results show that behavioural symptoms were “largely unrelated to sensory auditory processing” but rather based on cognitive factors, predominately attention (Moore, 2010).

The links between APD and ASD are less well understood than the relationship between APD and ADHD. Dawes et al (2009) showed that children who were diagnosed with co-morbidity of APD and ASD were overrepresented (by 9%) in a specialist clinic at Great Ormond Street Hospital, London, UK. This study also noted that children who were diagnosed with APD but not ASD presented with behavioural features characteristic of ASD but had not received a formal diagnosis. Dawes (2009) cites recent electrophysiological studies (Whitehouse and Bishop, 2008) to show that impaired auditory behaviour is related to deficits in cognitive behaviours rather than deficits in low level auditory dysfunction.

A higher order cognitive deficit would more readily explain the findings of enhanced and impaired auditory function, rather than a “mixed auditory processing profile” which relates to a global deficit which spares detailed processing as suggested by Mottron et al (2006). This would further be supported by Moore et al (2010) and the evidence of impaired higher order functioning as the primary deficit in auditory processing.

However, caution must be taken when interpreting the incidence of co-morbidity in Dawes et al (2009) between APD and ASD as the incidence was based on the referrals received to a single specialist paediatric centre. An argument could be put forward that children with ASD would be more likely to be referred to a specialist paediatric centre due to their behavioural difficulties, therefore resulting in an overestimation of incidence.

2.7.6 Language impairments (LI) and APD

The relationship between LI and APD has been and remains highly controversial (Ramus, 2012). The examination of this relationship dates back prior to the 1977 conference where the term APD was first coined. There are many LIs; however this section will limit the discussion to the two most common developmental impairments; Dyslexia/ Specific Reading Disability (Dyslexia/ SRD) and Specific Language Impairment (SLI), with the focus being on the former. Dyslexia is defined as “a deficit in reading and spelling despite adequate intelligence and access to conventional instruction” (Rosen, 2003). In contrast SLI refers to impaired spoken language abilities, in the presence of typical cognitive ability, but without the causal factor of neurological impairment or hearing loss (Bishop et al, 1997 cited in Rosen, 2003).

Prior to exploring the theoretical link between APD and Dyslexia, it is pertinent to first examine the typical development of reading. There are several theories with regards to the development of reading; the standard psychological model of reading acquisition was proposed by Frith (1985, 1986). Frith (1985) proposed that there are three main stages in reading development; Logographic, Alphabetic and Orthographic.

Preceding reading acquisition, language acquisition and development is reported to be a critical precursor to developing literacy (Joseph, 2006). Through early language development, young children acquire knowledge of important structures of speech including syntax (sentence structure) and semantics (meaning; Golinkoff and Hirsch-Pasek, 1995 cited in

Joseph, 2006) as well as gaining an increased vocabulary (McCormick, 2003). Early language development has been shown to be strongly related to sufficient stimulation, especially related to both quality and quantity of verbal interaction with caregivers (Nelson, 1996; Hart and Risley, 1995).

In the Logographic stage, the child develops the concept of printed words, but processes words visually based on the child's recognition of salient graphic features within the word. Hence recognition is based on logographic features such as shape or length of the word (Frith, 1985). This usually occurs relatively early in life, and is influenced by the child's speech and language development, as well as the quality and quantity of the child's interactions with print (Mason & Allen, 1986). As the child's familiarity with printed occurs progresses, it is postulated that the child reaches a maximum capacity for the storage of words based on visual cues, causing confusion between visually similar words. This critical capacity for the visual storage of words drives the need for the creation of a more detailed reading strategy (Joseph, 2006).

The Alphabetic stage gives rise to the development of the relationship between printed letters and sounds in speech, thus requiring letter to sound analysis by the child (Torgeson and Mathes, 2000). At this stage, it is essential that the child is able to visually represent words in a different format from that of the Logographic stage by representing ordered sequences of letters (or groups of letters), which must correspond with sounds in the child's phonological representation (grapheme to phoneme correspondence). The underlying critical component of this stage is the successful development of a child's phonological awareness (Griffith, 1991).

Lundery, Frost and Peterson (1998) postulated a four stage model of the development of phonological awareness, where the earliest form of phonological awareness is that of the awareness of Rhyming. Lane et al (2002) suggest that it is at this earliest stage that a child becomes aware that speech flow is a collection of individual words. At the Syllable stage of the development of phonological awareness, a child has the ability to distinguish syllables in spoken words, followed by the development of onset-rime awareness (third stage) which allows the child to distinguish the initial sounds of spoken words (and as been reported as the level of the theoretical deficit in phonological processing linked with poor rhythmic perception as described by Goswami, 2011). Finally, the fourth stage results in the child to code for individual sounds within words, leading to the child to be have phonemic awareness (Lane et al 2002). Griffith (1991) reports that phoneme awareness is the central precursor (of phonological development) required for the development of the alphabetic stage, and is reported to arise in typical developing children around the age of 6 years (Ramus, 2012).

With these mechanisms in situ, the child can read by sounding out sequences of letters and merging the corresponding spoken phonemes into words, thus recoding the printed word back into its oral representation (Share et al, 1995), therefore aiding in the decoding of written language (Chase and Tallal, 1991). Thus word recognition occurs through the phonological lexicon (Ramus, 2004).

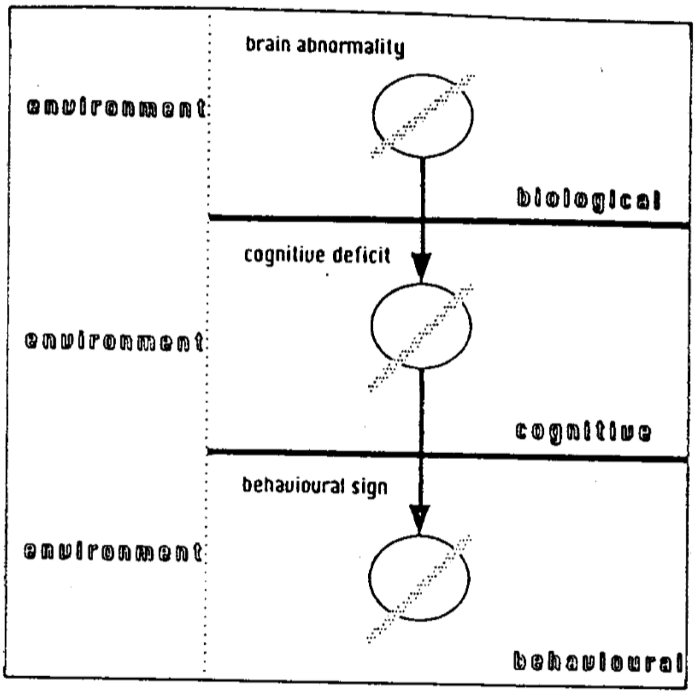
In addition, Wagner and Torgesen et al (1993) reported a strong link between phonemic awareness and working memory, proposing that ability to store phonological codes in working memory is crucial when confronting new, complex words. Munter and Snowling (1998) further argued that impaired storage of phonemes into the working memory may result in the individual being able to blend the sounds together to form the whole word.

Although the use of grapheme to phoneme correspondence allows for word recognition through the phonological lexicon, it is relatively inefficient (Ramus, 2004). The final "Orthographic" stage refers to the development of the child forming the orthographic lexicon, based upon repeated exposure to words which lead to the storage of whole-word grapheme sequences (Frith, 1985; Ramus, 2004). Therefore word recognition can occur through links between orthographic and semantic lexicon, rather than requiring grapheme to phoneme conversion that is followed by links between the phonological and semantic lexicon.

It is widely accepted that SRD is caused by an underlying deficit in phonology (Bryant et al, 1989; Goswami and Bryant, 1990; Bryant et al, 1996; Snowling, 2001), although the exact nature of the deficit in phonological awareness remains uncertain (Manis, Seidenberg and Doi, 1999). Repeated findings show deficits in phonology can be categorised into 3 areas; phonemic awareness, working memory and rapid recall (Wagner and Torgesen, (1987). Whether these competencies are independent or are a result of an underlying deficit is still unknown (Ramus, 2012). Ramus (2003) reports that an individual's reading development require grapheme to phoneme correspondence (Alphabetic stage), therefore if an individual possesses poor phonological representation and/ or recall this will have a detrimental effect on their ability to learn and spell.

Frith (1995) offered a shared theoretical framework for reading deficits, acknowledging the potential of multiple factors that may result in an individual poor reading/ phonological awareness. Frith (1995) categorised these framework as three sections: biological, cognitive and behavioural. A further adjoining section (environmental) was added (Fig 2.6)

Fig.2.6 Frith's causal model of Dyslexia (Frith, 1995; figure 2, p 8)



Frith (1995) suggests that poor phonological awareness and grapheme to phoneme correspondence are cognitive deficits that lead to behavioural difficulties in reading. However, it is postulated that the underlying cause of these cognitive deficits is biological (i.e. abnormal physiological function of the brain). However, Frith acknowledges that there are major interactions between environmental and biological influences, suggesting that behavioural signs of poor reading are not necessarily related to impaired physiological function. Frith (1995) theorises that an individual with a biological impairment may not present with reading deficits given there was suitable remedial training (environmental influence). Alternatively, an individual who presents with poor reading may not have an underlying biological impairment but rather their deficit may be as a result of environmental factors leading to poor alphabet knowledge. Therefore Frith concludes that a reading deficit cannot be specifically categorised as a physiological deficit in all cases.

In addition, Frith (1995) suggests the roles of additional factors such as poor attention and subtle visual deficits such as visual stress, which is reported to a condition which provokes visual distortions and impaired reading fluency (Wilkins, 1995). This has been shown to be improved using coloured overlays (Wilkins et al, 2001). These additional factors could theoretically result in a reading deficit but without causing a deficit in phonological awareness (for further discussion, see section 2.7.6.2, regarding the “Magnocellular Deficit” theory). Furthermore, Firth (1995) suggests that the underlying biological deficit leading to poor phonological awareness and reading deficits is impaired speech processing.

Whether the underlying cause of phonological deficiency is a result of a specific impairment in speech processing remains controversial (Ramus, 2012). Alternative theories have suggested a more basic deficit in sensory perception in the auditory modality as the underlying cause of phonological deficit found in individuals with Dyslexia. The most prominent deficit in auditory processing linked to Dyslexia is that affecting temporal cues. However, there is a lack of consistency between theories regarding the underlying nature of these temporal deficits. The three most prominent theories were reported by Tallal et al (1980) who reported a rapid temporal deficit, Stein (2001) who reported a general rapid temporal deficit in both auditory and visual domains, and Goswami et al (20011) which reported a deficit in rhythmic perception. The following subsections will examine the relationship between underlying auditory and reading deficits.

2.7.6.1 Language impairment and rapid temporal auditory processing deficits

The connection between auditory processing and language impairment was first suggested by the study by Efron (1963) which showed deficits in auditory processing (specifically deficits in auditory temporal processing) in a group of adults with acquired aphasia, following brain injury. This was proposed following findings that the aphasic group performed significantly worse on an auditory temporal order judgement task than a non-aphasic control group (who also had brain trauma) leading Efron to conclude: ‘‘we should not look upon the aphasias as unique disorders of language but rather as an inevitable consequence of a primary defect in temporal analysis’’ (Efron, 1963).

The role of rapid temporal auditory processing was later emphasised by the work of Tallal and colleagues who produced a series of papers comparing dysphasic children (former term for those with SLI) and typically developing children. Tallal et al (1973) used modified temporal order judgement (TOJ; named the Auditory Repetition Task or ART) and discrimination tasks to compare dysphasic children against an age matched control group. The task required participants to discriminate between a series of synthetic stimuli using both “long” and “short” inter-stimulus-intervals (ISI). Stimuli included complex tones, steady-state vowels and stop-vowels (/ba,da/ continuum with “short” and “long” formant transitions (F1, F2, F3)). Dysphasic children performed significantly worse on short stimuli including tones, vowels and consonant transitions with short ISI but not long stimuli or ISI. The authors concluded that dysphasia resulted from the inability of the central auditory system to sufficiently process rapid temporal speech cues (Consonant-Vowel syllables).

Tallal et al (1974) found similar results using speech stimuli, whereby dysphasic children showed poorer performance on rapid-formant transitions compared to a control group. Tallal et al hypothesised that by lengthening the transition, individuals with dysphasia would perform better and this proved to be the case (as seen by the findings of Tallal, 1975).

Tallal et al (1980) explored the possibility that rapid temporal auditory dysfunction could explain reading deficits. This study used the same tasks used previously with children with SLI, comparing a group of children with impaired reading ability with an age matched typical reading control group (mean 9.6 years). Those with reading deficits were shown to produce similar results to the control group on long ISI (428msec) for both TOJ and same/different task. However the reading impaired group scored significantly lower on shorter ISI. Further support of these findings was produced by Reed (1989) who compared 23 reading impaired children compared to age and gender controls using a variety of stimuli. The reading impaired children performed significantly worse on both rapid tone and stop-consonants with brief ISI. However there was no difference between groups from longer duration vowel stimuli, nor with rapid visual stimuli suggesting that the deficit was primarily auditory and temporal in nature. Despite the suggested deficit in rapid auditory processing in individuals with Dyslexia, only 45% of the Dyslexic sample in Tallal et al (1980) showed evidence of poor performance on the auditory tasks, thus the claim that an underlying auditory temporal processing deficit is the cause of phonological deficit in Dyslexia seems implausible. In addition, there are several limitations of the initial methodology; these include a small number of participants, a low number of trials per subject, and poor reliability in the tasks used, thus leading to high degree of measurement error.

There are further criticisms of the rapid auditory processing theory as described by Tallal et al; primarily the failure of further studies to replicate the original findings, using a range of various temporal processing assessments. McAnally and Stein (1996) showed no significant difference between typical developing and dyslexic participants on gap detection testing (the most direct assessment of auditory temporal processing). Bishop et al (1999) found no significant difference between typically developing control group and SLI on a range of temporal processing measures including the ART stating that individual differences found were influenced more on nonverbal (cognitive) ability that language impairment. A potential confounding factor involved in the study (Bishop et al, 1999) was the poor definition of the SLI group, as although all in the group showed reduced performance on language tasks, some did not show the substantial mismatch between verbal and non-verbal ability required to be diagnosed with SLI with only 6/14 children within the SLI group having significant mismatch between verbal and non-verbal abilities. The findings of Share et al (2002) contradicted Tallal et al's work as it showed that poor readers at school entrance struggled with long ISI rather than short.

Mody et al (1997) investigated the role of temporal processing deficits in poor and typically developing age matched controls by using acoustically matched sine-wave representations of /ba/-/da/ and TOJ of /ba/-/da/ (non-synthetic speech). The study found no significant difference between the sine-wave representations, but significant differences of the TOJ for the speech /ba/-/da/. Mody et al concluded that difficulties seen were due to speech specific difficulty not a more basic underlying auditory perceptual deficit. This study has more recently been criticised by Denenberg (1999) citing that the "poor readers" were not significantly poor readers compared to average readers, but rather that the control group displayed above average reading. Therefore Denenberg states that the findings cannot be used to infer the link between temporal auditory processing and individuals with SRD.

The criticism of Mody et al (1997) by Denenberg (1999) does not explain the difference between the groups. It is important to state that a correlation between factors does conclude causation, even if the “poor” readers group were too proficient at reading to be labelled as having SRD (as criticised by Denenberg, 1999), if a rapid auditory temporal processing deficit is the underlying causative mechanism in SRD then it would be reasonable to assume individuals with better reading should also perform better on auditory temporal tasks and therefore the poor reading group should perform poorly compared to the good reading group. However, this is not the case.

Ahissar et al (2000) showed a link between auditory temporal processing and reading ability in adults but correlation between the “poor” reading ability and poor auditory temporal processing was weak. Ahissar et al (2000) suggested that this may due to amelioration of reading difficulties in the adult listeners within the sample group. However, analysis of the original study by Tallal et al (1980) with children with SRD showed only 8 out of the 20 of the SRD group exhibited listening difficulties with short ISI, hence such amelioration may be plausible for those exhibiting auditory processing deficits but would be unlikely to explain why the remaining 12/20 SRD participants showed no evidence of a temporal auditory processing deficit. McArthur (2000) suggested a confounding variable that may possibly offer an explanation in the relatively good performance of some SRD children in Tallal (1980). McArthur suggested that poor auditory processing score in the SRD group is not due to rapid auditory temporal processing deficit but rather in a deficit in auditory discrimination that becomes apparent when increasing the task demand on the listener’s auditory discrimination ability.

Ahissar et al (2000) also showed a significant effect of poor cognitive ability (short term memory) in adults with childhood reading impairment. This poor cognitive ability was deemed to be the cause of the high variability of poor psycho-acoustic performers in this group. The role of cognitive ability on psycho-acoustic performance has been discussed previously, however with specific regards to TOJ tasks (Tallal et al's ART); Locke (1998) showed that TOJ performance was strongly associated with cognitive capacity (attention) suggesting that the results of TOJ task used by Tallal et al could possibly be explained by reduced attentional capacity. In addition, the SRD group performed more poorly on a range of auditory processing tasks that were based on rapid temporal changes (frequency discrimination) and that these additional deficits in auditory performance were seen in the participants with poorer cognitive abilities.

Rosen (2003) reported a limitation in ART test by participants in both the SRD and control group reaching a performance ceiling and therefore differences between the SRD and control group cannot be inferred. Several studies investigating rapid auditory temporal performance in SRD (without the impact of a ceiling effect) showed similar difficulties at long ISI as well as short for those individual participants (Nittrouer, 1999).

An enhanced temporal processing theory was suggested by Wright et al (1997), who investigated the relationship between a masking noise and short probe tone in SLI individuals. This relationship was examined by presentation of a short probe tone in the presence of a masking noise located in one of three conditions; backward (tone precedes masking noise), forward (masking noise precedes tone) and simultaneous (probe is presented in the middle of the masking noise). Results showed little difference between groups in forward masking and simultaneous masking paradigms but showed a large, significant deficit within the SLI group compared to the control counterparts for a backwards masking condition.

From this backward masking effect, Wright et al. suggest that the masking noise was perceptually interfering with the earlier tone, thus the earlier findings by Tallal et al using ART (stimuli /ba/-/da/) could be explained by the vowel masking the earlier formant transitions of the consonant (Wright et al, 1997).

The implication of the backward masking effect seen in Wright et al (1997) offers a simple theoretical link between auditory temporal processing and language difficulties, but unfortunately further analysis between backward masking and language impairments has not yielded such significant findings. Bishop et al (1999) found no significant difference on a backward masking task in a twin study (n=28) comparing language impaired twins with non-language impaired twin controls (matched for age and non-verbal IQ).

The impact of cognitive ability (attention, working memory and non-verbal IQ) on the performance of individuals undertaking psycho-acoustic tasks is known well known (Moore, 2010; Lum and Zarafa, 2010; Banai and Ahissar, 2004) as well as reading (Snowling, 2000). When comparing the control groups of Wright et al (1997) and Bishop et al (1999) there are group differences on non-verbal IQ tasks, with the control group of Bishop et al (1999) showing poorer performance (m=99.1 SD=14.6) compared to Wright et al (1997) (m=105.1, SD=6.5). Therefore, the lack of significant difference between the reading impaired group and control group in Bishop et al (1999) could be potentially explained by the impact of non-verbal IQ on the control group's poorer performance of psycho-acoustic measures.

There have been several other studies investigating the relationship between backward masking and language impairment, Rosen and Manganari (2001) showed a difference between dyslexic teenagers and age matched controls on backward masking but not forward or simultaneous masking. Montgomery et al (2005) showed similar distributions between dyslexic and control groups of younger children (age7-10 years, n=52). Ahissar et al (2000) however showed no significant difference in backward masking in adults with childhood reading difficulties. Rosen and Manganari (2001) provided evidence that refutes the theoretical link between masking of the consonant formant transition by the preceding vowel. The study used synthetic /ba/-/da/ and /ab/-/ad/, the former being representative of backward masking and latter of forward masking. Deficits on a backward masking paradigm compared to forward masking were associated with similar findings using synthetic speech. Further analysis shows that difficulty seen using speech-based stimuli disappeared using a non-speech paradigm, leading the authors to suggest that rather than basic auditory perception deficits at least a degree of linguistic deficit is seen as suggested by Mody et al (1997).

More recently, Rosen (2009) reanalysed the initial report by Wright et al (1997) citing statistical shortcomings of the original analysis. Reanalysis showed a large significant difference on backward masking but also a smaller yet significant difference between SLI and control groups for both simultaneous and forward masking. This reanalysis suggested that although deficits were seen primarily on backward masking, the significant difference between groups on both forward and simultaneous masking suggests that the auditory deficit seen cannot be categorised as a temporal processing deficit.

In a further experiment, Rosen et al (2009) used a four group design including a SLI group (n=14, mean age=15:8), non-verbal IQ and age matched control group (n=14, mean age 16:2) and two younger control groups matched on differing aspects of language development (grammar and single word vocabulary). Findings show that SLI group performed worse for both backward and simultaneous masking (not every participant in the SLI group showed deficits in masking threshold) compared to the age matched control group but not the language based younger controls. There was no correlation between the masking paradigm and measures of language.

An alternative theory of an underlying sensory deficit was put forward by Stein et al (Stein and Walsh, 1997; Stein 2001) describing the “Magnocellular Deficit”. The “Magnocellular Deficit” theory offers an elegant sensory-deficit origin for Dyslexia attempting to unify visual and auditory deficits theories under a single theory, based on deficits in the magnocellular system situated in the Cerebellum, which incorporated deficits in rapid auditory processing and visual deficits. Stein et al (2001) suggests that reading requires good orthographic (visual) and phonological (auditory) skills. The magnocellular system is reported to be responsible for timing visual events while reading (Stein and Walsh, 1997). In particular, the visual magnocellular system is thought to be responsible for maintaining both eyes onto a visual target, and therefore important for binocular fixation (both eyes focusing on the same target) and vergence control (the movement of eyes to focus on objects) (Stein, 2001). Deficits in the visual magnocellular have been suggested to lead to instability in binocular fixation and poor vergence control (Stein, 2001; Stein and Walsh, 1997; Stein, Riddell and Fowler, 1988). As reading is characterised by brief fixations followed by small saccadic movements (Rayner, 1978), such deficits are reported to leading to inability to efficiently visually fixate on a target and move on the next). Deficits in the magnocellular system were also reported to lead to impaired temporal auditory processing, thus leading to impaired phonological awareness (Stein, 2001). The magnocellular system codes for rapid temporal changes (Stein, 2001), and therefore deficits in this system would lead to deficits in the processing of rapid auditory temporal processing.

There are several criticisms of the visual impairments reported in the magnocellular deficit theory, including finding inconsistent with a specific rapid temporal visual deficit specific to the magnocellular system. Amitay et al (2002a) performed a series of visual tasks to a group of adults with Dyslexia (n=30). A series of visual tasks were designed to examine the Dyslexic group on temporal visual processing. Findings revealed that only a small subsection showed deficits based on rapid temporal visual impairment (6/30), but many showed deficits in non-rapid temporal processing, suggesting that as well as findings being inconsistent with the presence of rapid temporal visual processing, when present visual processing deficits cover a wide range of temporal and spectral frequencies.

The underlying mechanism of the visual magnocellular deficit theory has also been questioned. Stuart et al (2001) propose that visual processing deficits attributed to rapid temporal deficits in visual processing could be explained by poor attention. As poor cognitive abilities including attention have been raised in rapid temporal auditory processing tasks, an alternative explanation to rapid deficits due to deficits in the magnocellular system could be due to poorer attentional capacity in subgroups of Dyslexics.

There are major inconsistencies between empirical findings and the “Magnocellular deficit” theories based on investigations in the auditory domain. While the deficit in rapid auditory processing has been discussed earlier in this section (lack of consistency in results suggesting individuals with dyslexia suffer from a rapid auditory processing deficit, methodological limitations, including several studies (including Tallal et al (1980) suffering from small sample size and ceiling effects, reported issues with statistical analysis), there are additional criticisms that can made;

Amitay et al (2002b) examined an adult sample of dyslexic individuals on a wide range of auditory processing tasks including temporal discrimination tasks (amplitude modulation and a discrimination task between two tones with varying ISI), frequency discrimination, tone detection in narrow-band-noise and perception of lateralised position of sound based on interaural phase differences. Results revealed a subsection of the sample struggled on a variety of auditory processing tasks, however there was a lack of consistency in findings between temporal processing tasks with individuals who were deemed as poor auditory processors (based on performance on a myriad of auditory processing tasks) showed no deficit in the two tone temporal discrimination task at brief intervals as expected (based on a theoretical rapid temporal deficit). Alternatively, those individuals who were deemed to not have poor auditory processing did struggle on the two-tone discrimination task but did not struggle on the temporal task of amplitude modulation. Additionally, auditory processing ability was related to the cognitive abilities of the individual, with those showing poor auditory processing skills also scoring more poorly compared to their typical auditory processing dyslexic counterparts.

There is also evidence to suggest a lack of correlation between rapid auditory processing and measures of phonological skill or reading ability (Mody et al, 1997; Ahissar et al, 2000). It is plausible to argue that the importance of auditory processing for the development of phonological skills and reading skill is age dependent and that rather than a deficit in rapid temporal auditory processing skills, these skills may be delayed and therefore by adulthood, the auditory processing delay may been mature, and hence would not be present (or of limited presence in cases of more severe rapid temporal auditory deficits that may not fully reach maturity), resulting in the underlying deficit in phonological skill. In order to investigate whether rapid auditory processing deficits have an effect on phonological skills in children over a period of time, it would be pertinent to perform a longitudinal study assessing phonological and auditory processing skills. Share et al (2002) investigated the role of auditory processing, phonological and reading skills in children in a unique longitudinal study. 500 participants were investigated from Kindergarten (age 5) to Grade 2 (age 7). Importantly this age group were at the age that children are typically in the alphabetic moving to the orthographic stages of reading development. In addition, this study utilized the rapid auditory processing task performed by Tallal et al (1980). Results showed impaired auditory processing at long ISI compared to short ISI (in contradiction to the rapid auditory temporal deficit). Interestingly, there was a significant correlation between deficit in long ISI auditory temporal processing and phonological ability at age 5; however deficits in temporal auditory processing were not predictive of later phonological impairment.

Despite numerous criticisms, there is further support for the rapid temporal auditory deficit theory from the use of intervention studies designed to remediate rapid temporal auditory processing (Tallal et al, 1996), with intervention studies offering a further insight into the underlying issue of causation through attempted to remediate a specific component (unlike correlation-based studies that although report on relationship, cannot report on causation).

Tallal et al developed FastForWord (Scientific Learning Corporation), a computerised intervention programme designed to remediate rapid auditory processing deficits through the use of artificially temporally elongated speech sounds (spectral content is undisturbed). As the participant moves through the training programme, the temporal elongation becomes less therefore the “games” becoming more challenging to the user. Tallal et al (1996) reported the successful use of this programme with children with rapid temporal auditory processing deficits and language learning abilities. Results suggested that significant improvements in speech discrimination and language as a result of the intervention, however this study did not utilize a control group, therefore leading to the possibility of the improvements being a result of a placebo effect.

Additionally, independent studies examining FastForWord have not yielded such positive findings. Gillam et al (2001) summarised 5 small scaled, independent assessments of FastForWord. Whilst the designs suffered from small sample sizes (and therefore statistically underpowered), the paper investigated FastForWord against conventional remediation programmes. Results indicated that while participants who undertook FastForWord showed positive results, there was no significant difference compared to conventional programmes. More Recently, Strong et al (2011) provided a meta-analysis investigated the effectiveness of FastForWord. Six studies (published 2005-2009) met the inclusion criteria for inclusion. Results indicated that there was no evidence that FastForWord was effective in treating language and reading abilities in children compared to active or untreated control groups.

More recently, an alternative auditory temporal processing theory has been proposed based on larger temporal scales (Goswami et al) as opposed to rapid temporal auditory processing deficit. The following subsection aims to examine this theory.

2.7.6.2 Language impairment and deficits in auditory rhythmic perception

Goswami et al (2002) suggested that processing at larger temporal scales in this clinical population was the underpinning deficit. Goswami et al (2002) investigated the amplitude modulation/ beat perception between 24 children with diagnosed Dyslexia and age/ reading match controls. Comparisons between the groups were also made for a TOJ task, rapid frequency discrimination, as well phonological tasks examining phonological awareness, short term memory and rapid naming.

The Dyslexic group presented with significantly poorer amplitude modulation detection compared to superior reading counterparts. To a lesser extent, this was also true of the TOJ task and rapid frequency discrimination. All three auditory measures were shown to predict phonological awareness and memory but only the amplitude modulation task predicted rapid naming.

These findings led to Goswami et al (2002) to hypothesise that amplitude modulation/ beat perception with long temporal aspects relates to the detection of amplitude envelope of speech signal in particular detection of perceptual centres or “p”-centres which are the perceptual moments of speech and non-speech and in speech are typically associated with the onset of a vowel. Goswami et al (2002) argued that amplitude modulation/ rhythm perception offered a non-speech specific mechanism for segregating syllable onset and rhyme. In contrast rapid spectral changes would account for temporal fine structure changes that would be perceived by a subject as changes in speech at the segmental level (e.g. /p/ – /b/ or /b/ – /d/). Developmentally this infers that as rhythm awareness precedes awareness of onset and rimes, which precede phonemic awareness difficulties in rhythm awareness (as demonstrated by amplitude modulation) would be the primary underlying deficit in reading impairment.

Goswami et al (2002) also offered this as the theoretical basis underlying the focus on rhyme and rhythm in pre-school and later literacy development. Furthermore they suggested that findings within this reading impaired population for other auditory tasks such as backward masking was due to the inclusion of “p”-centres in the stimuli presented rather than a perceptual deficit.

Criticism of this theory was proposed by Rosen (2003) who argued that when the dyslexic group was considered in isolation then Amplitude modulation/beat detection did not correlate with non-word reading (Goswami et al, 2006).

Goswami et al (2006) reported further investigations into the role of amplitude modulation comparing a group of children with diagnosed Dyslexia against age matched and reading matched younger age control groups. Using an adaptive computer-based forced choice paradigm Goswami et al (2006) tested performance of the groups for amplitude modulation and other auditory processing tasks including TOJ. Both verbal and non-verbal IQ were controlled for in contrast to Goswami et al (2002).

Dyslexic participants performed poorly on many auditory processing tasks including TOJ task and amplitude modulation compared to control groups. Analysis of individual task variance showed the TOJ task did not predict phonological skill or literacy unlike amplitude modulation, thus supporting Goswami et al (2002) that amplitude modulation/beat detection is the primary causal auditory deficit in reading impairment (Goswami et al 2006).

More recently Goswami et al (2010) examined the role of amplitude envelope rise times in relation to prosodic sensitivity and phonological ability. A cohort of 56 typically developing and dyslexic children was measured on tasks of auditory temporal processing (amplitude modulation), prosodic sensitivity using tests modelled on earlier tests by Kitzen (2001) and phonological awareness. Dyslexic children showed significantly poorer performance on phonological and prosodic sensitivity tasks. Perception of amplitude envelope rise times was predictive of both phonological and prosodic sensitivity tasks as well as reading and spelling.

Amplitude rise time deficits have also been shown to present universally in Dyslexic individuals across multiple languages. Goswami et al (2011) compared children with diagnosed developmental Dyslexia across English, Spanish and Chinese languages. These children were compared to two control groups (reading age and chronological age) from their own languages. Amplitude rise time sensitivity proved to be the only consistent predictor of phonological awareness and reading ability across languages despite the phonological and orthographic differences between the languages.

These findings led to Goswami to refine her earlier work and propose a new causal theory between auditory processing and developmental Dyslexia. The “Temporal Sampling Framework” theory (TSF) (Goswami, 2011) offers a neural basis for the amplitude envelope deficits seen in earlier work with the reading impaired population. Goswami (2011) states that temporal coding is accounted for by the synchronous neural firings at different frequency bands (Delta 1.5-4Hz, Theta 4-10Hz and Gamma 30-80Hz) such as phase-locked firing of neural fibres to an incoming acoustic signal such as amplitude modulations. The neural firings allow for coding of amplitude modulations used for dissemination of prosody and syllabic segmentation of speech, shown to be an important predictor of phonology and reading skill.

Goswami (2011) states that from her earlier work and adapting the Multi-time Resolution Model (MTRM) of Poeppel et al (the auditory system analyses the incoming signal on multiple temporal scales, i.e. Delta, Theta and Gamma) that the underlying neural deficit in Dyslexia is a “rightward lateralised deficiency in Theta and Delta networks in the auditory cortex”. Theta oscillatory networks have been shown to be important in syllabic (Luo et al, 2007; Poeppel, 2008) and prosodic perception (Ghitze et al, 2009). Furthermore, the TSF is stated to offer a causal effect to attentional difficulties seen in dyslexia (such as wide variety of multiple auditory processing abilities seen within this population). Goswami (2011) states that as attention is enhanced when stimuli arrive in phase with neural oscillations then an impaired ability of this system to phase-lock would result in poorer attentional capabilities compared to individuals whose phase-locking ability was un-impaired.

This theory offers a more detailed and comprehensive argument for reduced auditory processing performance as the cause of reading deficits (namely reduced amplitude-rise time perception caused by impaired neural phase locking within the Auditory Cortex). However this has seen recent criticism from Ramus et al (2012) stating that findings from Huss & Goswami (2011) which showed reduced frequency discrimination as well as reduced slow temporal processing implies that in the absence of a clear relationship between frequency discrimination and temporal processing, attentional capabilities should be questioned. Furthermore, Ramus et al (2012) states that low frequencies “may categorise attentional processes required for perceptual integration”. In addition Ramus et al (2012) suggests that the reduced temporal abilities may be categorised by slower identification rather than a more basic segmentation process.

In summary, auditory processing abilities have been proposed as the causal deficit for reading impairment; specifically deficits in auditory temporal acuity have dominated these propositions. However limitations in study design, inconsistent differences between studies (including a lack of consistent correlations between auditory skills and reading/phonological skills), heterogeneous subpopulations within the reading impaired group and poorly defined control groups have resulted in a lack of acceptance of a single theoretical link. In addition, there are very few longitudinal studies regarding links between auditory processing and reading skills, with evidence for/against this theoretical link based on studies in a wide range of ages. This seems somewhat unusual given the development of auditory processing, reading and phonological skills over childhood; one may expect that key auditory processing skills would alter over time dependent on age/ developmental stage of the child. Regardless of these criticisms, there have been several suggested remediation programmes reported to improve auditory processing abilities. The use of intervention studies involving an intervention designed to alter/alleviate one specific area of potential benefit may provide an alternative way of investigating the issue of the underlying cause of Dyslexia. Unfortunately, studies so far published have proved controversial, lacking in consistent findings, with significant methodological limitations (i.e. use of control groups and blinding).

One of the more prominent themes has been the use of music to enhance auditory processing capabilities, with several remediation strategies supporting use of music. The following sections will discuss the role of music processing and potential remediation benefits for individuals with deficits in auditory processing ability.

2.8 The Relationship between music and speech

It is widely suggested that music and speech share several structural similarities (Anvari et al, 2001); both are predominately auditory in modality involving a sequence of sounds, and involve combining a number of small singular elements in series (according to rules) to produce a larger structural percept. Music, for example uses the combination of individual notes to produce melodies; whereas speech combines individual phonemes to produces syllables and further to words. Both require a normalisation process to achieve perceptual consistency. In speech, perception of individual phonemes remains constant despite individual changes in duration, intensity, timbre and pitch. Such constancy can also be found in music, with melodies providing a same perceptual constant despite these changes in aspect, as long as intervals between pitch remain equal (Downing and Harwood, 1986). Furthermore, both require substantial memory capacity for storing representations whether it is words (language) or melodies (music) (Jackendoff, 2009).

Lamb and Gregory (1993) suggest that auditory analysis skills used in speech perception (e.g. segmenting and blending) are similar to those used for rhythmic, harmonic and melodic discrimination. Saffran et al (1999) builds upon these similarities by proposing that despite different elements between music and language, these similarities allow learning music and language to be achieved using the same principles. Furthermore recent advances in neuro-imaging using functional MRI have shown that music and speech share several common cortical mechanisms (Patel and Peretz, 1997).

Fernald (1989; cited in Anvari et al, 2002) states that speech directed to young children is often referred to as “musical speech” due to its musical characteristics such as slow tempo, high pitch and volume of repetition. This musical speech has been shown to be present throughout different cultures (Fernald, 1989; 1991) and that its use is intuitive with young children, regardless of relationship with the child (Dunn and Kendrick, 1982 cited in Anvari, 2002). Furthermore, Patel (2003) suggests that the linguistic rhythm of a culture leaves an imprint on its musical rhythm, therefore enhancing the link between music and linguistic features in that cultural relationship. Patel (2008) offers further evidence for this link stating that note length in a culture's music correlates with the length of syllables in spoken language.

Hannon and Trehub (2005a) offer further evidence in support of cultural bias in perception of music with an experience dependent tuning of musical rhythm developing over the first year of life. At 6 months of age, infants (who have no previous exposure) are able to distinguish rhythmic variations of both isochronous and non-ischronous (Ischronous rhythm is typical in western music, whereas non-ischronous rhythm is typical of eastern European music) rhythms in music. By 12 months of age, infants have developed an adult-like cultural-specific bias in music rhythm (Hannon and Trehub, 2005b). This development is presumably due to statistical learning from the infant's typical environment (Hannon and Trehub, 2005b). However, such cultural-biases are easily ameliorated by exposure to foreign music structures for a relatively short space of time in infants (10 minutes a day for two weeks), unlike adults. This finding suggests that infant representations are perceptually different than adults, indicating a sensitive period for acquiring rhythm which may be as a result of infants not having the same degree of perceptual rhythmic entrainment due to lack of experience, and therefore are more easily able to modify rhythmic perception.

Despite these similarities, there are several differences noted. Firstly, many of the shared characteristics such as the use of memory and learning in a social context are domain-general characteristics involved in other sensory systems such as vision (Jackendoff, 2009) and therefore not specifically related between music and language. Secondly, despite both music and spoken language using an auditory-based hierarchal structure, use of individuals percepts in rhythm and pitch differ significantly (Jackendoff, 2007).

2.9 Impact of musical training

There is a now a plethora of investigations examining the role of musical training in enhancing the development of cognitive skills including language, auditory processing and motor control. The term "musical training" implies the active process of learning to play music (either through instrument or singing). The following section examines the evidence relating to the impact of musical training and aptitude on cognitive abilities.

Anvari et al (2002) investigated the role of musical ability in children using a cross-sectional correlational study design implementing two groups of 4 and 5 year olds (n=50). These groups underwent a series of comparisons for tasks of phonemic awareness, musical ability, reading, auditory memory, maths and vocabulary were performed. Musical skills correlated significantly with reading and phonological awareness in both age groups, as well as reading in its own right. This suggests that there is a partially overlapping auditory mechanism common to music and reading beyond that phonological awareness.

In addition, auditory memory proved to be correlated with both music and reading in the four younger age groups only and only for pitch discrimination in the older group, suggesting that auditory memory is important for younger children but is less so for the older group. The authors suggest this finding could be explained by tapping the development of the phonological system throughout childhood, with younger children with less proficient phonemic decoding abilities therefore requiring more reliance on memory.

A series of studies by Foreguard et al (2008) confirmed the findings of Anvari et al (2002). Foreguard initially investigated the relationship between phonological awareness and musical ability (as measured by a pitch processing task) between musically trained and non-musically trained groups of children. All participants were recruited from an on-going study (Foreguard et al, 2007) with the musically trained children had a mean of 35 weeks of musical training (SD= 52), the non-musically trained group were not enrolled on any form of musical training. A correlation between musical ability and phonological awareness was seen for both groups but with a significantly stronger correlation in the musical group. In a further study, musical skills in typically reading children related strongly to reading ability. Unfortunately, this second study suffered from very small group sizes (music, n=6, non-music, n=4) making generalisation difficult to justify.

Foreguard et al (2008) also investigated the link between musical ability and language in 31 children with diagnosed SRD by comparing melodic and rhythmic discrimination against standardised normative values of the Primary Measures of Music Audiation (Gordon 1986)[2] and phonological ability. Results showed the SRD children to perform more poorly compared to age-matched norms in both melodic and rhythmic discrimination. Furthermore, regression analysis showed phonological ability to predict reading, with musical ability predicting phonological ability but not reading ability directly.

In a further study, Foreguard et al (2008) investigated a musically trained control group (normal reading ability) against a non-musically trained (normal reading ability) control group and a non-musically trained SRD group (in all three groups n=5). All children were matched age, gender and non-verbal ability, and were tasked with the same investigations as in study 3. The results showed the SRD group too performed poorly on tasks of musical and reading performance compared to the normal reading control groups. The musically trained group performed significantly higher than the non-musically trained typically developing reading group and SRD group on melodic discrimination but no significance differences were seen between typically developing reading groups (musically trained against non-musically trained).

The Primary Measure of Music Audiation (Gordan, 1986) is a test of music aptitude for tone and rhythm designed for typically developing children aged 5-9. The test involves a picture based (to remove literacy skills) same/different task for two subtest; tone and rhythm. This involves the listener to responding to a set of stimuli (tone or rhythmic) and reporting whether the stimuli sets are same/different. Differences in sets of stimuli alter becoming increasingly complex throughout the series of stimuli sets. (Walters, 1991)

Foreguard et al (2008) suggested that use of musical training may improve deficits of rhythmic and melodic deficits shown in children with SRD. However, the study suffered from several short-comings. The small sample numbers used creates difficulty in inferring results for a larger population, given the lack of statistical power would not rule out Type 2 experimental error (Field, 2005). Furthermore, with the music groups being trained prior to the baseline assessment could further cast doubt on the results as group differences could have occurred prior to the initial assessment (unfortunately, pre-post assessment scores were not disclosed).

In an earlier study, Atterbury (1985) also suggested use of musical training as a remediation for poor reading performance. Atterbury (1985) compared groups of poor readers against age matched control group (age: 7-9 years) on a series of musical tasks; tonal discrimination, rhythm production and rhythm perception. Results again showed musical skill to be poorer in the reading deficit group, leading to the author's suggestion that improving musical ability would also improve reading skill.

Despite limitations discussed for behavioural tasks, the use of imaging studies has revealed several anatomical differences between musicians and non-musicians. Musicians have been shown to have a higher density of gray matter in motor, auditory and visual regions, with the density correlated with musical proficiency and also starting age of musical training (Gaser and Schlaug, 2003). Heschl's gyrus (location of the AI) was shown to be larger in musicans than non-musicians; size was also correlated to musical proficiency (Schnieder et al., 2002). The left Planum temporale (area of temporal lobe, which contains AII and AIII), known to process complex acoustic stimuli has been shown to be larger in professional musicians than the right Planum temporale (Schlaug, 2001). The Corpus Callosum has also been shown to be larger in musicians than non-musicians (Schlaug (1995). In addition, neural connections between the primary motor cortex, spinal cord and areas involved with the secondary and tertiary AC differ in musicians and non-musicians (Bengtsson et al, 2005) thus providing a possible link for increased behavioural abilities of musicians in rhythmic production such as finger tapping (Hund-Geogiadis, 1999; Hutchinson et al, 2003).

These anatomical differences may offer some insight into the functional differences seen between musicians and non-musicians for speech and language processing and reading ability. Gray matter density responds to the density of neuronal cell bodies present (Purves et al, 2008); therefore musicians have higher density/more neurones than non-musicians. This could impact the amplitude of neuronal firing patterns in response to incoming stimuli, creating increased correlation of neuronal activation compared to non-musicians, leading to a potential impact on increased synchrony and coding of stimuli, thus creating better neural synchrony for important perception abilities, in particular rhythmic perception (Peelle and Davis, 2012). Rhythmic perception has been linked to prosodic perception required for reading (Goswami et al, 2011). As this increased density occurs in both visual and auditory cortical areas, this has the potential to impact on the cortical system in response to bimodal stimulation which is required in reading.

The relative difference in size of the left than right AII and AIII regions in musicians compared to non-musicians may also offer some anatomical basis to improved behavioural performance of musicians over non-musicians. It has previously been noted that the AII and AIII code for complex stimuli (Demanez and Demanez, 2001) and also receive non-auditory innervation Demanez and Demanez, 2001). Although AII and AIII occur bilaterally, Wernicke's area is typically located within in the same region of the left temporal lobe (Bogen and Bogen, 1976). Wernicke's Area is known to be the primary site of spoken and written language perception and comprehension (Fridriksson et al, 2008) and hence increased capacity of this region could potentially result in increased neural integration between auditory and language perception centres.

As previously noted, there are some rhythmical similarities between music and spoken language, and perception of these rhythms is based on cultural bias (Hannon and Trehub, 2005a). Therefore if musical training increases the neurological entrainment of important cultural rhythmic perceptions in music, this could also potentially increase the neurological entrainment of important rhythmic perception in culturally relevant speech.

The use of electrophysiological measures to investigate the neurological effects on musical training has indicated several physiological differences between musically trained and non-musically trained populations. Electrophysiological measurements such as Electroencephalogram (EEG) have been used to investigate neural synchrony of the cognitive system (Ward, 2003). Moreno et al (2009) utilised a control study experimental design to investigate the effect of musical training in school children. 32 children without previous musical tuition were "pseudo-randomly" assigned to either a music or painting intervention group. Unfortunately, there was no information regarding the randomisation procedure. The intervention groups were matched for language, socio-economic status and all subjects were right handed. Pre and post intervention test batteries were performed for IQ, verbal short term memory, working memory, reading skill and pitch discriminations using both speech and music stimuli. In addition, EEG traces were recorded during behavioural testing to compare electrophysiological and behavioural changes.

The intervention period lasted 6 months, consisting of bi-weekly 75 minute training sessions. Findings revealed that the musical group showed enhanced abilities on reading and pitch discrimination measures (with speech stimuli) with specific components of the EEG waveform amplitude (N300) being greater in the music group. The study concluded that musical training improves basic auditory analysis and development of phonological representations required for reading. Electrophysiological differences between groups were suggested to be as a result of increased efficiency in neural networks. However, Fujioka et al (2006) suggested that N300 component on the EEG trace was related to increased attentional capability and rather an alternative conclusion could be argued that musical training increases attentional capacity within the auditory domain.

Wang et al (2009) also suggested that musicians were able to detect a series of sound patterns over a longer duration than non-musicians. 20 adolescents (all within normal hearing) were defined as either "musician" (n=10) or "non-musician" (n=10) based on whether the participant was currently undergoing musical tuition. The Mismatch Negativity (MMN)[3] component of the EEG recordings was elicited using sequentially repeated tonal patterns including an odd tone in the sequence (a tone that differed in frequency compared to the others in the sequence). In addition, the gaps between tones between the various tonal sequence trains were also varied.

Findings from Wang et al (2009) showed that musicians elicited MMN over longer duration tonal sequences compared to non-musicians, suggesting that musicians are able to detect patterns of sound input over longer durations, a skill required for detecting melodies over longer durations.

Parbery and Clark et al (2009b) also showed significant differences between musically trained and non-music adult populations in both speech in quiet and noise, using a cohort study design. Comparisons between “musician” (n=16) and non-musician (n=15) groups were made on speech in quiet and multi-talker babble (noise) elicited by the stimuli syllable /da/ using Auditory Brainstem Response (ABR) testing. ABR results were analysed by 2 examiners who were blinded to group. An independent third examiner was used if there was a disagreement between the initial examiners. Musicians were found to have faster neural timings, enhanced representations of speech harmonics and less degraded waveform morphology in the presence of background noise, related to temporal aspects of the stimuli rather than spectral aspects.

These findings were then correlated to results obtained in an earlier study (Parbery and Clark 2009a) which examined behavioural differences between musicians and non-musicians in speech in quiet and noise. Findings suggested strong correlations between more robust ABR results and better SIN performance. This has lead the authors to conclude that more robust speech-evoked ABR results in background noise and better performance on behavioural

[3] Mismatch Negativity is a component of an ERP waveform elicited by a deviant stimulus in a sequence of stimuli. It occurs after an infrequent change in a stimuli sequence and is elicited regardless of attentional state (Näätänen & Alho, 1995).

speech in noise tasks were as a result to the greater ability of the musician to phase-lock to the tempo of the stimuli waveform. However, the authors acknowledge that study lacks the ability to define whether such benefits are a result of bottom-up or top-down processing, or a combination of the two.

This study also could not account in potential participant selection bias, with regard to potential differences in population sampling pools for “musicians” and “non-musicians”. The definition of the “non-musician” group was of participants with less than 3 years musical training, which last occurred greater than 7 years prior to their enrolment on the study. Moreno et al (2009) suggested that changes as a result of musical training can occur relatively quickly (within 6 months of training), and therefore this leads to the possibility that some participants in the “non-musician” group could have some degree of musical influence compared to those without any musical tuition at all. However, the author has acknowledged that in order to compensate for these variables would be to run a prospective study with all participants initially having no musical training (similar to Foreguard et al, 2008).

Low level synchronisation in the Alpha band has been shown to be specifically linked to attentional state (Cooper et al, 2003). Musicians are required to actively attend to incoming acoustic stimuli in order to perceive and manipulate the musical instrument played (or sound production by the vocal system in the case of singing). The recurrent activation of neuronal tracts is required for efficient processing via neural synchronisation (Gotts et al, 2012). Musicians require recurrent dedicated sessions in order to enhance their musical abilities, leading to the potential improvement of neural entrainment in response to the stimulus for Alpha band activation levels. Wrigley and Brown (2010) suggest a neural oscillation model as the basis for auditory attention, particularly in response to auditory scene analysis (the analysis of several competing auditory streams of information). If Musicians have better attentional related neural synchrony to auditory attention, it would be reasonable to presume that this increased ability would relate to improvements in their ability to pick out wanted streams of auditory information from unwanted (such as listening to speech in adverse listening conditions such as multiple speakers in a classroom). Therefore, this could theoretically underlie the electrophysiological and behavioural measurement shown by Parnaby and Clark (2009) in response to speech in noise tasks.

Musicians have been shown to have anatomical and physiological differences compared to non-musicians as a result of their active musical training. In addition, these anatomical and physiological differences have been related with improved behavioural performance on auditory tasks and reading measures. Similar claims of improvement on behavioural tasks have also been made as a result of listening to music, despite listening to music being suggested to be a more passive process. The following section examines the impact of listening to music.

2.10 Impact of listening to music

The reported relationship between listening to music and academic achievement/ intelligence is long standing; however it is only in more recent years that this relationship has been investigated. Rauscher et al (1993) compared spatial-temporal reasoning abilities in 36 college students following listening to music for 10 minutes, namely Mozart. Students who had listened to the classical music performed significantly better on these tasks. These findings led to Rauscher et al (1993) suggesting that listening to classical music leads to temporary heightened spatial temporal abilities (the ability to mentally manipulate objects in three-dimensional space) coining the term “Mozart Effect”. The participants were noted to have an 8-9 point increase in scoring on Stanford-Binet Intelligence Test which includes the spatial-temporal reasoning task. It has however been noted that the 8-9 point increase is within the 15 point standard deviation of scores (Chabris et al, 1999).

Hetland (2000) provided a large-scale meta-analysis involving 31 experiments between 1993 and 1999, investigating the impact of listening to classical music on the performance on spatial-temporal tasks. Hetland (2000) showed that listening to music provided a significant improvement, with a medium effect size (d= 0.47) reported. Hetland (2000) included the use published and unpublished studies in the meta-analysis in an attempt to avoid publication bias, but did not analyse the implication of publication bias.

More recently, Pietshnig et al (2010) provided a large scale meta-analysis investigating the impact of the "Mozart Effect". Pietshnig analysed 39 studies between 1993 and 2007, including 19 unpublished studies (obtained from Hetland, 2000). While listening to Mozart provided a significant improvement on spatial tasks, the effect size was small (d=0.15). In addition, comparison of other music stimuli compared to no stimulus provided an overall effect that was comparable to the Mozart effect. Of particular interest was the analyse of "published versus unpublished" on effect size with effect sizes being far higher for published studies suggesting that those studies showing significant results with large effect sizes were more readily published.

Further investigation into the role of Mozart Effect has resulted in conflicting data, with no further studies being able to replicate the largest increase in spatial-temporal abilities seen in the original study (e.g. Chabris et al, 1999). An alternative hypothesis to explain this increase was put forward by Thompson et al (2001) who suggested that improvements on intelligence tests were not due to improvements in neural priming (as suggested by Rauscher et al 1993) but rather from an increased arousal state caused by listening to music. Thompson et al (2001) compared spatial test results of participants who had either listening to a happy piece of a Mozart symphony (from Rauscher et al, 1993), Albinoni's Adagio (a sad-sounding piece of music), or silence. Only the Mozart group performed higher on task of spatial awareness, with changes closely paralleling changes in mood and arousal. In addition, following hierarchal regression analysis removing mood and arousal, no significant variance was found to music. These findings were shown to be consistent with conclusions from Chabris et al (1999) who performed meta-analysis of "Mozart Effect" research. Thompson et al (2001) suggested that initial findings shown in Rauscher et al (1993) could be explained by the Mozart Sonata being more arousing than silence.

Hussain et al (2002) further investigated the impact of musical mode and tempo on mood and arousal. 36 Participants (age: 18-27) completed a pre and post-test battery including the same spatial-temporal task performed in Rauscher et al (1993) and questionnaire related to mood and arousal. Four versions of Mozart's sonata K448 was created; fast major, fast minor, slow major, slow minor. Performance on the spatial task was superior for the faster tempo and major mode rather than the slow tempo, minor mode. Responses from the mood and arousal questionnaire correlated with performance on the spatial-temporal task.

Nantais and Schellenberg (1999) showed that similar enhancements on spatial tasks using lively music from a different composer (Schubert), suggesting that the enhancements noted by Rauscher et al (1993) were not specific to Mozart composed symphonies. Schellenberg and Hallam (2005) re-analysis of a large school-based study (n=8000) investigating the role of music on childhood academic attainment showed little or no "Mozart Effect" on spatial-temporal task compared to when the participants listened to popular music of the era ("Blur" and "PJ and Duncan"). Despite limitations of the initial study with regards to control for compounding variables in a large sample size (including individual differences, but also group differences due to school teaching, and also potentially, group differences due to differing teaching focus within groups of schools in different Local Educational Authorities), the authors suggested that this effect was due to the increased arousal to well-known and popular music, citing that a "Blur" effect was also noted.

As the initial Rauscher et al (1993) study focused solely on spatial-temporal reasoning abilities, there has been little investigation of the role of music on other tasks of cognitive performance. Schellenberg et al (2007) investigated the role of tempo and mode on a range of cognitive abilities using subtests of the Wechsler Adult Intelligence Scale. Results indicated similar findings to previous studies relating to mood and arousal on several intelligence subtests, leading authors to conclude that tempo and mode, linked to arousal and mood were the causative factor behind enhancements on intelligence scores.

The impact of music on mood and arousal has been previously well established. Gabrielsson, 2001; Krumhansl, 1997; Mitterschiffthale et al, 2007; Peretz, 2001a; Schmidt & Trainor, 2001) have shown physiological changes in response to mood patterns caused by music, including changes in pulse and respiration rate (Krumhansl, 1997), and activity of the cerebellum (Peretz, 2001a; Schmidt & Trainor, 2001). In addition, Mitterschiffthale et al, 2007 showed changes in activation of emotional centres within the brain as well as increased auditory activity.

There are currently several commercially available listening programmes designed for the remediation of difficulties such as language impairments and auditory processing deficits. The following section will discuss music-based interventions focusing on auditory processing and reading deficit remediation.

2.11 Music-based listening programmes

The role of musical-listening interventions gained popularity in the 1990's (Mudford and Cullen, 2005) with several varying therapy regimes being reported. Despite differences between individual treatment regimes, there are several theoretical similarities. All musical-listening regimes claim to remediate numerous neurodevelopmental difficulties via listening to music that is spectrally filtered, which in turn is claimed to improve the neural-synchronisation of the auditory pathway and associated neurological systems. Of the programmes available, the two most prominent theories are based on the work of Bérard and Tomatis. One of the most prominent commercial programmes available is "The Listening Programme®" (TLP®) by Advanced Brain Technologies, which is based upon the "Tomatis theory".

The “Tomatis theory” describes the theory put forward by Alfred A. Tomatis, a French otorhinolaryngologist. Tomatis theorised that different frequencies of audible sound acted upon different functions of human physiology. Tomatis described that low frequency sound were associated with balance and rhythm as well as direction, co-ordination and localisation. Mid-high frequencies were associated with cognitive abilities such as memory, attention, speech and language capabilities and concentration. In addition, higher frequencies were reported to elicit improved auditory cohesion (Jeyes et al, 2010).

The “Tomatis theory” was first described by Alfred A. Tomatis, a French Otorhinolaryngologist during the 1950’s, Tomatis theorised that different frequencies of audible sound acted upon different functions of human physiology. Tomatis suggested that a person can only deliberately vocalise a sound that falls within the limits of an individual’s ability to monitor their own voice, and therefore improvements in a person’s auditory skills of self-monitoring would allow greater control of their own voice (www.Tomatis.com [date accessed 12/12/13])

Tomatis stated that the ear has the ability to attune itself to the entire sound spectrum of an incoming acoustic stimulus, and that it was required to do so with maximum speed and precision. In order to achieve optimum perception, the ear would need a typical response to sound (the typical characteristics of the external and middle ear such as increased high frequency resonance and correction of the impedance mismatch by the middle ear, as described in section 2.1) and the absence of distortion in these characteristics. Additionally, right-ear dominance to the control and analysis of sound was required, due to earlier claims that the right ear was more important for sound analysis (see section 2.3 for further discussion) (Heath, 2008)

Tomatis suggested that individuals with listening difficulties had a psychological refusal or reluctance to accept certain stimuli from the acoustic environment by “locking” the ear via the lack of tension of the middle ear muscles, thus creating impeding the conduction of acoustic stimuli (Heath,). Tomatis further claimed that different frequencies of sound had differing effects on the body; the higher density of inner hair cells at the basal end of the Basilar membrane in the Cochlea suggested that more impulses to high frequency sound than low frequency in the Cochlea, and that these were essential in speech. Furthermore, Tomatis stated that the Vestibular system (also situated within the inner ear) responded to lower frequency acoustic innervation, therefore linking low frequency spectral content of a signal with body rhythm and coordination.

Tomatis also placed considerable emphasis on the role of the Auricular branch of the Vagus Nerve (CN X), which innervates the Pinna, External Auditory Canal and Tympanic Membrane. Tomatis proposed using spectrally filtered music would increase the tensions of the Tympanic membrane "unlocking" the ear to allow acoustic information to move freely through the auditory system and therefore improve listening skills. Tomatis also reported that through the innervation of the Auricular branch of the Vagus Nerve(www.advancedbrain.com [accessed 12/12/13]), this allowed a direct link between an individual's own vocalisations and what was heard. In order to innervate these different frequency bands, Tomatis suggested the use of three listening zones (Jeyes et al, 2010):

- The Sensory Zone, which contained low frequency acoustic information less than 750 Hz and was designed to innervate balance and coordination.
- The Language Zone, which contained acoustic information between 750Hz to 4000Hz and was designed to innervate speech and language progression
- The High Spectrum Zone, which contained information between 4000Hz and 20,000Hz and was designed to innervate the brain and increase electrical potential needed for energy and idea formation.

Using this theory Tomatis developed the "Electronic Ear" to deliver spectrally filtered music. This involved a specialised headphone set utilizing both bone conduction and air conduction transmission. Traditionally, this treatment involved an 80 minutes per day listening phase for a 30 day listening period (Kershner, 1986a). During this time, the input was electronically gated in order to contract and relax the middle ear muscles. In addition, timing between bone conduction and air conduction stimulation methods were altered in order to train for more rapid response to the auditory system, and that the intensity level to the left ear was reduced in order to provide the listening with a right ear dominance (based on increased exercise of the middle ear system) (Heath, 2008).

Despite these claims, there are several criticisms of the Tomatis method. Primarily, there a several major theoretical flaws: Firstly, a right-ear dominance as described by Tomatis does not exist, with advantages being shown for both left and right ears based on the characteristics of hemispheric specialisation (for further details, see section 2.3). In addition, Tomatis uses a musical based intervention programme, by the nature of the incoming stimulus, it would be perhaps more reasonable to suggest a left ear dominance would be more likely than right ear due to right hemispheric specialisation for melodic sequences.

Secondly, Tomatis theory was based on the “exercise” of the middle ear muscles (namely the Stapedius and Tensor Tympani). While the Tensor Tympani and Stapedius muscles contract in order to add extra stiffness to the middle ear system to reduce the system’s conduction of high intensity energy (known as the Acoustic Reflex), these muscles are not contracted in response to low level stimuli (Katz, 2000). This questions why the involvement of this element of the middle ear system requires “exercise” if it is only implemented in the presence of sound that are approximately greater than 80dB (Katz, 2000). In addition, to cause excitation of the Acoustic Reflex, the intensity of the incoming sound stimuli must be greater than that required to elicit it (greater than 80dB), therefore raising the question of whether the intervention is safe or whether it poses a risk of noise-induced hearing loss/ Cochlea hair cell damage.

In addition, the inclusion of the importance of the innervation of the Tympanic Membrane and external ear by the Vagus Nerve seems unusual, as this does not provide sensory input to the brain in the auditory modality (Yost, 2000), and therefore the suggestion that its input is important in the connection between the external ear and the larynx via the Vagus Nerve in order to help with self-monitoring appears implausible. It would appear more plausible to suggest the improvement of the effect the vocalisation-induced acoustic reflex (Borg, 1984), however this is innervated by the Facial Nerve (CN VII) (Yost, 2000). Furthermore, recent published articles have suggested a different underlying mechanism from the original theory suggesting that the underlying mechanism is a result of increased neural myelination of the central auditory nervous system in response to appropriate stimulation, increasing neural synchrony and speed within the auditory system (Sacarin, 2009).

While there are multiple subjective reports of the benefit of the Tomatis method, there is no known high level scientific evidence in peer-reviewed journals provided in support of the Tomatis theory. Most support for the Tomatis method is in the form of low-level anecdotal, unpublished evidence lacking in strong experimental design (ASHA, 2004). Currently, professional recommendations do not endorse the use of the Tomatis method (and other music-based therapies) stating safety concerns (including the sound intensity levels used) and lack of sufficient high level evidence (BSA, 2011; ASHA, 2004).

Despite the criticisms of the "Tomatis" theory, TLP® (developed by Advanced Brain Technologies) is based upon the earlier work of Tomatis, suggesting that different frequencies impact on differing physiological functions. TLP® uses "psycho-acoustically" modified classical music (recorded using a 24bit, 192kHz sampling rate) to "exercise" the ear (www.advancedbrain.com [accessed 15/12/13]). While there are several versions of TLP®, the classic TLP® involves the listener to listen through headphones (does not involve direct bone conduction transmission as required in Tomatis's Electronic Ear) and is played at a "comfortable listening level".

TLP® uses a 20 week programme consisting of 2 repetitions of a 10 week listening schedule, with each listener required to listen for 15 minutes twice a day. Each 10 week session is divided into 4 listening phases or "zones" with weeks 1 and 2 described as "Full Spectrum" and consists of listening to classical music that is unfiltered. Weeks 3-4 are described as "Zone 1" and involve listening to classical music that has filtered through a low pass filter at 750Hz (therefore attenuating frequency content above 750Hz). This Zone is based upon the "Sensory" zone of the "Tomatis" theory, and is reported to improve balance and coordination. Zone 2 occurs in weeks 5-6, whereby classical music is filtered through a bandpass filter (a high pass filter at 750Hz and a low pass filter at 4000Hz), and is based upon the "Language" zone of the Tomatis theory focussing on Memory, Concentration, Speech and Language. Zone 3 involves classical music filtered through a high pass filter at 4000Hz and is based on the

"High Spectrum" zone of the Tomatis theory, reported to improve energy, intuition and ideas (Heath, 2008).

In addition, to spectral filtering, Advanced Brain Technologies report that TLP® also uses a modular "ABC" design to each listening session, whereby each listening period (approximately 15 minutes) can be split into 3 phases. Phase A acts as a "warm up" and is reported to relax the listener and prepare the auditory system for more intense stimulation in Phase B. Phase B is reported to a more "intensive" listening experience designed to "exercise" the auditory system, while Phase C acts a "cool down" period returning the listener to a relaxed state. Further information regarding the modular design of TLP® and the musical filtering is not available due to the commercial sensitivity of the information (www.advancedbrain.com [accessed 15/12/13])

TLP® is reported has been claimed to make significant improvements in a wide variety of skills (Table 2.2) as is currently marketed to a wide range of ages including "children, teens, adults and seniors" (www.advancedbrain.com [accessed 23/12/13]).

Table 2.2 Areas of reported improvement following TLP®

Learning	Listening	Self-Regulation
Attention	Sensory Processing	Musical Ability
Communication	Social Engagement	Brain Fitness
Reading	Behaviour	Daily Living

Despite the claims of multiple improvements, Advanced Brain Technologies provide an insufficient theoretical basis for these improvements, offering a very limited synopsis of the "Tomatis" theory. In addition, evidence provided in support of TLP® is anecdotal, low level scientific evidence with the majority being from unpublished sources provided by Advanced Brain Technologies.

Treharne (2003, unpublished) investigated the role of TLP® in a cohort of 10 children (aged 8-16) referred to the department of Human Communication Sciences (University of Sheffield) for assessment of auditory processing difficulties. Participants had a wide range of non-verbal IQ scores at pre-intervention test stage and provided their own control group (given the wide range of performance on varying tasks performed).

Pre-post intervention data was compared showing a significant improvement of detection of speech in steady state (pink) noise on the Goldman, Fristoe & Woodcock, Auditory Skills Battery, Selective Attention subtest, (Woodcock 1974). However a high degree of variability of results was shown for other aspects of the selective attention subtest, with no significant differences noted between pre-post-tests scores in these other aspects. Participants provided their own control group (given the wide range of performance on varying tasks performed).

Further support is provided for the use of TLP® by Francis (unpublished), investigating the use of TLP® with children with "profound and multiple learning difficulties". This study involved a school-based case series/ cross over design of 12 students (including 5 with Rett syndrome) who participated in TLP. All undertook a modified TLP (15 minutes a day, 5 days a week, for 16 weeks) with a randomly allocated regular music period for 4 weeks pre or post TLP (Programme total= 20 weeks). Participants were videoed for 15 minutes at regular intervals throughout the intervention period, with 2 hour classroom observation made post listening. In addition, educational progress was noted through the use of the participant's annual school review and also observations noted by both parents and teachers.

Improvements in mood only were noted for the music group, with increased engagement noted with only TLP. However there are several methodological limitations of the study. Firstly, despite the age range (12-18 years) little is known of the participants in the sample, except that none had profound hearing impairment. The author admits that obtaining reliable data was difficult due to the nature of the participants complex needs, as such there is no access to standardised data but all results were based on observations.
The observation process is not well defined, without any evidence of the use of blinding or secondary observation leading to the possibility of examiner bias. It is also unclear of the

timing of the parental/teacher feedback, and also of the use of blinding of these groups to which intervention was currently employed. In addition, there no details were given regarding the “modifications” made to TLP®.

Jeyes (2009, unpublished) investigated the role of TLP in improving auditory processing abilities in a sample of children with Downs Syndrome using a case series design. A sample of 9 participants (age 5-12) undertook TLP with pre-post measures using a series of standardised tests including; TraCol (Treharne, 1999), CELF Receptive and Expressive Language, Digit Span and Naglieri Non Verbal Cognitive Ability Test.

Despite the attempted use of these tests, most were unable to be completed by the sample population, with a small number able to perform on the Mispronunciation Test. Parental observations were also recorded. Despite these limitations, subjects able to perform on the Mispronunciation Test did show a small improvement at the post-intervention stage, however without the use of a control group, it is impossible to infer if these improvements were due to the intervention or test-retest.

Furthermore, lack of control groups and bias create difficulties when analysing observations of the subjects. There was also no inclusion/exclusion criteria noted, in particular there is no mention of audiological examination. This is particularly important for this sample population due to the well reported higher incidence of hearing impairment, including fluctuating conductive hearing impairment (Shott et al, 2001), and therefore possible confounding variable when providing an auditory intervention.

Butler and Clarke (2003, unpublished) investigated in the impact of TLP on auditory processing skills in school age children using a case series approach using pre-post measurements of auditory processing using SCAN C (Keith, 2000). 20 participants (m=11, f=9 ,age 5-10 years) underwent a 10 week TLP intervention programme. In addition, the majority of the subjects were part of sensory programme for concentration and listening.

Participants were shown to generally improve in auditory processing abilities as shown on SCAN C subtests, but with no consistency to which subtests the participants improved in. In addition, some participants showed reduced thresholds at the post-intervention stage. As this study lacked any control groups, inferences regarding improved auditory processing abilities following TLP must be treated with caution, especially as many of the individuals were included in a sensory programme for concentration and listening therefore it is impossible to show whether improvements seen were due to TLP or rather the sensory programme.

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Further unpublished pilot studies have been put forward as evidence pertaining to the benefits derived from TLP. Harris (unpublished, undated) provided a small case series of 4 children aged (12-13) based within the same class at school. All children were currently undergoing speech and language intervention at school. All children underwent a pre-post test battery of standardised auditory processing tests including SCAN A (Keith, 2000) and TAPS R & TAPS UL. All children showed very significant improvement in auditory processing as shown by performance of the test battery, however caution must be taken when interpreting these findings due to the lack of control groups and possible confounding variable of ongoing speech and language intervention.

A larger school based study was provided by Jeyes (2002, unpublished) using a case series design with 38 pupils of a primary school (aged 7-11). A pre-post test battery was performed including the Quest test of pre-reading skills to assess auditory discrimination and memory. No standardised auditory processing tasks were performed. Reading age was also calculated using either the Schonell or Salford sentence tests, unfortunately the author states that the same where applicable was used at the pre and post test battery, implying that different tests were potentially used at pre and post test level with little information given about inter-test reliability. Educational progress was assessed using the National Foundation for Educational Research progress tests performed at the end of each academic year to track academic progress.

Large differences were seen on experimental data, however all subjects did not make uniform improvements. In addition, despite the relatively large sample size, no statistical analysis was reported for the study in the report published by Advanced Brain Technologies. Parental and teacher reports showed improvements but without a placebo control it cannot be truly ascertained if the noticed improvements were truly due to improvements caused by TLP or a placebo effect and in fact improvements were down to the maturity of the child.

Nwora and Gee (2009) offered the only known published article investigating the use of TLP®; a case study of a 5 year old child diagnosed with ASD, specifically "pervasive developmental disorder". In particular, the study focused on the participants sensory processing and receptive/expressive language. Data was collected via video footage, standardised carer questionnaires (The Listening Checklist and The Sensory Profile) and clinical observation at pre and post intervention stages. Video footage was examined by both authors independently and data compared to establish inter-rater reliability.

Improvements were noted in almost every aspect in this case, including posture and handwriting, as well as reported language skills and sensory processing. Unfortunately the study revealed little information regarding the child and school interventions (assuming that a child with a diagnosis of ASD would have on-going support in a school-based setting). Furthermore, the investigation is limited by the use of a single case, as cannot be generalised to a wider population, but rather acts as a pilot study that warrants further investigation with a 5 year old child diagnosed with ASD, specifically "pervasive developmental disorder". In particular, the study focused on the participants sensory processing and receptive/expressive language. Data was collected via video footage, standardised carer questionnaires (The Listening Checklist and The Sensory Profile) and clinical observation at pre and post intervention stages. Video footage was examined by both authors independently and data compared to establish inter-rater reliability.

The current evidence advocating the use of TLP is anecdotal, with investigations used suffering from several experimental design flaws such as small sample size, lack of control groups, involvement of compounding variables such as other ongoing interventions and lack of statistical analysis.

2.12 Gap in knowledge

Deficits in auditory processing and reading difficulties are reported to have a high incidence in the paediatric population, with several theories proposing a causative link between the two conditions. In addition, it is now known that higher order cognitive function plays an important role in perceived deficits of auditory processing ability. Despite current controversy in academic circles regarding this link (or whether auditory processing deficits are true auditory deficits or auditory manifestations of higher order cognitive impairments), there are now several remediation therapies available that claim to alleviate such difficulties via the improvement of the CANS ability to efficiently transmit neural responses.

The use of classical music has been suggested to improve cognitive abilities and more recently a spectrally enhanced classical music programme (TLP®) has claimed to improve auditory processing abilities, reading ability, academic achievement, attention, and memory, although the underlying theory of such improvements appears implausible. Additionally, while most research using TLP® focuses on its use in remediation of individuals with known deficits in one or more of the aforementioned skills, Advanced Brain Technologies does not make distinctions regarding its use for individuals without deficits in these skills. This appears especially poignant with regards to the large prospective commercial market of typically developing children.

Currently, there are no well-designed control trials published to investigate the ability of spectrally enhanced classical music (TLP®) to improve auditory processing and reading ability in typically developing school age children. Interestingly, TLP® is marketed to people of all ages “children, teens, adults and seniors” (www.advancedbrain.com). It would appear that impact of a listening programme would be dependent on the age, given the development of both auditory processing skill and reading in childhood. Presumably, improved neural synchrony as a result of auditory stimulation (Sacarin, 2009) would drive improved auditory processing skills, including those linked to phonological awareness and then to reading development (however, the underlying theoretical link for the impact of TLP® on the auditory processing skills in relation to reading improvement is unpublished). Given the importance of the development of auditory processing skills incumbent in phonological development, this would seem most appropriate at the age when phonological awareness is the key requirement for reading development (Alphabetic stage of reading) and therefore approximately aged 5-6 years (Stuart, Mastertson and Dixon, 2000).

Behavioural tests of auditory processing have been shown to be unreliable in younger age groups less than 7 years old (Moore et al, 2010) suffering from large intra-subject reliability. In addition, auditory processing skills, including speech discrimination in noise (the most common report of subjective listening difficulty (Witton, 2002) and temporal discrimination skills (controversially linked with reading deficit (Tallal et al, 1980; Wright et al, 1997)) are still developing throughout later years of the first decade of life (Hartley and Moore, 2001; Keith, 2000). In addition, given the class design of the schools interested in potentially being involved in the study (7 year old children grouped in the same class as younger children, and 8 to 9 years olds grouped in a separate classroom), it was more difficult to access 7 year old children in the classroom setting for the intervention. Therefore, based on the continued development of auditory processing skills, lack of age related definition linked to the administration of TLP® and ease of study design; the age range of 8-9 year old was chosen.

2.13 Aims of Current Study

The aim of this study to investigate whether the use of TLP® could affect an advance in auditory processing and reading skills in typically developing school age children (aged 8-9 years) compared to unmodified classical music and a non-music control group?

CHAPTER 3

METHODOLOGY

3.1 Research Questions

Does the use of TLP® affect an advance in auditory processing skills in typically developing school age children (aged 8-9 years) compared to unmodified classical music and a non-music control group?

Does the use of TLP® affect an advance in reading skills in typically developing school age children (aged 8-9 years) compared to unmodified classical music and a non-music control group?

Is there a relationship between advancements in reading ability and auditory skills of school aged children (aged 8-9 years) measured at the pre and post intervention stage?

3.2 Hypotheses

Typically developing children (aged 8-9 years old) that have undertaken music based auditory stimulation training (The Listening Programme®) will show significant advancements in auditory skills compared to children who listen to unmodified classical music, including improvement in auditory temporal resolution (Backward Masking) and speech discrimination in noise (Scan C Auditory figure-ground subtest)

Typically developing children (aged 8-9 years old) that have undertaken music based auditory stimulation training (The Listening Programme®) will show significant advancements in reading (sight word reading and phonemic decoding) skills compared to children who listen to unmodified classical music.

There is a significant correlation between reading (phonemic decoding) and auditory (temporal resolution) skills of school aged children (aged 8-9) at the pre-intervention stage.

There is a significant correlation between advancements in reading (phonemic decoding) and auditory skills (temporal resolution) following auditory intervention.

3.3 Null Hypotheses

Typically developing children (aged 8-9 years old) that have undertaken music based auditory stimulation training (The Listening Programme®) will not show significant advancements in auditory skills compared to children who listen to unmodified classical music, including improvement in auditory temporal resolution (Backward Masking) and speech discrimination in noise (Scan C Auditory figure-ground subtest)

Typically developing children (aged 8-9 years old) that have undertaken music based auditory stimulation training (The Listening Programme®) will not show significant advancements in reading (sight word reading and phonemic decoding) skills compared to children who listen to unmodified classical music.

There is not a significant correlation between reading (phonemic decoding) and auditory (temporal resolution) skills of school aged children (aged 8-9) at the pre-intervention stage.

There is not a significant correlation between advancements in reading (phonemic decoding) and auditory skills (temporal resolution) following auditory intervention.

3.4 Study-design and Sample Size Analysis

A school-based randomised partially blinded control trial was chosen to allow for comparison between intervention groups using pre and post intervention measure comparisons. Partial randomisation allowed for the reduction of group bias as both the participants and investigator were blinded to the assignment of the music-based intervention, with the music based interventions were labelled as "A" or "B" throughout the intervention stage. However, the study was not fully blinded as the investigator and participants were aware of the allocation of the non-music control group (Audiobook). The use pseudo-double blinding of the intervention groups allowed for removal of researcher bias regarding the music-based interventions. A school based design allowed for greater control of the administration of the interventions compared to a home-based design as all participants would be provided with the same intervention period.

The sample size calculation was based on an 80% power and statistical significance of 0.05. There are currently no studies investigating the impact of TLP® with sufficient data published in order to calculate effect size. Therefore the effect size estimate (d=0.47) was based on a Meta-analysis investigating the impact of listening to classical music on spatial temporal tasks (Hetland, 2000).

22 participants would be required for each group; therefore a total of 66 participants would be required. A dropout rate of 25% was presumed. Therefore a total of 28 participants in each group would be required.

Ethical approval was granted by the University of Sheffield University Department for Human Communication Sciences Research Ethics Review Panel (Apendix 1).

3.5 School Recruitment

Head teachers of local primary schools within the Sheffield region -were contacted via email by the primary investigator. The introductory email included attached electronic copies of the School Recruitment Pack which included a School Information Letter, and Recruitment form (Appendices 2 and 3 respectively).

Head teachers were advised to respond via email to the lead investigator to declare their interest with a potential time available for a telephone discussion regarding the study. Following receipt of an electronic declaration of interest by the schools interested in participation, a telephone discussion - with the primary investigator was arranged to answer - any questions concerning the study. Two schools declared interest in the study, with one school wishing to participate following telephone discussion.

The final stage of school recruitment involved a meeting with the Head teacher of the school wishing to participate. A printed copy of the School Recruitment Pack was given, and the school recruitment form was signed by both Head teacher and primary investigator. A copy of the signed recruitment form was given to the school for their records.

3.6 Participant Recruitment

Following recruitment of a suitable primary school, 88 (number of children in the year group) Participant Information Packs were given to school for distribution to the families of potential participants. The Participant Information Pack contained a Parent/Carer Information Sheet, Participant (Child-friendly) Information Sheet and Consent forms (Appendices 4, 5, 6 respectively).

These packs were distributed by school within the Home-school book of potential participants. A return deadline was set a week prior to the start of pre-intervention testing. Parents/Carers who were willing for their child to participate were asked to sign the consent forms and return them to school (who collected all forms). Signed consent forms were collected by the primary investigator following the deadline, prior to the start date of the pre-intervention testing period.

Potential participants for whom written parental consent was given were then allocated an appointment time to undergo the pre-intervention test battery within the school environment.

3.7 Participant Selection

27 potential participants (m=16, f=11) undertook the pre-intervention test battery. Informed parental consent was given for each child prior to testing. Each participant was issued an

individual participant number used for anonymity and randomisation. The inclusion and exclusion criteria are shown below:

Table 3.1: Inclusion and Exclusion Criteria

Inclusion	Participant aged - 8 to 9 years old throughout the duration of active involvement in the study. Peripheral hearing acuity found to be equal to or less than 30dbHL at 500Hz and 25 dBHL at 1000-8000Hz on Pure Tone Audiometry.
Exclusion	Failure on the study's screen for hearing acuity. Participant inability to complete practice items of experimental measures. Involvement in other specifically designed auditory training programs administered by other professionals (assessed through consent form). Participants have a diagnosis of APD, Dyslexia, or Specific Language Impairment (assessed through consent form).

2 potential participants did not meet the inclusion criterion. 2 participants (m=1, f=1) did not pass Pure Tone Audiometric screen, and were referred to Sheffield Children's Hospital for further diagnostic audiological testing. 1 participant (m=1) did not complete the practice items of TOWRE and school were informed of this in order to give additional help to the child's reading.

24 participants were enrolled on to the study (m=14, f=10). Descriptive data regarding the three interventions groups is reported in table 3.2.

Each participant was randomly assigned to one of 3 intervention categorises; A, B or C. An online statistical randomisation package was used to assign study numbers to the intervention group. Category A and B were music interventions which were blinded to both subject and investigator. Category C was the non-music audio-book control. 8 Participants enrolled onto each intervention.

There were 3 participants who did not complete the study. 2 participants were unavailable to complete post-intervention testing, 1 participant was available and completed the intervention stage but was unable to complete auditory processing tasks due to development of a perforated Tympanic Membrane and ear infection between completion of intervention and post-intervention test period. Therefore, a total of 21 participants were able to fully complete the study.

Table 3.2 Descriptive data of the three experimental groups

Group	Participants in group	Gender ratio (m:f)	Age	Non-verbal IQ	Reading ability	Final Number of Participants
TLP®	8	4:4	9.00 (0.38)	113.14 (9.14)	119.57 (6.45)	6
Unmodified Classical Music	8	6:2	9.00 (0.43)	112.50 (15.89)	107.86 (12.24)	8
Audiobook	8	4:4	8.84 (0.32)	117.29 (11.86)	107.86 (11.85_	7

3.8 Experimental measures

A number of auditory based measurements and reading measurement was included in the test battery. All auditory and reading tasks were performed in a quiet room. School staff had access to the room at all times. The Non-verbal IQ task performed was performed in two group settings in order to minimise effect of investigator explanation and reduce participant time away from curricular activities (the maximum time requested = 30 minutes).

In order to minimise the participants' time away from usual curricular activities a 3 stage pre-intervention test protocol was followed (Table 3.3):

Table 3.3 Pre-intervention test protocol

Stage 1 (singular test environment)	Pure Tone Audiometric Screen TOWRE (Wagner, Torgesen and Rashotte, 1999)
Stage 2 (group test environment)	Draw a Person (Non Verbal IQ) Test (Naglieri, 1988)
Stage 3 (singular test environment)	Backward Masking (IHR IMAP study) (Barry et al, 2010) Auditory Attention (IHR IMAP study) (Barry et al, 2010) Scan C Auditory Figureground (+8dB) (Keith, 2000)

The post-intervention test protocol was used consisting of all of the stage 3 pre-intervention test materials and the TOWRE reading test from the stage 1 pre-intervention test battery.

The following subsections describe the efficacy of use for each test used in the protocol and their methods of delivery.

3.8.1 Institute of Hearing Research (IHR) System for Testing Auditory Responses (STAR) Backward Masking Subtest (Barry et al, 2010)

Despite current controversy regarding rapid temporal auditory discrimination and reading ability (Rosen, 2003; Ramus, 2003), rapid temporal auditory discrimination elicited using Backward Masking paradigms has been reported to be the underlying deficit in phonological and reading deficits (Wright et al, 1997). In addition, Backward Masking paradigms are one of the more common clinical assessment tools of auditory temporal discrimination (Emanuel, 2002). Furthermore, most tests of auditory temporal discrimination associated with reading deficits are experimental measures lacking in standardisation, normative data and are unavailable clinically (e.g. Auditory Repetition Task (Tallal, 1980).

The rationale regarding the use of the IHR STAR Backward Masking paradigm is to investigate rapid temporal auditory discrimination (with deficits reported, albeit controversially, to be the underlying cause of phonological deficits linked to poor reading) using a tool that is available clinically and has appropriate standardised normative values for age. The alternative option of using Random Gap (despite being commercially available as part of the SCAN 3C test battery (Keith, 2000)) was rejected due to the lack of evidence regarding its link with reading deficits.

The procedure required use of a suitable laptop (a minimum of a 2 gigabyte processor, 1 gigabyte RAM, and Windows XP operating system), with the IHR STAR presentation platform software available. In addition, an USB IHR audio-device attached to Sennheiser HD25-1 headphones was required.

The target stimulus used was a 1000Hz tone of 20m/s duration (with 10 m/s cosine onset ramp), with a 90dB SPL initial presentation level. The masker was a narrow-band-noise (centred at 1000Hz with an 800Hz width), with 30dB/Hz level and 300m/s duration.

The threshold estimation procedure involved a 3 alternate-interval forced choice oddball response paradigm, consisting of 3 tracking rule procedure (Barry et al, 2010):

1) 15dB, 1 down, 1 up
2) 10dB 1 down, 1 up
3) 5dB 3 down, 1 up

Thresholds were recorded as the mean of level of the last 3 trials in a 20 trial run. There were 2 runs of 20 trials, with overall Threshold calculated as the mean of each trial threshold, and was calculated within the IHR STAR platform.

Participants were sat in front of a laptop computer screen (in a quiet room) with a three button control in front of them. Sennheiser HD25-1 headphones connected (via USB IHR audio-device) to the laptop (contained the STAR Backward Masking subtest) were placed over the participants ears and the stimuli were presented diotically. Prior to undertaking the testing paradigm, up to 6 practice items (3x automated trial abandon of 2 trials designed to prevent trials being contaminated by lack of attention/ comprehension in early stages) were ran. Participants were instructed to respond to the odd-one-out by pressing the appropriate corresponding button on the control panel using the hand they write with.

3.8.2 Institute of Hearing Research (IHR) System for Testing Auditory Responses (STAR) Auditory Attention Subtest (Barry et al, 2010)

Deficits on pyscho-acoustic auditory processing tasks have been shown to be correlated with performance on tasks of higher cognition (BSA, 2011). Moore and Ferguson (2010) showed that performance of auditory processing abilities in a large scale study (n=1469) of children aged 6-11 years old was significantly related to poor cognitive, communication and speech in noise performance. Multivariate regression analysis indicated that poor performance in tasks of auditory processing skill was mainly attributable to poor cognition, specifically attention. The rationale of the use of this task was to act as a vigilance task investigating the participants' sustained attention throughout the test batteries, in order to investigate the impact of poor sustained attention of the test battery, and therefore accounting for a potential confounding variable related to auditory processing task.

Equipment set up was identical to that used with the Backward Masking task.

Participants were placed in front of a laptop computer screen with a 3 button control panel in front of them. Headphones connected to the laptop were placed over the participants ears and stimuli were presented diotically. The laptop contained the STAR (System for Testing Auditory Responses) auditory processing test package containing the Auditory Attention subtest.

The task involved the use of a 1000Hz target tone (fixed duration of 200m/s, presented at 80 dB SPL) and modulated cue tone (fixed duration of 125m/s, presented at 75 dB SPL). Reaction time measurements (m/s) for both cued and non-cued target tones were recorded for participant responses (pressing the middle response button of the 3 button control panel when target tone was presented). The hypothesis reported suggests that a participant's reaction times should be slower for non-cued trials compared to cued, with inattentive children not demonstrating benefit from the cue (Moore and Ferguson, 2010).

The testing paradigm consisted of 7 practice trials which gave feedback to the subject during practice by showing an error message "oops" if the participant did not respond at all or did not respond to the appropriate target signal. Following completion of the practice items, a block of 36 trials were performed. These trials consisted of 20 cued and 16 non-cued random interval presentations. Participants were instructed to place their fingers of their writing hand over the middle button of the control panel and to press the button as soon as the target tone was heard.

The analysis of reaction time differences between cued and non-cued responses were calculated within the IHR STAR programme (non-cued reaction time – cued reaction time), with smaller reaction time differences suggesting poorer attention (participant did not make use of the cue).

3.8.3 Test of Word Reading Efficiency (TOWRE) (Wagner & Torgesen, 1999)

The TOWRE is a standardised measure of fluency and accuracy of a participant's print based reading, consisting of two subtests; Sight Word Efficiency (SWE) and Phonemic Decoding Efficiency (PDE). The SWE consists of a list of real words increasing in phonemic difficulty as the participant reads down the list. The PDE consists of a list of pronounceable non-words that increase in phonemic difficulty as the participant reads down the list. These are used as important indicators for reading problems (Torgesen et al, 1999). The test is rapidly administered and offers appropriate normative data allowing for further analysis in relation to chronological age.

The TOWRE was chosen for its rapid administration (given the limited access to the participants during school), and available normative data. Both subtests (SWE and PDE) were used in order to give an overall view of reading ability; Total Word Reading Efficiency. TLP® has been claimed to improve reading ability, however, a sufficient underlying theoretical basis of how this intervention improves reading is lacking. It would be implied that improvements in reading ability may be secondary to improved auditory processing skills (particularly improved temporal processing skills). The links between auditory processing and reading are controversial (See section 2.7.6 for an overview), however they are purported to be linked to an underlying phonological deficit, and the use of the TOWRE PDE subtest is further supported.

Each subtest contains two forms, labelled A and B, each with practice items and test items. In order to assess a participants reading accuracy and underlying phonemic decoding ability, both of the subtests (using Form A) were used.

Participants were asked to read aloud practice items from SWE Form B. Following successful completion of practice items, the test side of the SWE form B was demonstrated. Participants were then asked to read the practice items from SWE form A. Following successful completion of these items, the participant then undertook the task of reading aloud from the test side of SWE Form A. This paradigm was reproduced for the PDE task.

Participants were instructed that this was “reading race” and that they should read aloud down the lists of words quickly but clearly, and that if they could not “do” an item they were to skip to the next item.

If the participant hesitated for 3 seconds or more, the tester prompted the participant to move to the next word. The participant was instructed to continue down the lists until told to stop or when the participant was unable to pronounce anymore items. The participant was allowed to keep track of which item they were on by using a finger, and this was always shown to the participant at the practice item stage.

The testing period for each section was 45 seconds and was measured by the tester using a stopwatch. Form A was placed in front of the participant with practice items showing, the tester enquired whether the participant was ready and when the participant indicated so, the tester commenced the task by saying “go”. The task was completed at the end of 45 seconds by the tester saying “stop”. This paradigm was completed for both SWE and PDE subtests.

Scoring was provided by the tester, who deemed whether the word was pronounced correctly (in accordance with the pronunciation on the TOWRE recorded sheet.

3.8.4 SCAN C Auditory Figure-ground (AFG) Subtest (+8dB) (Keith, 2000)

Difficulties of speech discrimination in noise are reported to be one of the primary functional difficulties of children with deficits in auditory processing (Dawes and Bishop, 2010). SCAN C (Keith, 2000) AFG (+8dB) is a US produced, commercially available, standardised test of speech in background noise used for auditory processing testing. It includes age-related normative data. SCAN C is noted to be the most commonly used test for diagnosing APD (Hind, 2006; Emanuel, 2002). Dawes and Bishop (2007) showed a significant impact of accent on scores of UK children on

SCAN C AFG due to the use of an American accent, and offered age-related conversion scores in order to compensate for accent effects in UK children. In view of the prolific reports of poor speech in background noise in children with deficits in auditory processing, popularity of SCAN C in APD testing, and conversion factors for US-UK normative data; SCAN C AFG was used to investigate the functional deficit in auditory processing ability.

Sennheiser HD25-1 headphones connected to a Sony D-EJ021 CD player (containing the test CD) via a Belkin Y-lead adapter were used in this test procedure. The volume was set to a comfortable level (volume 4 on the digital volume control of the CD player) as deemed by the investigator prior to instruction. The headphones were placed over the participants' ears and participants were instructed to repeat back to the investigator the word they heard through the headphones. They were advised by the examiner which ear would be tested prior to commencement of testing. The investigator also had a headphone (AKG K99) situated over their right ear (connected to the CD player via the other lead of the Y-adapter) in order to monitor the progress of the participants. All other instructions were incorporated from the SCAN C Test, with scores recorded based on the investigators judgement of correct word reported back from the participant.

3.8.5 Audiometric Screening (pre-intervention test battery)

APD is generally characterised as difficulties in listening in the presence of normal peripheral hearing (BSA, 2011, ASHA, 2004). In view of this description and the effect of potential hearing loss on tests using auditory stimuli, a pure tone audiometric evaluation was completed to rule out any potential hearing loss.

A modified screening paradigm was used based on the school hearing screening protocol currently employed by Sheffield Children's Hospital. Audiometric evaluation was performed using a Kamplex KD29 portable Audiometer with TDH 39 Headphones, calibrated to BS EN 60645-1 (IEC 60645-1) and the relevant BS EN ISO 389 (ISO 389) series standards.

Headphones were positioned over the participant's ears, and a push response button was given to the participant. The participant was instructed to "press the button as fast as they could" when a sound was heard.

Two practice presentations at 50dBHL at 1 kHz (pure tone) were given to the left ear, for which the participant responded. Following successful completion of the practice trials, intensity of the stimuli was dropped to 25dBHL at 1 kHz and two presentations were presented with varied intervals, in accordance with BSA recommended procedure for Pure Tone Audiometry (BSA, 2011). If successful responses were obtained then this procedure was repeated for the following frequencies, 2, 4, 8 kHz.

If successful responses were obtained at each of these test frequencies, two presentations of 30dBHL at 0.5 kHz were performed. Successful completion of all frequencies performed allowed for further testing paradigm to proceed. Failure to complete the screening procedure resulted in the participant being referred to Sheffield Children's Hospital's Audiology service for further assessment.

The presentation intensities of 25dBHL and 30dbHL were used in order to factor in a potential masking effect by background noise in the test environment (due to the lack of soundproofing). These intensities were based upon the hearing screening protocol for Sheffield School Nursing Screening.

3.8.6 Draw a Person Test (Naglieri, 1988)

The Draw a Person (DAP: Naglieri, 1988) is a non-threatening assessment of non-verbal IQ with age appropriate standardised scores. This test was performed at pre-intervention stage in order to investigate the possible confounding variable of IQ on psycho-physical performance of the auditory processing and reading tasks.

Potential study participants undertook this test in two group sessions. Group administration of the DAP test was performed to reduce time participant time away from usual curricular activities. In addition, group administration allowed for the reduction of potential administration effects caused by possible slight differences in instruction. In both sessions, instruction were read from the DAP manual to avoid instruction effects.

Potential study participants were instructed to draw three pictures; man, woman and themselves on blank pieces of paper. Each drawing was instructed to be labelled with the child's name. The session was described as a "quiet drawing test" so that there was no conference between participants. Participants were instructed to use a single drawing implement of their choice.

The testing period lasted approximately 15 minutes in duration, with participants turning over their drawing and returning to their class when they felt they had drawn the best three pictures they could produce.

3.9 Interventions

The school was provided with intervention session registers to track the participants' use of the intervention. The School was instructed to provide 2 daily intervention sessions during quiet working times, and were to be a minimum of 30 minutes apart in accordance with TLP® protocol issued by Advanced Brain Technologies.

3.9.1 The Listening Programme (TLP®)

The TLP® programme was provided by Advanced Brain Technologies on loan for this study. The programme was provided on 5 iPod Nano's, with TLP® intervention described as an experimental TLP® intervention designed specifically for a 10 week programme used for school use, compared to the "classic" 20 week programme. The programme used in this study was reported to involve the same 4 stage filtered classical music as described in the 20 week TLP® programme, involving; Full Spectrum, Green (sensory), Orange (cognitive/communication) and Red (creative) zones (as described in section 2.11). Further information regarding the specific design of the TLP® intervention programme used in this study was deemed commercially sensitive by Advanced Brain Technologies, and was unavailable to the investigator.

Participants listened to the intervention using AKG K99 headphones using a shared single iPod with a connection to the headphones being provided simultaneously via a Belkin Y lead adapter. One iPod was kept in school as a reserve.

3.9.2 Music control programme

The music control programme was provided by Advanced Brain Technologies on loan to this study. The programme was provided on 5 iPod Nano's. Participants listened to the intervention using AKG K99 headphones. The music was classical music that was not spectrally filtered. Two participants shared a single iPod with a connection to headphones being provided simultaneously via Y lead adapter. One iPod was kept in school as a reserve.

The comparison between spectrally filtered music and non-filtered music allowed for the investigation into the impact of spectral filtering of music on auditory processing and reading abilities.

3.9.3 Protocol for music interventions

The music intervention protocol was identical for both music programmes. A detailed programme list was given to school staff in order to ensure that participants were listening to the allocated track at the correct point (Appendix 7).

3.9.4 Non-music Control (Audio-book)

The non-music/audio-book control group was designed to investigate the impact of a music intervention on auditory processing and reading skills by comparison against a non-music intervention. 4 children's' audio-books were downloaded from www.booksshouldbefree.com designed for public use. The 4 books chosen are shown in Table 3.4.

Table 3.4 Author and Title of Audiobooks used for the non-music control intervention

Author	Title
Mark Twain	The Adventures of Tom Sawyer
Kenneth Graham	Wind in the Willows
Jules Verne	Around the World in 80 Days
Rudyard Kipling	The Jungle Book

The audio-books were burnt onto writeable CDs, with each track representing one chapter. Several CDs were required for each book, and were labelled according to book, and intervention tracks. All CDs were placed into a CD container and labelled 1-4 (corresponding to the appropriately labelled CD players).

Four Sony DEJ011S CD players were used to administer the CD based intervention. The CD players had a digital volume controlled which was set to volume 4 by the investigator prior to the intervention period. In addition, the CD players possessed a digital memory allowing the CD player to start a track exactly where it had been stopped, including mid-way through a track. Opening/changing the CD wiped this memory. Participants were advised not to open/change the track except when instructed to do so by the teacher.

The audio-book control group followed the same intervention regime as the music programmes, with 2 intervention session, daily during quiet working time. A detailed protocol was given to school staff to instruct the participants to finish the designated tracks at the appropriate time (Appendix 8). Each intervention session lasted approximately 15 minutes and stopping points mid-track were allocated in some instances by the primary investigator as it was deemed an appropriate point in the chapter to stop the story.

3.10 Statistical Analysis

Analysis of data was performed using SPSS 19 statistical analysis package. Descriptive statistics were calculated for pre intervention measures. A one ANOVA was calculated between groups to investigate for potential differences between groups at the pre-intervention stage for Age and Non-verbal IQ.

In order to investigate the first and second research hypotheses, a repeated measures ANOVA was performed with group and time as factors to calculate differences between groups (between subjects) for pre and post intervention differences (within subjects). The interactions between time x test were also investigated in order to ascertain the interaction between the test measures over time (if group x time interaction was insignificant). Post hoc comparisons were performed for significant interactions.

To investigate hypotheses 3 and 4, Pearson's correlation coefficients were calculated for individual pre-intervention data of auditory and reading analysis (hypothesis 3) and for (pre-post intervention) improvements in auditory processing and reading (hypothesis 4). Fisher's Z tests were performed to assess if any correlation was significant.

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 Effects of Auditory Interventions on auditory processing and reading abilities

"Typically developing children (aged 8-9 years old) that have undertaken music based auditory stimulation training (The Listening Programme®) will show significant advancements in auditory skills compared to children who listen to unmodified classical music, including improvement in auditory temporal resolution (Backward Masking) and speech discrimination in noise (Scan C Auditory figure-ground subtest)."

"Typically developing children (aged 8-9 years old) that have undertaken music based auditory stimulation training (The Listening Programme®) will show significant advancements in reading (sight word reading and phonemic decoding) skills compared to children who listen to unmodified classical music."

Prior to further analysis, a single one-way ANOVA was performed in order to investigate any differences between experimental groups for the reported confounding variables of age and non-verbal IQ. There were no significant group differences for age [F (2, 19) = .554, p = .584] or non-verbal IQ [F (2, 19) = .144, p = .867].

Table 4.1 illustrates the pre and post intervention scores (and standard deviations) separately for the 3 intervention groups. A repeated measures ANOVA was used to determine whether the intervention groups differed across the 4 main outcome measures (Total Word Reading Efficiency, Auditory Figure-Ground, Backward Masking and Auditory Attention). The effect of time x study group was not significant, [$F(10, 90) = 0.338$, $p = 0.968$]. This suggests that there were no significant differences between groups for each outcome measures as a result of the interventions.

The interaction between test and time was also investigated to determine whether there were statistically significant differences between outcome measures and time. The test x time interaction was significant [$F(5, 90) = 12.542$, $p < 0.001$]. Post hoc analysis was performed, significant interactions between test x time were found for Auditory Attention [$F(1, 18) = 13.795$, $p < 0.005$] and Backward Masking [$F(1, 18) = 45.553$, $p < 0.001$]. No other outcome measures showed significant test x time interaction. These results suggest that both the Auditory Attention and Backward Masking auditory processing tasks showed a significant change over time.

Table 4.1 Means and Standard Deviations for pre-post intervention scores for auditory and reading tasks

	TLP®		Unmodified Music		Audiobook	
	Pre	Post	Pre	Post	Pre	Post
SCAN Total AFG	32.14 (2.610)	34.57 (2.878)	32.57 (2.573)	33.86 (2.340)	32.71 (1.890)	32.57 (3.645)
SCAN AFG Left Ear	16.43 (1.718)	17.00 (2.082)	15.88 (1.727)	16.57 (1.512)	16.00 (1.000)	16.14 (2.035)
SCAN AFG Right Ear	15.71 (1.380)	17.57 (1.272)	16.88 (1.246)	17.29 (1.380)	16.71 (1.113)	16.43 (2.070)
Overall Auditory Attention (m/s)	384.79 (154.357)	326.414 (93.042)	410.61 (121.187)	367.271 (89.530)	384.11 (118.364)	302.243 (99.142)
Cued Auditory Attention (m/s)	216.288 (81.336)	201.686 (92.584)	303.838 (104.489)	268.614 (99.503)	261.529 (116.091)	201.743 (77.217)
Non-cued Auditory Attention (m/s)	421.993 (164.796)	422.743 (135.333)	462.913 (156.203)	456.129 (137.621)	499.986 (139.511)	355.600 (129.501)
Backward Masking (m/s)	73.00 (11.446)	61.54 (14.393)	73.00 (6.633)	64.44 (9.331)	73.86 (13.934)	56.01 (21.538)
Total Word Reading Efficiency	11,957 (6.451)	116.71 (11.658)	107.86 (12.240)	113.43 (9.744)	107.86 (11.852)	110.14 (10.415)
Sight Word Reading Efficiency	67.71 (3.546)	67.00 (4.899)	58.29 (11.131)	63.86 (8.255)	58.00 (9.950)	64.57 (5.940)
Phonemic Decoding Effiency	41.57 (8.658)	41.43 (10.081)	54.14 (8.611)	37.29 (8.240)	30.71 (9.160)	32.71 (8.460)

4.2 Correlations between reading and auditory processing skill

"There is a significant correlation between reading (phonemic decoding) and auditory (temporal resolution) skills of school aged children (aged 8-9) at the pre-intervention stage."

"There is a significant correlation between advancements in reading (phonemic decoding) and auditory skills (temporal resolution) following auditory intervention."

There were no significant differences between groups for auditory processing and reading measures. Data was therefore collected was pooled together to create a single sample for correlational analysis. Using a Pearson's correlation coefficient, correlations between auditory processing and reading skills were examined at the pre-intervention stage. The significance of correlations were calculated using a Fischer's Z test and tabulated. Significant correlations for auditory processing and reading tasks at the pre-intervention stage and pre-post intervention differences between auditory processing and reading tasks are shown in Tables 4.2 and 4.3 respectively.

Very strong significant positive correlations were found between Total Word Reading Efficiency and Sight Word Efficiency [$r= .899$, $n=21$, $p <0.001$] and Phonemic Decoding Efficiency [$r= .856$, $n=21$, $p < 0.001$] at the Pre-intervention stage. In addition, Sight Word Efficiency and Phonemic Decoding Efficiency were also shown to have a very strong significant positive correlation with each other [$r= .731$, $n =21$, $p <0.000$]. These correlations suggest that individuals who scored higher on Total Word Reading Efficiency also scored higher on Sight Word Efficiency and Phonemic Decoding Efficiency.

A strong significant positive correlation was also shown between Auditory Attention and Backward Masking [$r= .509$, $n=21$, $p <0.05$]. This suggests that those who scored lower scores on Auditory Attention also scored lower on Backward Masking. In the Backward Masking and Auditory Attention tasks, the lower the score/threshold the better the participant's ability to perform the task. Auditory Attention also showed a strong negative correlation with Sight Word Efficiency [$r = -.442$, $n = 21$, $p <0.05$]. This correlation shows that individuals with lower Auditory Attention Scores (better performers) scored higher on Sight Word Efficiency tasks.

Auditory Figure-ground was not significantly correlated with any other measure of auditory processing or reading. Backward Masking was not significantly correlated with any reading measure.

Additionally, correlations between Age, Non-verbal IQ and auditory reading measures were examined for the pre-intervention scores. There were no significant differences between Age and Non-verbal IQ with any measure of auditory processing or reading ability. However, correlation between Age and Non-verbal IQ showed a strong, significant positive correlation [r= .490, n = 21, p < .05].

Table 4.2 Significant correlations between pre-intervention scores on auditory processing and reading skill tasks

		Total Word Reading Efficiency	Sight Word Reading	Phonemic Decoding Efficiency	Total Auditory Figure-ground	Overall Auditory Attention	Backward Masking
Total Word Reading Efficiency	Pearson Correlation		.899**	.856**			
	Sig. (2-tailed)		.000	.000			
	N		21	21			
Sight Word Efficiency	Pearson Correlation	.899**		.731**		-.442*	
	Sig. (2-tailed)	.000		.000		.040	
	N	21		21		21	
Phonemic Decoding Efficiency	Pearson Correlation	.856**	.731**				
	Sig. (2-tailed)	.000	.000				
	N	21	21				
Total Auditory Figure-ground	Pearson Correlation						
	Sig. (2-tailed)						
	N						
Overall Auditory Attention	Pearson Correlation		-.442*				.509*
	Sig. (2-tailed)		.040				.015
	N		21				21
Backward Masking	Pearson Correlation					.509*	
	Sig. (2-tailed)					.015	
	N					21	

**. Correlation is Significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 4.3 shows significant correlations for pre-post differences between auditory processing and reading tasks. Improvements in Total Word Reading Efficiency showed strong significant positive correlations with Sight Word Efficiency [r = .598, n=21, p < 0.05], thus showing that participants who showed greater improvements in Total Word Reading Efficiency also showed greater improvements in Sight Word Efficiency and Phonemic Decoding Efficiency. Correlation between improvements in Sight Word Efficiency and Phonemic Decoding Efficiency were not significant.

Phonemic Decoding Efficiency also showed a strong significant positive relationship with Auditory Attention [r= .533, n=21, p, 0.05], and a strong significant negative relationship with Auditory Figure-ground [r= -.563, n=21, $p < 0.05$]. Improvements in Phonemic Decoding Efficiency did not show a significant correlation with improvements in Backward Masking.

Table 4.3 Significant Correlation between pre-post intervention differences for auditory processing and reading tasks

		Total Word Reading Efficiency	Sight Word Efficiency	Phonemic Decoding Efficiency	Total Auditory Figure-ground	Overall Auditory Attention	Backward Masking
Total Word Reading Efficiency	Pearson Correlation		.598**	.660**			
	Sig. (2-tailed)		.005	.001			
	N		21	21			
Sight Word Efficiency	Pearson Correlation	.598**					
	Sig. (2-tailed)	.005					
	N	21					
Phonemic Decoding Efficiency	Pearson Correlation	.660**			-.563*	.537*	
	Sig. (2-tailed)	.001			.023	.015	
	N	21			21	21	
Total Auditory Figure-ground	Pearson Correlation			-.563*			
	Sig. (2-tailed)			.023			
	N			21			
Overall Auditory Attention	Pearson Correlation			.537*			
	Sig. (2-tailed)			.015			
	N			21			
Backward Masking	Pearson Correlation						
	Sig. (2-tailed)						
	N						

**. Correlation is Significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

CHAPTER 5

DISCUSSION

5.1 Summary of data analysis

The results of the study show that the use of TLP® did not result in a significant advance in auditory processing and reading abilities of the participants compared to the use of an unmodified music programme or a non-music programme. There was no consistent correlation between participants' auditory temporal processing and reading abilities at the pre-intervention stage, or in improvements in auditory temporal processing and reading.

5.2 Effect of Intervention on auditory processing and reading abilities

The results of this study suggest that there were no significant group differences between groups on any auditory processing or reading measure employed in this study [$F(10, 90) = 0.338$, $p = 0.968$], and therefore further interpretation of these results was not possible.

5.3 Effect of time of auditory processing and reading abilities

Despite the results of this study suggesting that there were no significant differences between intervention groups for pre and post intervention scores, the effect of time was significant [$F(5,90) = 12.542$, $p < 0.01$). This suggests that while the results lacked in differences between groups on auditory processing and reading measures, differences in results between pre and post intervention test periods was significant. Further post-hoc analysis revealed significant differences between pre and post intervention stages for the Auditory Attention [F (1, 18) = 13.795, p < 0.05] and Backward Masking tasks [F (1, 18) = 45.553, p < 0.01}. There were no further significant pre-post differences for any other auditory processing or reading measure.

It has previously been suggested that improvements in Auditory Attention and Backward Masking can occur as a function of age. Hartley and Moore (2000) revealed improvements in Backward Masking suggesting a possible maturational effect due to improved neural synchrony. Moore et al (2010) also showed improvements in Backward Masking and Auditory Attention as a function of age, thus raising the possibility of improved performance on Backward Masking task being secondary to improved performance of Auditory Attention. Thus improvements seen on Backward Masking and Auditory Attention measures could be as a result of a maturational effect. However, in both Hartley and Moore (2000) and Moore et al (2010), such effects were over a timescale of years; however the improvements in this study occur over a period of 12 weeks, thus this time period appears too short to be explained by a maturational effect. An alternative explanation could be provided by a test-retest effect, with improvements in both Auditory Attention and Backward Masking task being due to the participants' familiarity with the tests.

5.4 Effect of Accent on SCAN C Auditory Figure-ground task

The results of the participants in this study for the SCAN C Auditory Figure-ground task were poorer than expected for the age when calculated against the normative data produced for the test (Keith, 1999). Dawes et al (2007) previously documented an accent effect for British participants on the SCAN C tasks (including Auditory Figure-ground) when compared to normative data produced for the SCAN C (based on data from American participants). When a correction factor was introduced (provided by Dawes et al, 2007), the participants performed similarly to what was expected from the normative data provided by SCAN C. This suggests that most participants enrolled on this study, had age-appropriate Auditory Figure-ground scores and would support the findings of Dawes et al

(2007) that British subjects suffered from an accent effect that resulted in initial poorer than expected compared to the normative data provided by the SCAN C test.

5.5 Effect of Age and Non-verbal IQ

The effect of participant intelligence and age have both been previously cited as potential confounding variables in research examining psycho-acoustic performance during tests designed to examine auditory processing abilities (Moore et al, 2010; Banai and Ahissar, 2006; Hartley and Moore, 2000). It has been suggested that this is due to maturational effect (age) and suggested increased attentional capacity with increased intelligence (Moore et al 2010). To examine the potential confounding effects within this study, statistical analysis was performed to search for significant difference between the groups on these potential confounding variables. There were no significant differences between groups for Age [$F(2, 19) = .554$, $p = .584$] or Non-verbal IQ [$F(2, 19) = .144$, $p = .867$].

There were no significant group differences for non-verbal IQ and age for pre-intervention data between groups. Therefore non-verbal IQ and age cannot be accredited as potential confounding variables in this investigation.

5.6 Correlation analysis

There were no significant group differences between groups for auditory processing and reading tasks, therefore, data from all three experimental groups were combined for correlation analysis. The relationship between auditory processing (specifically backward masking) and reading skill (phonemic decoding) advancements showed no significant correlation, thus refuting the causal link between rapid temporal resolution and reading ability (Table 4.3) as noted by Wright et al (1997). The following subsections discuss the significant correlations found.

5.6.1 Correlations between reading and auditory processing skills

Total Word Reading Efficiency was not significantly correlated with any auditory processing task, but there was a strong significant positive correlation with the performance of its two subtests (SWE and PDE) for both the pre intervention stage and pre-post intervention differences. A strong significant correlation was also seen between the SWE and PDE at both data collection periods supporting the accepted claim of improved reading ability in subjects with higher performance on phonological awareness tasks (Goswami and Bryant, 1990; Snowling et al, 2002;, Ramus, 2003; Rosen, 2003).

Rapid temporal resolution has previously been reported to be the causal factor underlying phonological awareness ability (Tallal et al, 1973, 1974, 1980., Wright et al, 1997). This predictive ability has been shown using several tasks of temporal auditory processing including Backward Masking (Wright et al, 1997). In this study, reading ability was not significantly correlated to Backward Masking task for either Total Word Reading Efficiency or Phonemic Decoding Efficiency at either pre intervention data collection stage or for pre-post intervention differences. The findings from this study suggest that there is no relationship between Backward Masking and Reading (including phonological awareness). These findings are consistent with those of Bishop (1999) who investigated the role of Backward Masking in reading ability, and support growing evidence that rapid temporal resolution is not a predictor of reading ability.

A further demonstration of the lack of causal evidence between temporal discrimination and reading ability can be seen from intervention studies investigating the role of specific language programmes (FastForWord by Tallal et al) designed to artificially elongate formant transitions in order to improve auditory discrimination and therefore phonological and reading abilities. Although investigation by its creators has shown that FastForWord does elicit improvement in language abilities (Tallal and Merzenciah, 1996), however these findings have contradicted the results of several independent studies (see section 2.7.6.1).

Total Auditory Figure-ground was not significantly correlated to any auditory processing or reading measure performed at the pre-intervention stage, but did show a strong, significant negative correlation with Phonemic Decoding Efficiency for pre-post intervention differences. This strong, significant relationship was unexpected given that speech perception in noise and reading abilities have been previously shown to be positively correlated (Ziegler et al, 2009; Brady et al, 1983). In addition, poor reading performance in children has been persistently linked to background noise in a child's educational setting (Shield and Dockrell, 2003; Bradley, 2003; Pickard and Bradley, 2001). The finding of a negative correlation between improvements in speech discrimination in noise and poorer phonemic decoding skills (important for reading ability) appear counter-intuitive. A possible explanation was found through further examination the data involved whereby it appeared that this correlation was driven by poorer performance on the Phonemic Decoding Efficiency task for several participants at the post-intervention stage compared to pre-intervention stage. It would be unusual for a child to truly regress with regards to phonological skills, more likely would be to hypothesise a third confounding variable which impacts on behavioural experimental measures; motivation/ attention of the participant while performing the task.

There was also a significant positive relationship for Auditory Attention and Phonemic Decoding Efficiency differences showing that poorer performance on Phonemic Decoding Efficiency between pre-post intervention stages was related to poorer performance on the Auditory Attention task. This offers support to the previously mentioned hypothesis related to poor post-intervention scores on Phonemic Decoding Skill in comparison of pre-intervention scores.

Auditory Attention was also showed a strong significant negative correlation with Sight Word Efficiency at the pre-intervention stage (higher performance on Sight Word Efficiency correlated with better Auditory Attention scores). Given that the Sight Word Efficiency task involves the repetition of real words in a set time period (45s) with word difficulty increasing throughout the task (increased length of word), it could be assumed that smaller, more common words would be easily recognisable through grapheme to grapheme correspondence in the orthographic lexicon. However, as the participant progresses through the task, words become larger multisyllabic items that place greater pressure on the orthographic lexicon, and become less familiar to the participant then it could be assumed that the participant resorts back to their phonemic decoding ability which requires active attention and memory (Ehni, 1984; 1987). The lack of interaction between Sight Word Efficiency differences and Auditory Attention differences between pre and post-test could be explained through the participants' ability to have stored the words into their orthographic lexicon following the task and due to potentially increased vocabulary during the pre-post intervention stage. This results in subjects not requiring to place such strain an attention-based tasks.

5.6.2 Correlations between Auditory processing skills

The Auditory Figure-ground task was not significantly correlated with any other auditory processing measure at either the pre-intervention stage or between pre and post intervention differences. This is unsurprising given that Backward Masking is suggested to be predicted by Auditory Attention (Moore et al, 2010), the Auditory Figure-ground task has been shown to be predicted by working memory (Lum et al 2010).

The Backward Masking and Auditory Attention tasks showed a strong, positive, significant correlation at the pre intervention stage (better performance on Auditory Attention was related to better performance on Backward Masking). This finding is consistent with Moore et al (2010), whose findings also showed a significant correlation between these 2 measures. Moore et al (2010) suggested that performance on Backward masking task was pre-dominantly due to higher order attentional capacity rather than a lower level bottom-up auditory processing capacity. Further evidence for this attentional impact has also been suggested by other studies investigating the use of Backward Masking, with high intra-subject variability in Backward Masking threshold being linked to poor attentional performance (Buss et al, 1999; Cohen-Munram, 2006) In addition, Edwards and Hogben (2004) suggested that a child who obtains a high threshold of auditory perceptual tasks is a result of poor sustained attention on a boring task rather than auditory perception.

If there was a causal link between Auditory Attention and Backward Masking threshold one would expect pre-post intervention differences to show a significant correlation between the two variables, however, in this was not the case (pre-post intervention differences between the 2 variables was not significant). This was surprising given that both measures were shown to improve significantly between the two intervention stages, however this lack of correlation in improvements would suggest the impact of a third unaccounted variable.

5.6.3 Correlation between potential confounding variables (age and non-verbal IQ) and measures of auditory processing and reading skill

The age of participants and non-verbal IQ scores showed a strong, significant positive correlation at the pre-intervention stage. This was expected and agrees with previous test data (Nagerli, 1989) that improvements on the Draw-a-Person test were correlated with increased age. There were no further significant correlations between non-verbal IQ or age with any measure of auditory processing or reading skill, despite previous links with age and Backward Masking (Hartley and Moore, 2000; Buss et al, 1999). This lack of correlation could be explained by the strict age-criteria employed by the study, suggesting that for age to become a significant factor, a participant sample must involve considerable age differences.

5.7 Limitations of Current Study

A priori sample size analysis revealed the need for a minimum of 28 participants per intervention group; however the sample obtained is smaller (The achieved power of this study was 32% to detect a medium size effect). This has a significant impact on the study's ability to draw concrete conclusions regarding the effectiveness of the interventions. This is due to effects being harder to detect in the sample, especially given the high-variability in the measures used, and thus leading to high probability of type 2 error (Button et al, 2013).

The lack of sufficient sample size was due to the limited number of returned consent forms from parents (23.9% of total potential participants completed the study). The possibility of another cohort from a performance-matched primary school would have potentially increased numbers, however this was not feasible due to time and equipment demands. Additionally, the lack of participant consent forms returned had a further impact resulting the inability to have a forth non-intervention group (inclusion of a fourth non-intervention group would have further reduced the statistical power of the study required for statistical analysis).

The wide variety of performance on each test also exacerbated the effect of a small sample on the means and standard deviations of group measures. The use of the measures chosen in this study was partially due to their commercial availability, common use and recorded test-retest reliability. However, variations would be expected between participants (especially in view of the skills investigated not yet reaching maturation). A larger sample size would have not only added sufficient statistical power to the study, but additionally also improved the effect of wide variability on group means (Button et al, 2013). An additional modification would be to use electrophysiological measurements to investigate auditory processing skills, in order to attempt to remove confounding variable of sustained attention and motivation effect on behavioural measurement outcomes. However, currently there are no suitable electrophysiological systems commercially available to provide this.

All children within the appropriate school year group were offered the possibility to participate in the study, however only a small sample was recruited. These children were reported by the school to generally be the high achievers in the year and thus potentially placed a sample bias for the whole group compared to the actuality of the average pupils’ performance in the year group. Findings from this study show that almost all the participants had a reading age higher than the chronological age, and no participant enrolled had reading age below that of their chronological age.

There were several known limitations in the school-based administration of the intervention strategies. Firstly, due to the small number of participants enrolled on the study, this resulted in a small sample population spread across a number of separate classes within the designated year group. This created difficulty for the teachers who were asked to administer the intervention programmes to a minority of individuals in class whilst trying to supervise the majority of the class who were not involved in the study.

This administration issue created major implications for the study; as the teachers were often involved in the supervision of the class as a whole, they did not record participants’ progress on the intervention (this was done without the investigator’s knowledge). This resulted in the study being unable to document the progress of the participants throughout the intervention programme, and therefore to comment on the participants’ adherence to the intervention programmes.

In addition, Teachers delegated the administration of the intervention to the participants themselves, which created difficulties in the daily administration of the intervention due to the lack of direct supervision for the participants, resulting in difficulties following the intervention protocol (all intervention programmes were designed to be administered by a supervising adult). As a result, it was noted that several participants reported that they sometimes forgot the session or on one occasion allowed a participant who did not wish to continue on the study to undermine the study by not performing the intervention and convincing another participant (who shared the equipment) not to continue rather than indicate this to a teacher. As the intervention groups were spread throughout several classes, all intervention groups were affected.

While, the lack of supervision in administering the interventions was a major issue, the degree this occurred varied across the participants; unfortunately, due to the lack of recorded use this could not be calculated as a confounding variable.

There were also reports of several equipment difficulties; particularly the drain of power from the CD players used for the non-music control group. This created difficulties as on several occasions because the participants were unable to use the intervention due to a lack of batteries. This difficulty was potentially due to the inappropriate use of the equipment by the participants (not switching the CD players off, but only placing the CD players on pause), however as this was not directly supervised this cannot be confirmed. These difficulties were not passed on to the Head Teacher (due to the lack of direct teacher supervision) with whom the primary investigator had weekly contact throughout the Intervention Stage and only became apparent at the end of the post-intervention stage.

Previous studies investigating the use of TLP® have reported the need for direct supervision during administration (Jeyes, 2010), although these studies have often involved small class sizes where direct supervision of a larger proportion of the class was more plausible.

An alternative option would have been to introduce the interventions into the school year group curriculum, whereby all children would listen to the intervention and only those with parental consent would be tested, or alternatively the school would consent that all children would could also be tested. This would result in the administration of the interventions being Teacher-led, and for a far higher sample size (thus improving the statistical power of the study, and reducing the implication of sample size bias). Unfortunately, this alternative also poses several limitations, namely the difficulties of introducing this into the curriculum, which in this case would have been further exacerbated by the government inspection of the school which took place during the Intervention Stage. As this would be a singular school deviation from the national curriculum, it would require the consent of all parents of the children involved (or from the parent-teacher association at the very least). Ultimately, even if this alternative strategy was implemented, it would have been impossible to complete due to the lack of equipment available.

The original TLP® intervention programme stipulates a 20 week intervention period composed of repeated 10 week cycles. The intervention programme used a single 10 week cycle. While it could be argued that the lack of a 20 week programme is a limitation of the study, the single 10 week cycle was used as a school-based programme designed by Advanced Brain Technologies. In addition, several non-published studies (obtained through the Advanced Brain Technologies website also have used a 10 week school-based programme and shown significant improvements in auditory processing and/or reading skill.

The auditory processing and reading tasks used were chosen due to the frequency of use in conventional auditory processing and reading assessments performed currently by professionals (Emanuel, 2002), and with high quality normative data with which to compare the study's results. The current study highlights the potential confounding variables of high order cognition (attention) on psycho-acoustic measures of auditory processing skill. However, as analysis in this study is correlational, this study cannot claim that high order cognitive abilities provide a causal role for participant's performance on behavioural tasks.

The role of attentional capacity has previously been noted by Moore et al (2010) on a larger scale prospective study of auditory processing disorder (using the Auditory Attention task involved in this study). Inattention is also a common behavioural characteristic of those with suspected APD (Richo, 1994), and thus the use of a single auditory attention paradigm only gives a snapshot of sustained attentional capacity at that point, therefore the attentional task employed does not provide an overall insight into a participant's attention but provides evidence of their sustained attention throughout the test periods. The use of a teacher or parental questionnaire may prove a useful addition for investigating a participant's potential improvements in attention; however there are limitations in the form of currently available questionnaires when related to auditory attention (see section 2.7.5)

The use of Backward Masking as the temporal resolution task involved in this study may also be questioned, especially in light of later evidence refuting the role of rapid auditory processing in reading development (Mody et al, 1997; Rosen, 2003; Ramus, 2003). The use of amplitude modulation (Goswami et al, 2011) may prove an alternative temporal resolution task; however its use is currently experimental and is not routinely used clinically. The amplitude modulation deficit suggested by Goswami et al (2012) has also received criticism (Ramus, 2012) and hence there is currently no consensus in the role of temporal auditory processing in reading ability. Furthermore, there are no amplitude modulations tasks developed that currently offer normative data. The use of a temporal discrimination task that is more commonly performed in clinical setting was judged to be more appropriate.

5.8 Future Work

Despite methodological limitations regarding group size and difficulties in intervention administration, this study has provided the first attempt at scientific investigation of the role of TLP® and offers a starting block for further investigation. While findings of this study do not support the use of TLP® in typically developing children (aged 8-9 years) with average or above average reading and average auditory processing ability, these findings cannot be used to conclude that TLP® does not impact auditory processing and reading abilities in this participant group due to the low statistical power of the study.

Additionally, this study cannot report on the use of TLP® with participants with APD or significant reading deficit. Further investigation involving comparisons with control interventions would be required on a larger scale (either with typically or non-typically developing populations). Furthermore, care would be required in accounting for confounding cognitive variables (such as attention and memory).

The need for larger sample is paramount for further analysis of the impact of TLP®. Despite the lack of statistical power, the results of the statistical analysis performed suggest the effect size of TLP® would be small and therefore the sample size would be need to be considerably larger than that reported to be needed for this study.

The use of TLP® on a larger scale in school would require alteration to the administration of the procedure (due to small groups within the setting requiring specific administration by a Teacher/ Teaching Assistant “on board” with the intervention). Alternatively use of larger group sessions in school requires a high volume of equipment, therefore development of an alternative presentation method (I.e. through sound-field system) may be prudent.

The use of TLP® was not shown to significantly benefit participants two weeks post intervention, however short benefit maybe seen through increased mood and arousal (Schellenberg, 2007). Finally investigation of the short term benefit (i.e. within 15-30 minutes of intervention) should also be investigated in order to establish whether TLP® affects an improvement in skills over that of unmodified music during this time period.

5.9 Conclusion

This study offers the first scientific attempt at investigating the impact of TLP® on auditory processing and reading skills in typically developing children (aged 8-9 years), for which TLP® is also marketed (as well as being marketed for those with difficulties in auditory processing and reading ability). The findings of this study suggest that there were no significant differences between the experimental groups for any of the auditory processing or reading tasks used. However, concrete conclusions cannot be drawn from this study due to its lack of statistical power. Instead this study acts as a pilot study for a larger investigation of TLP®. Additional modifications to study design (based on difficulties in the current study) are suggested.

The correlations between measures of auditory processing and reading were not consistently significant for pre-intervention scores and pre-post intervention differences. There were no significant correlations with overall measures, however some significant correlations were present between sub-tests, but these correlations could be explained by alternative factors such as higher order cognitive influence rather than a direct causal link between auditory processing and reading ability. In particular there was a complete lack of correlation between phonological awareness and Backward Masking supporting recent evidence (Rosen, 2003; Ramus, 2003, Ramus, 2012) refuting the theory that rapid temporal discrimination ability has a causal effect on reading ability. In addition, Backward Masking and Auditory Attention were strongly linked supporting the conclusion of Moore et al (2010) suggesting that auditory processing difficulties could be predominately due to inattention.

Significant correlations between auditory processing and reading improvements were also shown. However these correlations were unexpected as increased PDE was shown to be significantly negatively correlated with multiple auditory processing tasks. The correlation between reading ability and temporal resolution was not significant, refuting previous claims in the literature (Tallal et al, 1973, 1974, 1975, 1980., Wright, 1997).

Therefore, this study does lack sufficient statistical power to categorically conclude that TLP® does not improve auditory processing and reading ability in typically developing children (aged 8-9 years). However, no evidence was found to support the conclusion that TLP® would lead to an improvement in these abilities for the population tested. There were no significant correlations between rapid temporal resolution and phonemic decoding efficiency in this study, as suggested by supporters of the Rapid Temporal Auditory Processing theory linked with deficits in phonological skills. Auditory processing abilities were shown to be highly variable and consistent with the limitations of using psycho-acoustic measurements in assessing auditory processing ability previously stated in studies investigating the use of psycho-acoustic methods of measuring auditory processing abilities. This study shows the need for further development of electro-physiological measurements for clinical use in the analysis of auditory processing skills, in order to attempt to reduce the impact of higher order cognitive abilities and the effect of participant motivation in the assessment of auditory processing skills.

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APPENDICES

Appendix 1 Research Ethics Application Approval

The University Of Sheffield.

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Head of Department
Professor Joy Stackhouse, PhD., F.R.C.S.L.T., C.Psychol., A.F.B.Ps.S

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7th November 2011

Dear Kevin

Title: The impact of an auditory training programme (The Listening Programme) on the auditory and scholastic skills of mainstream school children

Thank you for your submission to the HCS Research Ethics Committee. The committee has reviewed your submission and supporting documents and grants you approval to commence the research.

We hope your project proceeds smoothly

Yours sincerely

Prof R Varley
Chair of HCS Ethics Committee

Appendix 2 School Information

<u>SCHOOL INFORMATION</u>

RESEARCH STUDY: <u>THE IMPACT OF AUDITORY TRAINING ON THE AUDITORY AND SCHOLASTIC SKILLS OF MAINSTREAM SCHOOL CHILDREN</u>

RESEARCHERS: KEVIN HOLE, DILYS TREHARNE, MICHELLE FOSTER, STUART CUNNINGHAM

Dear Head Teacher,

We would like to invite your school to take part in a unique research study, only a few schools have been approached. The aim of this letter is to give you a background to the need for this study and to inform you of the commitments required if you decide for your school to take part.

Children can have problems with hearing, they are often reported to struggle in difficult listening situations (such as in background noise), requiring instruction to be repeated and appear to have difficulties in differentiating pitch of sounds. In some cases, such difficulties are caused by a deficiency of the ear to detect the required sounds (i.e. a hearing loss). In other cases, these children are repeatedly found to have normal peripheral hearing, yet still have difficulties listening. This can impact academic performance, especially regarding the acquisition of written language and reading.

Numerous studies have shown auditory training and different musical listening programmes improve auditory processing and reading ability, although results from these studies are somewhat variable.

There are currently several different auditory training programmes available commercially. One such programme is "The Listening Programme ®", which requires listening to specifically filtered classical music. This has been reported to improve auditory processing and also reading ability.

The aim of this study is to investigate whether school aged children (aged 8-9 with normal hearing) would show improved auditory processing and reading ability using

The Listening Programme ® compared to listening to normal classical music or listening to a story.

The study requires children to listen to one of three listening programme at school for 15 minutes; twice a day, 5 days a week for a period of 10 weeks. The differing listening programmes would be provided by the investigators on the appropriate equipment required. A designated member(s) of staff would be responsible for the daily administration of the programmes.

Prior to the start of the programmes, the children will be assessed for inclusion onto the study by the lead investigator (at school) by undertaking a variety of listening and reading tests. These tests are to last approximately 30 minutes per child and would be repeated at the end of the 10 week period. Informed parental consent would be obtained by the lead investigator prior to a child being enrolled on the study.

The potential benefits for you as a school would be:

If you would like more information, please feel free to me on the number provided at the top of this letter.

Yours sincerely

Kevin Hole

Principal Investigator

Appendix 3 School Recruitment form

<u>SCHOOL RECRUITMENT FORM</u>

RESEARCH STUDY: THE IMPACT OF AUDITORY TRAINING ON THE AUDITORY AND SCHOLASTIC SKILLS OF MAINSTREAM SCHOOL CHILDREN

RESEARCHERS: KEVIN HOLE, DR DILYS TREHARNE, DR MICHELLE FOSTER, DR STUART CUNNINGHAM

Your name: __________________________ Date: _________________

Position in School: _________________________

Name of School: __________________________

Contact Number: _________________________

School Address: ____

____

Please initial box

1. I confirm that I have read and understood the information sheet provided for the above study and have had the opportunity to ask questions and discuss the study with my colleagues ☐
2. I understand that my schools participation is voluntary and that I and my pupils are free to withdraw at any time without having to give a reason ☐
3. I give permission for my school to take part in the above study. ☐

Name of Head teacher	Signature	Date
____________________	___________________	______
Name of researcher	Signature	Date
___________________	___________________	______

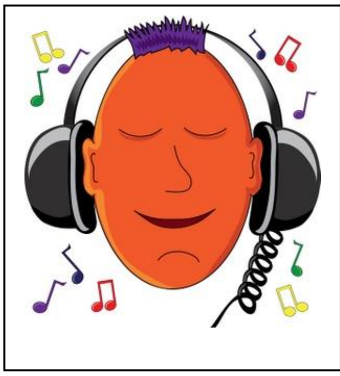
Appendix 4 Participant Information Sheet

THE IMPACT OF AN AUDITORY TRAINING PROGRAM (THE LISTENING PROGRAMME®) ON THE AUDITORY AND SCHOLASTIC SKILLS OF MAINSTREAM SCHOOL CHILDREN

CHILDREN INFORMATION LEAFLET

What is a Research Study?

A research study is an experiment to find an answer to a question.



Why have I been chosen?

Your class has been asked to take part in the study,

the other children in your class have been asked to take part as well.

Why is the study being done?

We want to know if listening to different sounds like music or stories helps the way children listen and read.

Do I have to take part?

No, it's up to you and your family.

If you want to stop taking part in the study at any point, and you do not have to tell us why.

You will not be treated differently by the teachers/ people involved in the study if you decide you do not want to take part.

Who is taking part?

We are asking a lot of children to take part, including other children in your class.

What will happen to me if I take part?

We will come to school and ask you to take part doing some listening and reading games. This takes about half an hour.

After this, you will take part in some listening activities during school-time for a term. These activities involve you to listening to music or stories through headphones and will happen every day in class for half an hour.

When you have completed your listening activities, you will take part in some more listening and reading games.

Will joining in the games help me?

We cannot promise that joining in will help you, but it will help us to work out whether listening to different types of sounds helps the way children listen. This could also help children who do have listening and reading problems.

Who is running the study?

The study is being run by people who work at the University of Sheffield

Who will know if I am taking part in the study?

Although we may use the information you give us to help, we will not tell anything about you to anyone else.

Your parents/guardians will know you are taking part. Your teacher and other children in the class will also know you are taking part.

Has the study been checked?

This research study has been checked University of Sheffield Ethics Panel. The job of the Ethics Panel is to make sure that the research is safe to take part in. The Ethics Panel is happy for the study to take place.

Who do I ask if I have any questions?

You can ask your parents/guardians or teacher. If they don't know the answer they can ask the person who runs the study.

You can also ask the person who comes in to play the listening and reading games.

Thank you very much for reading this information sheet – we hope you enjoy taking part.

Appendix 5 Parent Information Sheet

PARENT INFORMATION

RESEARCH STUDY: THE IMPACT OF AUDITORY TRAINING ON THE AUDITORY AND SCHOLASTIC SKILLS OF MAINSTREAM SCHOOL CHILDREN

Dear Parent/ Guardian

We would like to invite your child to take part in this research study. Before you decide whether or not you wish your child to take part, it is important that you understand why this research is taking place and what is involved. Please take time to read this information carefully. Please discuss the study with your child, family and friends. If you have any further questions, please contact the lead researcher (contact details are available at the top of this page).

What is the Purpose of this study?

This study aims to investigate the effect listening to specially modified music on a child's ability to perform different tasks. Several studies have suggested that listening to different sounds improve the ability of a person to perform different types of listening tasks. Further to this, improvements have also been seen with performance in school. The duration of your child's involvement (should they wish to take part) is approximately 12 weeks.

Why has my child been chosen to participate?

Your child has been chosen to participate because they attend a school that is participating in this study, and are within the age range required (8 to 9 years old) so that they can complete the listening tasks required This study requires to participants to meet the following criteria:

- Participants are aged 8 to 9 years old throughout the duration of involvement of the study
- Pass the study's hearing screen
- Have Informed Parental Consent to participate
- Participants are able to complete the tasks required in the study
- Participants are not involved in other specifically designed auditory training programs administered by other professionals.
- Participants do not have a diagnosis of APD, Dyslexia, or Specific Language Impairment.
- Participants first language is English.

.

Does my child have to take part?

No, the decision to take part is the choice of your child and yourself. If you decide to take part, please fill in the enclosed Consent forms and return them to your school, who will forward them to the lead researcher. If your child does take part in this study, they are free to withdraw from the study at any point without giving a reason, and would not be pressured to continue. If your child does withdraw from the study, their education will not be effected.

What happens to my child if they decide to take part?

If your child decides to take part then they will first of all have their hearing checked by the lead researcher in school. If any hearing problems are detected, the lead researcher will then refer your child to Sheffield Children's Hospital for a hearing assessment. If your child passes the hearing test, then they will then play a number of computer based listening games, and take part in a quick reading test. The session is expected to last approximately 30 minutes.

Following this, your child will then be placed into one of the three groups listening to different types of intervention, whereby your child will listen through headphones to different sounds such as music or stories. This will take place in school, lasting fifteen minutes, twice a day for around one term. Your child will not be expected to do anything extra at home.

Once your child has completed the listening stage of the study, your child will then be asked to play the computer based listening games they played at the beginning, as well as taking part in another quick reading test.

As some of the listening games involve spoken English, the study will only invite children for whom English is their first language. We would like as many children to take part in the study as possible, if you decide for your child to take part please fill in the consent forms enclosed and return to the lead researcher.

What are the potential benefits for my child?

Previous research has shown that listening to modified music may improve a child's ability to listen. Other studies have claimed these benefit may also include improvements in reading ability. However these studies were small, and such benefits may not occur in this present study. Our findings will hopefully help to decide whether listening to different types of sounds (whether music or stories) offer some benefit to all children with normal hearing.

What are the potential disadvantages for my child?

There are no known potential disadvantages for your child to take part in the study.

I do not want my child to take part in the study, what will they do instead?

If your child does not take part in the study, they may still be able to take part in the class activities associated with the study (i.e. drawing a picture of a man, and listening to music or stories). However your child would not take part in any of the reading/listening tasks required, and no information would be collected regarding your child.

Will my child's involvement remain confidential?

Your child will be involved in listening to different types of sounds in groups, and therefore other children in that group will be aware of your child's involvement. Further to this, your child's school teacher will also be aware of your child's involvement. However all of your child's results will remain confidential and only available to the lead researcher and research team.

Your child's details will be kept in a secure location at the workplace of the lead researcher (Children's Hearing Services, Sheffield Children's Hospital), and your child will not be identified in any publications made regarding this study.

Who is funding this study?

This study is funded by the Learning Beyond Registration of the Strategic Health Authority in South Yorkshire, and will form the basis of the lead researcher's post graduate study.

Who is supplying the equipment?

The equipment involved in the study is been provided by the University of Sheffield, with the I Pods (music programmes) being donated by Advanced Brain Technologies (supplier of the specially modified music)

Has this study been checked and is it in agreement with ethics regulations?

This study has been approved by the University of Sheffield Department of Human Communication Sciences Ethics Review Panel.

What happens if I wish to complain?

If you wish to complain about this project, in the first instance please contact the lead researcher. If you feel that that your complaint has not been dealt with in an appropriate manner, please contact the University of Sheffield Registrar and Secretary on the details provided below:

Office of the Registrar and Secretary

Firth Court

Western Bank

Sheffield

S10 2TN

Telephone: 0114 222 1100

email : registrar@sheffield.ac.uk

How do I get more information about the study?

If you need any more information regarding the study, please contact the lead researcher (Kevin Hole) using the contact details provided below:

Email: Kevin.Hole@Shef.ac.uk Telephone: 0114 271 7454

Yours Sincerely

Kevin Hole: Lead Investigator/ Postgraduate Researcher

Appendix 6 Participant Consent Form

RESEARCH STUDY: The impact of an auditory training program (The Listening Programme®) on the auditory and scholastic skills of mainstream school children

Your name: ___________________________ Date: ___________

Your child's name: ___________________________ Contact Number: _________

Your relationship to child: _____________________

Address: ____

____

Your child's school ________________________ Please initial box

1. I confirm that I have read and understood the information sheet provided for the above study and have had the opportunity to ask questions and discuss the study with my child. ☐
2. I understand that my child's participation is voluntary and that I and my child are free to withdraw at any time without my child's education, medical care, or legal rights being affected ☐
3. I confirm that my child has not been diagnosed with Auditory Processing Disorder, Specific Language Impairment, Dyslexia or a known hearing loss. ☐
4. I give permission for my child to take part in the above study. ☐
5. I give permission for my child's details to be forwarded to the local Audiology department in the event that a hearing loss is identified. ☐
6. I understand that information gained in the study regarding my child will be strictly Confidential ☐
7. I understand that my child will be allocated to only 1 of the 3 intervention groups ☐

Name of parent / guardian	Signature	Date
___________________________	____________________	_______
Name of researcher	Signature	Date
__________________________	____________________	______

Appendix 7 Music Programme Intervention Protocol

Below is the track lists to be performed. Two tracks (each approximately 15 minutes) should be performed a day. This track list is the same regardless of whether the child is on Programme A or B.

Week 1 Day 1- 001 & 002 Day 2- 003 & 004 Day 3- 005 & 006 Day 4- 007 & 008 Day 5- 009 & 010	Week 6 Day 1- 051 & 052 Day 2- 053 & 054 Day 3- 055 & 056 Day 4- 057 & 058 Day 5- 059 & 060
Week 2 Day 1- 011 & 012 Day 2- 013 & 014 Day 3- 015 & 016 Day 4- 017 & 018 Day 5- 019 & 020	Week 7 Day-1- 061 & 062 Day-2- 063 & 064 Day-3- 065 & 066 Day-4- 067 & 068 Day-5- 069 & 070
Week 3 Day 1- 021 & 022 Day 2- 023 & 024 Day 3- 025 & 026 Day 4- 027 & 028 Day 5- 029 & 030	Week 8 Day-1- 071 & 072 Day-2- 073 & 074 Day-3- 075 & 076 Day-4- 077 & 078 Day-5- 079 & 080
Week 4 Day 1- 031 & 032 Day 2- 033 & 034 Day 3- 035 & 036 Day 4- 037 & 038 Day 5- 039 & 040	Week 9 Day-1- 081 & 082 Day-2- 083 & 084 Day-3- 085 & 086 Day-4- 087 & 088 Day-5- 089 & 090
Week 5 Day 1- 041 & 042 Day 2- 043 & 044 Day 3- 045 & 046 Day 4- 047 & 048 Day 5- 049 & 050	Week 10 Day-1- 091 & 092 Day-2- 093 & 094 Day-3- 095 & 096 Day-4- 097 & 098 Day-5- 099 & 100

Appendix 8 Audiobook Intervention Protocol

Schedule For Programme C (Audiobooks)

There are 4 Audiobooks on CDs for the comparable volume of time to the iPod Programmes. The books used are:

Around the World in 80 Days	Tom Sawyer
Wind in the Willows	Jungle book

Below is the schedule list for the CD Audiobooks. The CD players have a memory, when they are switched on, the CD will resume at the point where the CD player was switched off. Please keep check on time and play CD for the period stated below (if the 15 minute session is completed midway through a track, switch the CD player off and continue. On occasions where noted the listening session allocated for that day maybe slightly shorter or longer than 15 minutes.

<u>Tom Sawyer Schedule</u>

<u>Week 1</u>

Day1- CD1 Track 1 complete and Start track 2

Day 2- CD1 Track 2 Complete and *CHANGE CD- CD 2*

Day 3- CD2 Track 1 complete

Day 4- CD2 Track 2 Complete and Start Track 3

Day 5- CD2 Complete Track

*CHANGE C*D- CD3- Complete Track 1

<u>Week 2</u>

Day 1- CD 3- Track 2- 30 minutes listening

Day 2- CD 3 Track 2 Complete, Track 3 Complete

CHANGE CD- CD4

Day 3- CD4- Track 1 Complete

Day 4- CD4 Track 2 Complete

Day 5- CD 4 Track 3 Complete

CHANGE CD- CD 5 and complete Track 1

<u>Week 3</u>

Day 1- CD 5- Track 2 & 3 Complete

Day 2- CD5- Track 4 complete

CHANGE CD- CD6- Track 1 15 minutes

Day 3- CD6 – Complete CD 6

<u>NOTE THIS IS 40 MINUTES (please split into two 20 minute listening sessions)</u>

<u>END OF TOM SAWYER AUDIOBOOK</u>

<u>Wind in the Willows</u>

<u>Week 3</u>

Day4- CD 1 Track 1 Complete

Day 5- CD 1 Track 2 Complete

CHANGE CD- CD2

<u>Week 4</u>

Day 1- CD2 Track 1 Complete

Day 2- CD2 Track 2 Complete (35 minutes)

CHANGE CD- CD3

Day 3- CD3 Tack 1 Complete (2x18 minutes)

Day 4- CD3 Track 2 Complete

CHANGE CD- CD4

Day 5- CD4 Track 1 complete

<u>Week 5</u>

Day 1- CD4 Track 2 Complete

CHANGE CD- CD5

Day 2- CD5- Track 1 (2x10 minute session)

Day 3- CD5- Track 1 Complete (2x10minute sessions)

CHANGE CD- CD6

Day 4- Track 1 (2x10minute sessions)

Day5- Track 1 Complete

CHANGE CD- CD7

Week 6

Day 1- Track 1 Complete (2x20 minute sessions)

Day 2- Track 2 Complete

END OF WIND IN THE WILLOWS AUDIOBOOK

Around the World in 80 Days

Week 6

Day 3- CD 1 Track 1&2 (in one sitting) & Track 3

Day 4- CD1 Track 4&5 (one sitting) & Track6-7

Day5- CD1 Track 8 Complete

CHANGE CD- CD2

CD2 Track 1&2 Complete

Week 7

Day1- CD2- Track 3-4 Complete

Day 2- CD2- Track 5 Complete

CHANGE CD- CD3

CD3- Track 1 Complete

Day 3- CD3- Track 2+3 Complete

Day4- CD3-T rack 4+5 Complete

Day5- CD3- Track 6 Complete

CHANGE CD- CD4

CD4- Track 1 Complete

Week 8

Day 1- CD4- Track 2&3 Complete

Day 2- CD4- Track 4-5 Complete

CHANGE CD-CD5

Day 3- CD5- Track 1+2 Complete

Day4-CD5- Track 3+4 Complete

Day 5- CD5- Track 5 Complete

CHANGE CD- CD6

CD6-Track 2&3 Complete- Start Track 4(until subjects have been listening for 15 minutes)

Week 9

Day1- CD6-Track 4, 5, 6 Complete

CHANGE CD- CD7

Day 2- CD7- Track 1+2 Complete (reduced listening time)

END OF AROUND THE WORLD IN 80 DAYS

The Jungle Book

Week 9

Day3- CD1- Track 1 complete, Track 2 pause after subject has been listening for 15 minutes)

Day 4-CD1- Track 2 Complete, Track 3 15 minutes

Day 5-CD1- Track 3 Complete

CHANGE CD-CD2

CD2-Track 1-pause after 15 minutes)

Week 10

Day1-CD2-Track 1+2 Complete (2x17minute sessions)

Day 2-CD2-Track3 Complete (2x10minute sessions)

CHANGE CD-CD3

Day 3-CD3- Track1 Complete

Day 4-CD3- Track 2 Complete

Day 5-CD3- Track 3 Complete

END OF LISTENING PROGRAMME.

STUDENTS MAY CONTINUE TO LISTEN TO JUNGLE IF WISH FOLLOWING POST INTERVENTION TESTING IN SUMMER TERM