Pitch Perception, Production and Musical Development of Hearing Impaired Children

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November 2013

A thesis submitted to UCL for the degree of Doctor of Philosophy

In the UCL faculty of Brain Sciences

DECLARATION

I, Sian Edwards confirm that the work presented in the thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signed: ……………………………………………………………………….

ABSTRACT

Children with cochlear hearing loss are offered a range of intervention devices to manage their hearing impairment. The most common devices fitted are hearing aids, cochlear implants or a combination of both (bimodal stimulation with a cochlear implant on one ear and hearing aid on the other). The main goal of these devices is to improve listening and communication for speech and language development. However in more recent years additional focus has been given to non-speech sounds such as music. Pitch is an important aspect of music because it carries the melody; however it is represented differently by the different devices used. The impact this has on children's musical ability is not fully understood. This thesis explores this area and aims to determine if groups of hearing impaired children who use different intervention devices have a differential impact on pitch perception, singing and general musical ability.

The primary research question addressed within the thesis was, do differences exist between different groups of hearing-impaired children who use different amplification devices for general musical ability, pitch perception and singing ability?.Fifty seven children aged between 4 and 9 years old (15 Cochlear implantees, 21 hearing aid users, 8 children with bimodal stimulation and 13 normally hearing children) were assessed for pitch perception and singing while their parents completed a questionnaire on their general musical ability. Results indicated that children using purely

electrical stimulation (bilateral cochlear implants) performed more poorly for pitch perception, than children using acoustic information either through bilateral hearing aids or bimodal stimulation. This result was not demonstrated for singing competency, however a reduced comfortable singing range and greater voice irregularity was observed for the cochlear implantees when singing. Normally hearing children performed better with respect to pitch perception and singing competency but did not show a significantly better score for musical enjoyment or involvement in comparison to all three hearing impaired groups. The results indicate that the bimodal configuration could provide some benefits for pitch perception for hearing-impaired children that have useable residual hearing. This doesn't however extend to pitch production in terms of singing competency. The findings derived from this research study are important not only to build on current research literature but also to inform future clinical practice.

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CHAPTER 1 : INTRODUCTION

Music forms an integral part of our modern society; it is important in educational, developmental and social domains (Trehub 2003). Music can influence many different areas of our lives, and in turn can impact directly on quality of life. A quote from Ludwig van Beethoven (1934) illustrates this point perfectly:

"Music is a higher revelation than all wisdom and philosophy. Music is the electrical soil in which the spirit lives, thinks and invents" (Ludwig van Beethoven 1934)

In all societies around the world, a substantial amount of time is spent listening to music. It is important to understand the extent of self-exposure to music because it provides an indication of the different functions and importance of music within society. Sloboda (2009) suggested that there are six main activities for listening to music within western culture. These are: when travelling (e.g. in the car, walking), conducting physical work (e.g. cleaning, cooking), brain work (e.g. private study, reading), body work (e.g. exercise), emotional work (e.g. mood management) or attendance at live musical performance. Within these activities four recurring functions are observed: distraction, entertainment, energizing and meaning enhancement (Denora 2000). With such a wide range of potential uses it is likely that different individuals use music in their own ways depending on their lifestyle and interests.

As children develop, they are encouraged to get involved in musical activities because of the pleasure it could bring and the importance it has on educational and emotional development. In the United Kingdom (UK) music forms part of the national curriculum for the education of children aged from 5 to 16 years old (Department of Education 2013). It is expected that the developing child will improve their level of ability as they develop through the educational “key stages”.

Music enjoyment is a holistic experience and people respond differently to the diverse range of instruments and artists. However there are key elements that make up the majority of musical pieces and if these can be analysed separately it can provide information on the critical aspects for perception. Pitch is considered to be the most important aspect of music because it relates to the delivery of melody information (Chasin and Russo 2004). Other attributes of music also play their part, such as rhythm and timing, dynamic changes in level and the timbre of the musical instruments or voices.

For hearing-impaired (HI) children music delivery is altered due to the limitations due to their hearing loss and also the hearing instrument (cochlear implants, (CI) and hearing aids, (HA)) that they use. Hearing instruments are designed and fitted in order to improve hearing abilities with respect to speech perception (Flynn et al. 1996; Geers 1997; Geers and Moog 1991; Osberger et al. 1991; Snik et al. 1997; Somers 1991; Wilson 2000; Wilson and Dorman 2008a; Wilson and Dorman 2008b). However the signal processing approaches used in the hearing instruments could detrimentally affect pitch perception and production of music (McDermott 2004). This area has not been extensively researched because historical focus has been on enhancing speech perception rather than non-speech stimuli such as music.

1.1 Aim of the research

The primary aim of this research project was to determine if different amplification devices (bilateral CIs (BCIs), bilateral HAs (BHAs) and bimodal stimulation (BMS)) for hearing impairment (HI) have differential impact on pitch perception, pitch production and general musical ability in children. Comparison was also made between HI groups and a normal hearing (NH) group of children of the same age. These aims were undertaken within the thesis as the main study phase.

An additional aim was to ensure (wherever possible) that the materials used as a means of assessment within the main study phase were validated and provided a base of normative or baseline values for typically developing children. This was undertaken through a questionnaire validation study and a pilot study prior to the main study phase.

1.2 Research Questions

- Do differences exist between different groups of HI children using different amplification devices for their hearing loss in terms of general musical ability, pitch perception and singing ability?

- Are there differences in general musical ability, pitch perception and singing ability between HI and NH children

1.3 **Outline of chapters**

In Chapter 2 literature covering pitch perception and production in both a normally functioning auditory system and an auditory system with HI is reviewed. In this chapter pitch development in childhood, the consequences of HI, the common amplification devices for HI and the effects that those devices may have on pitch are discussed. The chapter also covers musical appreciation and enjoyment of HI listeners and the impact musical training can have.

As an additional research aim was to use validated measures within the main study phase of the research, validation of the Musical Stages Profile (MSP) questionnaire is presented in Chapter 3. The chapter also describes the collection of normative data and the creation of reference centile curves for the MSP questionnaire. Within Chapter 4 a pilot study is described, where feasibility of the main study phase protocol and test materials were examined with a group of NH children.

The final experimental chapter, Chapter 5, gives details of the main study phase. In this chapter results are presented on the pitch perception, singing and general musical ability of both NH and HI children. Interactions between perception, production and musical abilities are also discussed within the chapter. In chapter six results are synthesized and discussed, conclusions are then drawn and an indication of directions for future research is given.

CHAPTER 2 : BACKGROUND

2.1 Pitch Perception in a Normally Functioning Auditory System

According to the American National Standards pitch is defined as: *"that attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from low to high. Pitch depends primarily on the frequency content of the sound stimulus, but also depends on the sound pressure and the waveform of the stimulus."* (ANSI 1994).

Pitch is the perceptual correlate of fundamental frequency. Within the musical context, pitch is associated with musical melody information, harmony and key (Chasin and Russo 2004). It is seen as the most important perceptual acoustic dimension for categorising musical pieces (Patel 2008).

In order to understand the way in which pitch is processed within the auditory system it is necessary to explore the differing theories and proposed models associated with pitch perception for both pure and complex tones (Plack 2005).

The physiology of the auditory system is such that sound signals that enter it pass through the outer, middle and inner ear. It isn't until reaching the inner ear that frequency analysis and coding takes place. There are two main theories (place and temporal) for encoding pitch, and it is thought that both could be employed to achieve satisfactory pitch perception over a wide range of frequencies.

2.1.1 Place Pitch Perception

The "place" method for frequency coding is attributed to the structure of the basilar membrane and can account for perception of a range of frequencies. The basilar membrane (BM) divides the cochlea, and aligned along its length is the organ of corti, containing sensory hair cells which stimulate auditory nerve fibres (see figure 1). The inherent mechanical features of the BM (width, thickness and stiffness) enable each point along it to have a unique resonating frequency; organised tonotopically from apex to base .i.e. different frequency components have maximum excitation at different points along the BM when the sound wave travels along its length as seen in figure 2.

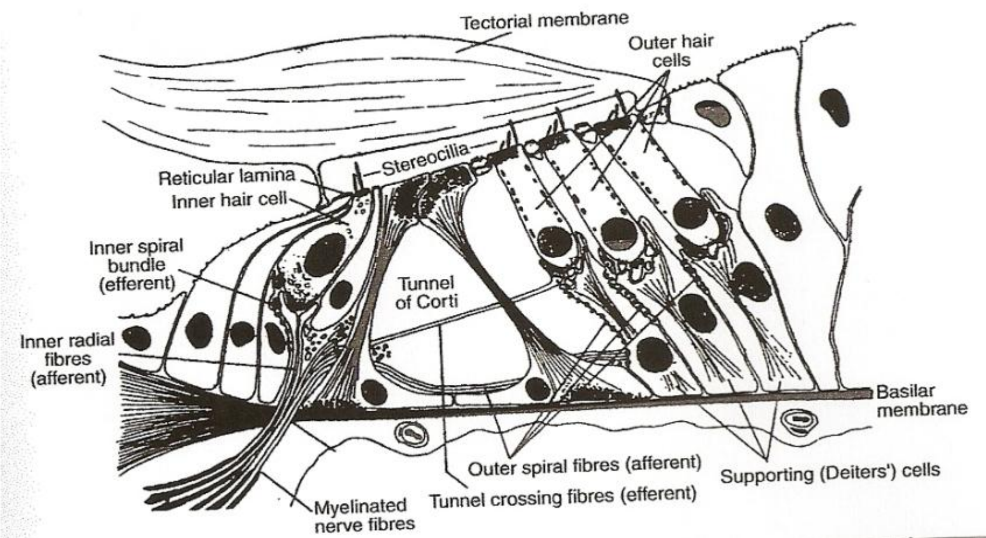


Figure 1. Cross section of the cochlea, detailing basilar membrane and organ of corti. Taken from P33 (Moore 2008)

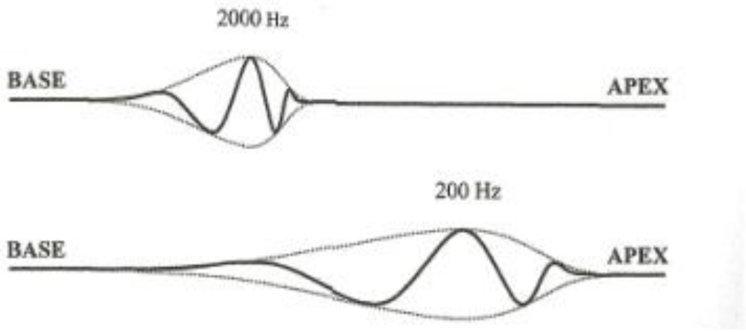


Figure 2. A snapshot of basilar membrane displacement, in response to pure tones of two different frequencies. The peak in the waveform for each frequency represents the distance along the basilar membrane where there is maximal displacement for the response, this is the optimal resonant frequency for that tone. For 2000 Hz the peak of response falls near to the basal end and for the 200 Hz the peak is nearer to the apex. Taken from p72 (Plack 2005)

Directed towards each point along the basilar membrane are a number corresponding neurons synapsing with inner hair cells (IHC's) in that region. The vibration of the basilar membrane causes stereocilia of IHC's to depolarize which in turn stimulates the auditory nerve fibres directed at that point on the basilar membrane. The BM performs a spectral analysis and this can be modelled as if there were a series of overlapping band-pass filters each tuned to a particular frequency. These filters are referred to as "auditory filters" (Moore 2008) and the centre frequency of each one is known as the "characteristic frequency". Neural activity relating to the stimulation is not represented by one individual auditory nerve fibre but by a distribution of responses by a population of neurones. This pattern of neural activity is known as the excitation pattern.

This frequency analysis is enhanced by an active tuning process attributed to the outer hair cells (OHC's) of the organ of corti. OHC's change shape, and their steorocilia bundles move in response to stimulation, which both lead to an increase in displacement of the travelling wave. This results in a sharpening of the excitation pattern around the characteristic frequency giving rise to the differing widths of auditory filters along the basilar membrane. Examination of agents affecting OHC functions has shown a loss of this active mechanism. The work of Ruggero and Rich (1991) demonstrated that the OHCs were responsible for this tuning. They conducted a study where furosemide was injected into the BM of a chinchilla. Furosemide was chosen because of its known adverse effect on OHC motility. Results from their study showed that the frequency selectivity and sensitivity of the system to detect sounds significantly decreased in response to tones and clicks presented in cases where the furosemide was injected. These results therefore demonstrated that mechanical responses of the BM are dependent upon the normal function of the organ of Corti and OHC's (Ruggero & Rich 1991).

The tonotopic organisation demonstrated by the basilar membrane and nerve fibre organisation is preserved through structures to the higher centres of the auditory pathway and are present within the primary auditory cortex in both cerebral hemispheres (Bendor & Wang 2005). Therefore ‘place pitch’ originates in the BM and is maintained up the auditory pathway.

2.1.2 Temporal Pitch Perception

The second theory of frequency coding is attributed to the behaviour of neural firings over time, and is known as “temporal” coding. IHC stereocilia excitation is based on the shearing motion between stereocilia and the tectorial membrane caused by the vibrating basilar membrane. As a result nerve fibres synchronise to fire at a particular phase of basilar membrane vibration relating to the stimulating waveform, this is known as “phase locking” (Plack 2005). Frequency information is extracted from the period between successive firing patterns which therefore has a relationship to the stimulus frequency.

Extraction of temporal information provides accurate low frequency coding however cannot convey frequencies above 5kHz due to two limitations. The first is based on the fact that each individual neuron has a recovery period after firing which limits excitation to an upper frequency limit of 1kHz. Due to a population of neurons firing, timing information can be averaged across multiple neurons phase locking to encode excitation of frequencies up to 5kHz after which breakdown of phase locking occurs.

2.1.3 Pitch Perception of Tonal Stimuli

Pure tones are rarely found in the real world. They are made up of sinusoidal variations in pressure over time, with a frequency spectrum with energy at only a single frequency. They are regarded as the basic units of most sounds and by summing them together in phase; complex waveforms are created (Plack 2005). The frequency of a pure tone refers to a waveform's repetition rate and correlates to the perceived pitch, through combinations of both place and temporal methods. The method is dependent on the frequency of the pure tone (Moore 2008).

Complex tones are made up of more than one pure tone (see figure 3), in which a number of frequency components are present which may evoke a pitch sensation. Complex tones are extremely common and the ability to extract pitch information from a mixture of frequencies is important, especially for music perception.

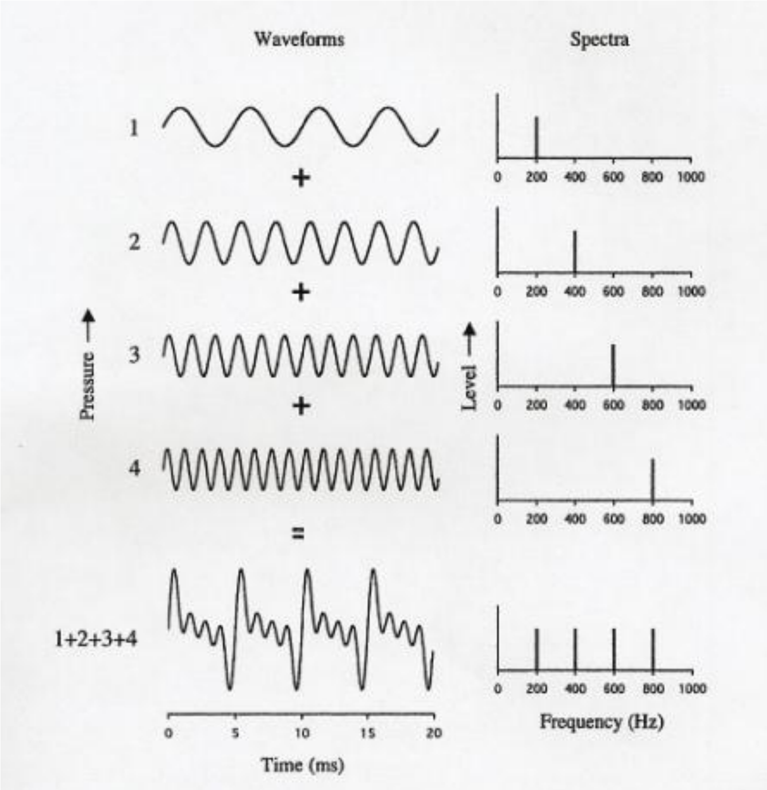


Figure 3. An illustration of a complex tone composed of pure tones at harmonic frequencies. Taken from p24 (Plack 2005)

Early research reported that the pitch of complex tones was based on the frequency of the lowest harmonic, “the fundamental frequency” (Ohm 1843). However later evidence demonstrated that pitch could still be evoked when this harmonic had either been removed (Schouten 1938), or masked by noise (Licklider 1956). This indicates that it must be possible for pitch information to be extracted from higher harmonics.

A variety of different models have been put forward to explain pitch perception of complex tones in the auditory system. Generally these have been related to the duality of place and temporal coding and therefore fall into two main types – “pattern recognition” models (Goldstein 1973; Terhardt 1974; Wightman 1973) and “temporal” models (Schouten 1940).

2.1.3.1 Pattern Recognition Models

Pattern recognition models propose that extraction of pitch is achieved by using the pattern of frequencies within resolved harmonics to derive the fundamental frequency (Cheveigne 2005). The resolution of harmonics is dependent on the frequency i.e. harmonic number, with low harmonics being resolved on the basilar membrane and higher harmonics being unresolved. Resolved harmonics are individually separated out as each harmonic would fall within a different auditory filter. When the travelling wave passes further along the basilar membrane multiple higher harmonics fall within individual auditory filters so that they are no longer individually separated out (see figure 4) (Plack 2005). The constraint of pattern recognition models is that they offer no explanation on how pitch is extracted from solely unresolved harmonics (Moore 2008).

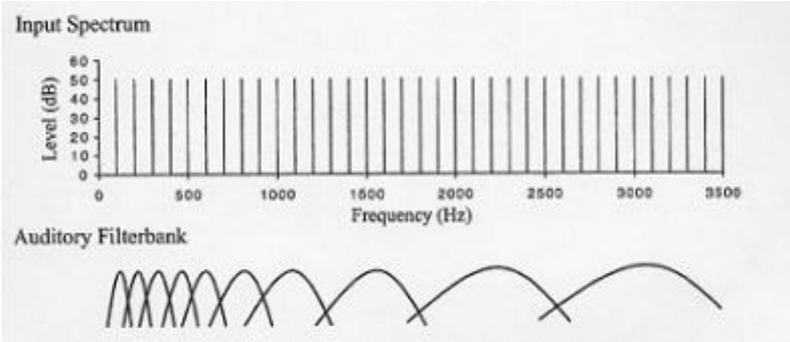


Figure 4. The spectrum and corresponding auditory filter banks for a complex tone consisting of a number of harmonics with fundamental frequency of 100Hz. Taken from p139 (Plack 2005)

2.1.3.2 Temporal Models

Temporal models propose that extraction is achieved through combinations of nerve fibre firings of both resolved and unresolved harmonics. This difference in resolution with higher harmonics means that pitch may be represented either by phase locking to individual low resolved harmonics, or by neurones phase locking to the envelope resulting from the interaction of the higher unresolved harmonics (Cheveigne 2005). Smith et al (2002) conducted a study which investigated the perceptual importance of envelope versus fine structure information. They synthesized stimuli which have an envelope of one sound and the fine structure of another, naming them ‘auditory chimaeras’. They were able to demonstrate that the envelope was most important for speech reception, and the fine structure information was most important for sound localisation and pitch perception.

The importance of fine structure information is confirmed as it has been shown that pitch is dominated by components derived from resolved harmonics (Plack et al. 2005) thus supporting a pattern recognition theory. However as reported previously pitch can still be perceived from just unresolved harmonics therefore implying that combinations of both models can be used.

Based on the models described above literature would suggest that a combination of both pattern recognition and temporal models are used for perception of both speech and music. However the fine structure (represented by resolved harmonics on the basilar membrane) is of paramount importance to musical pitch perception

2.2 **The Development of Pitch Perception**

2.2.1 Prenatal Development

The development of perception associated with music begins in the prenatal period, with the acquisition of perceptual, cognitive, motor and emotional skills. Prior to birth all human sensory systems begin to function (Hepper 1992) but hearing is regarded as the dominant sense, with the cochlea processing sounds from approximately 20 weeks gestation. At 25 weeks gestation the cochlea structure is fully formed but the sensory cells and connections continue to develop (Bibas et al 2008).

The assessment of the perceptual abilities of foetuses have been carried out with observation of foetal reaction and show that at 19 weeks gestation reaction to 500Hz tones can be observed. The frequency range then extends into the lower frequencies and then into the higher frequencies as the foetus develops (Hepper and Shahidullah 1994). In the Hepper and Shahidullah (1994) study the authors conducted a behavioural experiment which examined foetal reactions (between 19 and 35 weeks gestation) to pure tone auditory stimuli at 100, 250, 500, 1000, and 3000 Hz. A loudspeaker was placed on the mother's abdomen and foetal movement was recorded via an ultrasound scanner. By approximately 27 weeks gestation there were responses to 100, 250 and 500Hz stimuli. By weeks 33-35 the foetus responded to the higher frequencies (1000 and 3000Hz). Results of this study confirm that as the cochlea develops the range of acoustic information available to the foetus is enriched allowing greater discrimination of acoustic patterns that are important for pitch perception.

By 36 weeks gestation, the foetus has been shown to be responsive to external sounds and can discriminate between familiar and different speakers. Decasper et al. (1994) showed that foetuses of 36 weeks were able to discriminate between their mother's voice and the voice of a female stranger. This was demonstrated by examining foetal heart-rate changes in response to a tape recording of a speaker reciting a child's rhyme. There were two speakers one was the mother the second was a control. The same result was observed by Kisilevsky et al. (2003) where they measured an increase in foetal heart rate (from mean heart rate prior to voice onset) when a recording of the mother's speech was played; whereas the heart rate decreased with a recording of unfamiliar voice.

Although discrimination does improve in the foetus with maturation, it is restricted until birth due to the anatomical constraints. The amniotic fluid causes an amplification (of approximately 30dBA) in the spectral range between 100-1000Hz (Richards et al. 1992). This acts as a low-pass filter and means that vowels are usually more audible than consonants and fundamental frequency contours are enhanced more than broad spectral information (Smith et al. 2003).

By the time the foetus reaches full term (40 weeks gestation) discrimination between different vowel sounds and the processing of auditory sound streams associated with speech or music have been shown to be present (Granier-Deferre et al. 2011). In this study Granier-Deferre and colleagues (2011) assessed heart rate changes in 82 foetuses during sleep. They presented 5 stimuli altogether: a silent control, two different piano melodies, a natural Icelandic sentence and a chimera of a sentence where spectral information was removed. All auditory stimuli elicited heart rate change (deceleration), and there was a significant difference between conditions indicating discrimination and processing of the different complex stimuli in this stage of foetal development.

It has been demonstrated that the early development of the hearing mechanism ensures that the foetus begins perceptual learning associated with musical pitch perception prior to birth, whether sounds are generated internally or externally to the mother's body.

2.2.2 Infant Development (Under 5 years old)

Infants are immersed in rich auditory environments from birth, which helps to develop their expertise as listeners, especially within their home and cultural settings (Hargreaves 2009). Unlike in the prenatal period, examination of infant's perceptual abilities can be carried out using both behavioural and objective measures.

The perceptual abilities of neonates at birth show that they are able to process and discriminate a mixture of simple and complex auditory signals. Behavioural measures demonstrate that newborns are able to distinguish their mother's voice from that of other females (Eimas et al. 1971;Kuhl et al. 1992), as was also found for the prenatal period. Electrophysiological studies examining high density evoked potentials of neonates in a sleeping state show that relevant phonetic information is extracted from noise (Dehaene-Lambertz and Pena (2001) and discrimination of changing pitch contours is possible from a very early age (Carral et al 2005).

At 2 months of age melody recognition and discrimination has been acquired (He et al. 2007; Plantinga and Trainor 2009). He and colleagues (2007) investigated the emergence of discriminative responses to pitch changes in melodies. This was achieved by recording electroencephalogram (EEG) responses from 39 infants (between 2-4 months old) to pitch changes in piano tones. Responses to the deviant tones were significantly different from responses to standard tones, indicating discrimination of the pitch change. Plantinga and Trainor (2009) assessed 16, 2-3 month old infants. In this study an eye-movement preference procedure was used to distinguish discrimination and memory of melodies using stimuli created on an acoustic piano and played through a computer and speaker system. Results from the study confirmed the presence of pitch and melody discrimination abilities in infants of this age.

In addition to melody recognition and discrimination, perception of other musical attributes is possible during the early months of life. Baruch and Drake (1997) showed that infants at 2 months old can discriminate tempo changes in tone sequences. Other researchers have also shown rhythmic pattern discrimination at this very early developmental stage (Demany et al. 1977).

By 3 months of age it has be shown that infants display frequency resolution abilities in line with adults for low frequency stimulation (Werner and Vandenbos 1993). This was demonstrated by tracking eye-movement to short melody sequences and examining discrimination between melody sequences. This frequency resolution is assumed to be accurate enough for processing music (Trehub 2003).

The development of the acoustic perception abilities described above can be attributed to infant sound exposure. Young infants are often spoken to by carers using modified speech patterns; this type of speech is referred to as "Infant Directed Speech (IDS)" (also called motherese or parentese). IDS is characterised by exaggerated prosody, raised voice fundamental frequency, expanded pitch contours, larger dynamic range and rhythmic regularity (Clark 2009; Fernald 1991). A number of early studies have investigated infant's reactions to IDS by observing infant gaze patterns to loudspeakers playing both IDS and conventional adult speech (Cooper and Aslin 1990; Fernald 1985; Werker and McLeod 1989). The infants' abilities and preferences shown in these studies along with others previously noted confirms that pitch extraction and understanding is an inherent attribute which develops further with experience throughout infancy.

As demonstrated by the above studies basic pitch perception aspects such as pitch discrimination are processed very early in development (i.e. in infancy). These basic aspects form the basis of development of higher-level pitch structures, such as musical scales and harmony, which, are common to western music. It does however take considerable experience for cultural specific scales to arise such as tonal hierarchy and this can extend into the school years (Trainor and Unrau 2012).

2.2.3 Development throughout School Years

The way in which children develop musically is variable, and can depend upon individual differences such as innate abilities and environmental experience. As children develop through the school years, their perception of musical elements (such as pitch and rhythm) becomes more accurately measurable through assessment of singing and musical improvisation (Lamont 1998).

Evidence of pitch development is split into different areas. The main difference in the research methods literature is whether enquiry is focussed on fundamental pitch capacities such as absolute pitch detection and labelling pitch height; or whether melodic and harmonic relationships between notes are investigated. Assessment of relationships between pitches has been identified as being important for pitch perception within musical contexts Takeuchi and Hulse 1993).

Absolute pitch detection may be acquired during the school years for some children (Takeuchi and Hulse 1993). Young children seem to be able to perceive pitch height however they have difficulty labelling it. This mismatch is attributed to the fact that the terminology used to describe the relationships between musical and verbal concepts takes time to learn and understand (Costa-Giomi and Descombes 1996).

There is evidence that by 6 or 7 years of age children may have pitch identification accuracy that is similar to that observed in adults when detecting mistuned harmonics or melodies (Trainor and Trehub 1994; Trehub et al 1986). Trehab et al. (1986) conducted a study examining the sensitivity of the semitone and musical scale structure by infants and children. Testing was conducted with infants (aged between 9 and 11 months of age) and children (aged 4 to 6 years old) using a five note melody sequence, in a same-different task. The experiment results indicated that older children (aged between 4 and 6 years old) were better than infants in detecting semitone changes within musical scales. The infant group detected semitone change in all positions, however in contrast to the older group the infants were not influenced by whether they were presented within a musical scale. The findings suggested that infants and children can discriminate a semitone in musical contexts and that priority of diatonic structures emerges by 4 to 6 years of age. In a later study Trainor and Trehub (1994) investigated the role of key membership and implied harmony in a group of 18 adults (aged between 17 and 39 years old) and 84 children (42 aged 5 years old, 42 aged 7 years old). Listeners in all three groups were evaluated on their ability to detect three types of changes in one note of a melody (the three changes being out-of-key, out-of-harmony and within-harmony). Results showed that adults and 7 year olds performed better on out-of-key and out-of-harmony changes than within-harmony changes which reflects their ability to use knowledge of key membership and implied harmony. The younger group (5 year olds) performed better on the out-of-key change than the other two changes. This reflects the influence of key membership but not implied harmony in the younger sample.

The understanding of pitch and tonality has been shown to speed up with musical training as well as with age, however only by a small margin (Lamont 1998; Morrongiello and Roes 1990). Morrongiello and Roes (1990) conducted a study where two groups of children (one group of 5 year olds and the second group of 9 year olds) were assessed by asking them to draw melodic contours or patterns of rising or falling pitches. Children were split into groups based on their level of musical training. Their results showed that at both ages musically trained children performed slightly better than there untrained peers. Lamont (1998) examined children's listening skills associated with musical pitch. 408 children were recruited from two primary schools and two secondary schools. Participants were aged between 6 and 16 years of age and were tested using probe-note method. The note sequences consisted of seven diatonic scale notes with three different probe notes to be rated for goodness of fit. The three probe notes were the tonic (scale note), median (scale note) and the flattened submediant (non-scale note). Children were played 26 different sequences whereby a gap followed with one of the probe notes. The participants were asked to decide whether this probe note was a suitable next note in the melody. Following the listening task participants were asked to answer questions relating to their musical background, age, class and gender. The results showed that differentiation amongst categories of probe tones were different between three main age groups (6-8, 8-11 and 11-16) and within the broad age groups mentioned better performance was linked with experience. Lamont's (1998) results indicate that children (aged 6-16) are able to identify pitch in music; and pitch sensitivities increase as children mature and with musical experience.

2.2.4 Impacts of Music Instruction

Cognitive transfer is when individuals transfer knowledge learnt and applied in one context to another new context. Music instruction has been shown to improve pitch perception abilities however there is also evidence that other areas of cognitive reasoning may also be affected (Rauscher 2009).

The relationship between music instruction and cognitive processing triggers debate as currently, studies in the area cannot conclusively explain relationships observed (Rauscher 2009). The majority of results are presented as correlations but with no explanation of cause of relationships observed.

Links have been made to cognitive skills such as sequencing, spatial awareness, phonological awareness, reading abilities and general cognitive performance (Anvari et al. 2002; Costa-Giomi 1999; Gromko and Poorman 1998; Hurwitz et al. 1975; Rauscher et al. 1997; Rauscher and Zupan 2000; Schellenberg 2004).One of the earliest studies examined sequencing and spatial skills associated with instrumental instruction (Hurwitz et al 1975) and involved children aged 6 and 7 years old randomly allocated to one of two groups: one receiving music instruction five days a week for seven months and the other which acted as the control and did not receive any training. Outcomes included sequencing and spatial tasks as well as tasks of verbal intelligence. Significantly higher scores were seen by the experimental group for sequencing and spatial tasks but not for the verbal tasks. It was noted however that the positive effect observed could be attributed to the Hawthorne effect (McCarney et al. 2007), that is, an effect which observes participant’s improving performance solely because they are being studied and not due to the experimental parameters.

A later study was conducted by Rauscher (1997) to control for this effect. A similar style assessment with pre-school children was conducted where children's spatial reasoning was tested with four tasks from the Performance sub-test of the Wechsler Preschool and Primary Scale of Intelligence. There were three groups: one with music instruction, one with computer instruction using software designed to teach reading and simple arithmetic skills and one without any instruction. The music group was further split into two where half had individual keyboard instruction and the other group singing instruction. After several months children were assessed using the spatial and sequencing tasks. Significantly higher scores were seen for the keyboard music group for spatial tasks only, however no significant differences were seen for all the other children assessed. This raises another question concerning whether it is just instruction that causes the effect seen.

Other skills which may be enhanced by music instruction include general cognitive performance (Rauscher et al. 1997); phonological awareness and reading abilities as demonstrated by Anvari (2002) in a study examining 100, four and five year olds. A link between musical ability and general intelligence has been demonstrated (Schellenberg 2004). Schellenberg (2004) tested 144 six year olds split into two music groups (keyboard and singing lessons) and two control groups (drama lessons and no lessons). General intelligence was assessed before and after musical instruction and was shown to be significantly higher in both experimental groups. A later review of this study attributes the positive result gained to development of spatial intelligence (Rauscher 2009).

The findings from these related studies, although taken with caution, give an interesting perspective in children's development as the sound categorisation used to distinguish music from speech may have shared mechanisms (Patel 2008). The influence of confounding variables e.g. socio-economic background, exposure to extra-curricular activities etc should however be considered and has not within these reported studies.

2.3 **Music Production in a Normally Functioning Auditory System**

The term music production covers a wide range of musical abilities, such as improvisation, playing an instrument and singing. This review will focus predominantly on singing. This has been selected based on the recognised correlation of singing abilities to perception skills in particular with reference to pitch (Murbe et al. 2002). The vocal tract, larynx and lungs are considered to function as a musical instrument when singing.

Many characteristics of the vocalisation of singing are similar to those used for speech production. The human vocal tract is used to form the phonemes in a similar way for both speech and singing but the nature of the specific articulatory closures may be modified in singing to optimise the acoustic delivery of the sound. During singing production the sounds are typically voiced unless whispering is used for dramatic effect. In singing production, the vocal apparatus is used to create a wider range of frequencies, larger dynamic level changes and many more duration contrasts than are typically used for speech production (Sundberg 1987).

2.4 **The Development of Singing**

From an early age both at home and in school, infants are both exposed to and encouraged to participate in singing activities. Parents will often use lullabies to help to calm a child at night time, or nursery rhymes or activity songs for enjoyment (Trehub et al. 1997). This early exposure not only provides enjoyment, comfort and singing development, but also facilitates speech perception, production and rehabilitation (Wan et al 2010).

Prior to the 1970’s singing skills were assessed and categorised and children were labelled as either “musical” or “unmusical”. Within school settings if children were considered to be singing ‘out of tune’ they were categorised as “unmusical” and were not offered further musical training (Good et al. 1997). Davies and Roberts (1975; 1976) shifted the thinking away from this approach, recognising that all children had the potential to improve and develop their singing abilities with training. Welch (1985) suggested that singing ability for all typically developing children falls on a continuum where children acquire their singing skills by passing through well-defined developmental stages. With singing training this development can be accelerated and also the bypass the original endpoint.

There is a wide range and variability in children’s singing skills. The time taken for children to reach musical developmental milestones can vary across children (Leighton and Lamont 2006). Welch et al. (1996; 1997) conducted a longitudinal study to map singing skills of 5 year old children over a period of 3 years. Improvements in melodic test battery scores (Matching individual pitches, echoing melodic contours and copying small melodic fragments) were observed as children developed. Welch et al (1996; 1997) suggested that these results provide evidence that singing is a developmental process that is continuously changing. Two major studies have drawn on the developmental theories on singing development and have proposed phased models (Rutkowski 1997; Welch 1998). Both models were generated from systematic evaluations of singing behaviours (one in US and one in the UK) and agree that different phases of singing competency are exhibited from any group of children. These phases range from speech-like chanting up to the demonstration of expanded vocal pitch ranges that is allied with skilled competency in vocal pitch matching. The development of a child's singing has been found to be constrained by natural ability, training and anatomical features; as well as perceptual ability (Welch 2006).

2.5 **Consequences of Cochlear Hearing Impairment on Pitch Perception in Music**

This section focuses on the mechanisms associated with severe-profound cochlear HI only, because this is of relevance to the research carried out.

Individuals with sensori-neural HI are more likely to have poorer pitch perception than their NH peers. There are different potential causes of this and a large variability in ability between listeners, potentially due to different configurations of hearing loss and underlying residual abilities (Moore and Carlyon 2005a; Moore and Carlyon 2005b).

HAs and CIs aim to improve speech perception and address other perceptual difficulties; however, due to underlying perceptual limitations based on the effects of hearing loss, they cannot restore normal perception. In addition to this, the processing in both HAs and CIs will affect the perception of certain parameters in their own way due to their specific approaches to signal analysis and delivery. This will be explained further later in this chapter.

2.5.1 Physiological Consequences of Cochlear Hearing Loss

Cochlear hearing loss is responsible for a number of changes that affect representation of sound stimulation in the auditory system (Moore 2008). Most commonly this is attributed to damage to the sensory hair cells within the cochlea. This takes the form of damage to either the outer hair cells (OHCs), more rarely the inner hair cells (IHCs) or combinations of both for more severe hearing losses (Moore 1995).

The largest consequence of OHC damage is the reduction in the effectiveness and sometimes total loss of the active mechanism (Ruggero 1994). The normal functioning of this active mechanism gives rise to the high sensitivity and sharp tuning of the basilar membrane (BM), all of which are dependent on the integrity of the OHCs. The first evidence of the vulnerability of the active mechanism within the cochlea came from studies of responses to single neurones in the auditory nerve (Evans 1975; Evans and Harrison 1976; Robertson and Manley 1974). In these studies, OHC function was altered by restricting oxygen or by injection of ototoxic agents such as kanamycin, cyanide and furosemide. Lack of air supply, noise exposure and ototoxic agents all induce cochlear damage which results in HI. All the above studies demonstrate decreases in threshold and tuning properties of the auditory nerve response. Later animal models support this by showing negative effects of ototoxic agents and noise on the BM (Liberman et al. 1986; Ruggero and Rich 1991).

Loss of the active mechanism results in a number of perceptual changes (in humans) occurring in line with the physiological evidence above; these include reduced sensitivity to weak sounds, broadening of auditory tuning curves causing decreased frequency selectivity and loss of compressive non-linearity of the BM input/output response leading to loudness recruitment (Moore 1995).

IHCs are the sensory cells of the cochlea and are the transducers used to stimulate nerve fibres. In some cases of cochlear hearing loss, IHC's may be absent or non-functional. In these areas corresponding auditory nerve fibres are susceptible to death due to lack of stimulation, these particular areas are called "dead regions" (Moore 2008). The loss of such cells means auditory stimulation in these areas is perceived by off frequency neurones (neurones not directed to that point on the BM), or requires a much higher intensity level. When OHC's are present within dead regions, the active mechanism still functions by providing sharp tuning but at an elevated intensity level. This has been demonstrated by Liberman et al (1986) in a series of studies in which sampling the activity of different single nerve fibres with different characteristic frequencies assessed the functional state of the cochlea. Structural changes were observed resulting from both IHC and OHC damage. They, however, reported that IHC damage is rare and when it is observed it is usually teamed with OHC damage meaning that in these cases a lack of sensitivity and loss of active mechanism is observed.

2.5.2 Perceptual Consequences of IHC and OHC damage

The changes noted above can be responsible for the perceptual consequences listed below. These can be important for music and speech perception:

Reduced Frequency Selectivity

There is typically a reduction in frequency selectivity (ability of the ear to separate out different frequency components of a sound) (Plack 2005) ,which in turn is essential for many aspects of auditory perception; these include loudness sensitivity, frequency discrimination, speech understanding, timbre awareness, sound source separation and pitch distinction (Moore 1995).

Individuals with cochlear HI have poorer frequency resolution due to a reduction or loss of the active mechanism suggesting that they have broader filtering (2 to 3 times wider auditory filters) than NH counterparts. This usually is proportional to the extent of the individual's HI. In this case, segregation is degraded and poorer frequency selectivity is observed in comparison to a normal auditory system. Studies measuring frequency difference limens

(DLFs) in individuals with cochlear HI compared to NH groups support this finding (Moore and Peters 1992).

Reduction in the Precision of Phase Locking

Phase locking refers to the consistent relationship between action potential firing in an auditory nerve fibre and the phase of the stimulating sound wave. Phase locking forms the basis of the temporal models of pitch perception described earlier in the chapter. Cochlear damage has differing effects on phase locking. Harrison and Evans (1979) conducted a study where kanamycin was used to damage OHC's within the cochlea of a guinea pig. They found that this had no impact on the auditory nerve phase locking. In contrast Woolf et al (1981) conducted a similar animal study on a chinchilla, where they found that phase locking was significantly reduced over a range of frequencies between 400 and 3000 Hz. This effect on phase locking was also supported by a study which examined phase locking to complex tones in a cat (Miller et al. 1997). In this study Miller et al (1997) observed cat nerve fibres damaged with noise when presented with a synthesized vowel. Their results showed that fibres in the region of acoustic trauma (1–6 kHz) showed a reduced synchrony in phase locking to formant peaks of synthesized vowel sounds. Based on these animal studies assumptions can be made that human individuals with cochlear hearing loss may have reduced precision of phase locking to nerve firings, although this may not always be observed. Support for this assumption is shown by a human study which compared the ability of HI and NH subjects to use temporal fine structure information from complex tones. The study investigated the use of temporal fine structure information represented as a means of assessing the integrity of phase-locking in HI subjects. Subjects were required to discriminate a non-shaped stimuli where both spectral and temporal information was present (a tone that contained five equal-amplitude components) from shaped stimuli where spectral information was removed (the tone contained many components, but were passed through a fixed bandpass filter to reduce excitation pattern changes). If subjects were able to discriminate the shaped stimuli as accurately as the non-shaped it would show that they were utilising temporal cues and were not reliant on spectral cues. Results showed that HI subjects performed more poorly than NH for the shaped stimuli indicating that they were unable to access the fine temporal structure information with similar accuracy to NH subjects. HI performance was improved with non-shaped stimuli where spectral information was available (Hopkins and Moore 2007).

Loudness recruitment

Loudness recruitment refers to the abnormal growth of loudness that occurs when people have cochlear damage. It is associated with the loss of the active mechanism (Moore 1995). Once a sound becomes audible, the growth in perceived loudness increases more rapidly than normal. The upper level of comfort is typically at the same level as NH. This leads to exaggeration of perceived dynamic qualities (loudness) with auditory signals (Moore et al. 1996).

Affects in Temporal Processing and Integration

For everyday sounds there are unpredictable fluctuations in amplitudes observed. Listeners with cochlear HI may show reduction in temporal processing and integration abilities in comparison to listeners with NH (Carlyon et al. 1990). Poor temporal resolution is thought to occur due to a loss of cochlear nonlinearity and compression leading to loudness recruitment, loss of audibility and poorer frequency selectivity.. Accuracy of temporal integration is attributed to the level of hearing loss.

All of these factors can lead to problems in discriminating and identifying speech, music and environmental sounds (Moore 1996).

2.5.3 Pitch Perception with Cochlear Hearing Loss

The changes occurring due to cochlear damage have been shown to lead to a decrease in pitch discrimination and to introduce inconsistencies in pitch-scaling tasks (Moore and Carlyon 2005a). The degree to which this happens is, however, unknown and appears unrelated to level of hearing loss (Looi 2008). The broadening of auditory filters can lead to the loss of resolution of the fundamental frequency and resolved harmonics, thus impacting on overall pitch quality and pitch perception abilities (Moore 1995).

2.6 Speech and Music differences

Speech and music have different acoustic characteristics and therefore HA and CI settings that are appropriate for speech may not be optimal for music.

For accurate categorisation of sounds the auditory system has to develop rules to perceive native vowels, consonants, timbre and pitches used for both verbal communication and music appreciation (Patel 2008). Although many perceptual attributes associated with speech can also be appropriate for enjoying music; the perception of music can be considered more complex because musical enjoyment is not about categorisation of individual aspects, but is a much more holistic experience (Chasin and Russo 2004).

When considering the main reasons why the perceptual classification of speech and music differ within the auditory system it is of interest to observe the spectral and temporal profile produced by each. Speech is a predictable controlled signal with restricted variability. This is because speech signals are limited by human anatomy i.e. articulation in the human vocal tract. Therefore there is a restricted set of outputs that it can produce in terms of frequency, intensity and timbre. Music is typically a more complicated signal comprised of a wider range of frequencies and dynamic amplitude changes (Chasin and Russo 2004). Music has far fewer "universal" features than speech because it is changeable based on instrument, singer, genre and culture. This produces varied profiles both spectrally and temporally (Patel 2008).

2.7 Hearing Devices Available for Individuals with Cochlear Hearing Loss

Individuals with cochlear hearing loss are offered a range of intervention devices, their goal being to improve listening and communication. The choice of interventions is often governed by level of HI, as well as individual characteristics such as health, duration of deafness and preference. The most common forms of intervention offered are HAs, CIs or devices combining acoustic and electrical stimulation. Each of these devices has different approaches to sound delivery and also different manufacturers have their own ethos on the processing schemes and hardware to use to achieve optimal results. In turn, the way in which these intervention methods affect pitch perception and production in musical contexts differ (Chasin and Russo 2004). All devices are intended to enhance and improve listening and communication situations for HI listeners.

2.7.1 Hearing Aids

A HA is comprised of components that work to pick up a signal via a microphone, amplify it according to a prescription formula before filtering and passing to a receiver which converts it back into an acoustic signal (Dillon 2001). HAs contain multiple filters covering the low to high frequency range (up to 8,000Hz) to allow the amplification characteristics to be adjusted on a channel by channel basis to provide appropriate gain for the hearing loss (Kuk and Baekgaard 2009).

HA Prescription formulas are based on speech spectra to optimise audibility of the critical speech frequencies (Dillon 2001). Prescriptions do not, however, optimise frequencies across the range or allow dynamic variability appropriate for some music signals. The range of accessible frequencies will also be restricted by the bandwidth of the devices, which has been connected with a reduction in perceived quality of music (Franks 1982). Another area which has unknown effects on musical outputs are changes in amplification caused by the HAs specialized speech optimizing systems altering signal processing e.g. noise reduction and feedback suppression (Chasin and Russo 2004).

2.7.1.1 Pitch Perception with Hearing Aids

The processing scheme used in HAs could negatively impact on melody perception in addition to the limitations that are imposed by the hearing loss that the HI individual has.

Hearing Aid Parameters Affecting Pitch Perception

Compression characteristics

The concept of compression within HAs dates back to 1937 (Steinberg and Gardener 1937). Compressive amplifiers (also known as automatic gain controls) allow individuals with sensori-neural HI access to a range of intensities even though their dynamic range (range of audible intensities) is restricted and loudness recruitment may be present. Compression systems can often be helpful in musical contexts, by providing access to a larger range of intensities when the dynamic range is limited.

There are many different ways of implementing HA compression to avoid discomfort, reduce inter-phonemic intensity differences, make sounds comfortably loud, normalise loudness, reduce noise and maximise speech intelligibility. HAs combine various rationales for achieving desirable listening conditions for speech perception. These are achieved by altering compression attack/release times, compression ratios, compression thresholds/knee points, multiple compressors for different frequency bands or higher frequencies compressed into lower frequency ranges (Dillon 2001).

For optimal pitch perception it has been suggested that adjacent channel compressors are set to similar levels and the compression knee points are raised from previous settings (Chasin and Russo 2004). The evidence supporting these recommendations is limited and very little consideration has been given to the impact that frequency compression (FC), frequency transposition (FT) or multi-band compression has on music.

Feedback and Noise reduction systems

Most modern HA's have mechanisms to reduce environmental and wind noise and prevent acoustic feedback. The algorithms differ across different manufacturers. These features are beneficial to HA wearers in many situations but the effect that these have on pitch perception within music is currently unknown. It has been suggested that they appear to confuse some high frequency musical inputs with feedback noise and therefore erroneously reduce the intensity of those sounds (Chasin and Russo 2004).

2.7.2 Cochlear Implants

Over the past fifty years CIs have been introduced and implemented in clinical settings as a viable (re)habilitation option for patients with severe to profound HI bilaterally, who receive no or little benefit from acoustic amplification. CIs can be implanted either unilaterally or bilaterally depending on the individual situation. There are also individuals using bimodal stimulation, i.e. a CI on one ear with a HA on the contra lateral ear (BMS) or combined electro-acoustic stimulation on the same ear (EAS).

A CI is an electronic device, which transduces acoustic sound into electrical signals, which can directly stimulate auditory nerve fibres. The purpose is to by-pass the dysfunctional peripheral auditory apparatus to give sound perception (Cooper 1991). Current evidence confirms improved speech perception in quiet for severely or profoundly deaf adults and children following implantation (McDermott 2004). However the success of musical perception and production may be quite different.

2.7.2.1 Pitch Perception with Cochlear Implants

Research shows that cochlear implantees perform significantly worse than NH controls in pitch-based tasks, especially for tonal languages (Lee et al. 2002; Wang et al. 2012) and with music (Looi 2008; Wang et al. 2012). Tonal languages are of relevance as different speech characters or words are sometimes solely categorised based on pitch.

Lee at al. (2002) examined Cantonese tone perception of 15 unilaterally implanted Cantonese children. When compared to a matched NH group, the CI group performed significantly worse on a task where they had to identify Cantonese tones. A similar pattern of results was found by Wang et al (2012) where NH and CI adult groups were compared on lexical tone perception and the musical sounds in cochlear implants (MuSIC) perception test. Their CI group performed significant worse than the NH group in tasks of pitch discrimination, instrument identification, instrument detection and lexical tone perception. Their lexical tone perception also positively correlated to pitch discrimination within their CI group.

When making comparisons between CI users and HA users, CI groups show significantly poorer scores on pitch perception tasks (Looi et al. 2008). Looi et al (2008) conducted a study which examined pitch intervals within a music test battery. Pitch stimuli were recordings of the vowel /a/ sung by a trained male or female singer. Each stimulus consisted of two different notes with the same vowel, sung by the same singer, either one octave (12 semitones), half an octave (6 semitones), or a quarter of an octave (3 semitones) apart. This results showed significantly poorer results for CI groups in comparison to HA groups. In a more recent study the same researcher conducted assessments comparing four different groups (NH, unilateral CI users, bilateral HA users and individuals using bimodal stimulation (BMS)) (Looi and Radford 2011). The groups were compared for speech recognition as well as the same pitch ranking task performed in earlier studies (Looi et al. 2008). Again this study showed that children using HAs perform significantly better than children with CIs.

Cochlear Implant Parameters Affecting Pitch Perception

Cochlear Implant Coding

One reason for degraded pitch perception amongst CI users can be attributed to pitch-coding mechanism of the CI itself. Pitch associated with music contains more “fine-grained information” than is required for speech, where usually changes in pitch would signal gross linguistic information unless tonal languages are being discussed (Vongpaisal et al. 2006). Most CI speech processors extract only temporal envelope cues from auditory stimulation, meaning that fine structure cues are missed. The fine structure information encoded through normal cochlear auditory filters are beneficial for good pitch perception (Smith et al. 2002; Wilson et al. 2004).

Electrode Array Placement

Electrode arrays are common to every CI system however the length of the array and number of electrodes along the array can differ. Current CI’s range from 12 to 22 electrodes mounted on a carrier, which is surgically implanted in the scala tympani via the round window or cochleostomy. Most electrode arranges range from 18-24mm and will extend into the first turn and a half of the cochlea, although there are some which can extend up to 31mm and are designed to follow the full length of the basilar membrane (Boyd 2011). In order to elicit different pitch perceptions signals are filtered and directed to different electrodes according to the frequency-place map in normal hearing, with low frequencies being transmitted to the apical electrodes and high frequencies to the basal electrodes (Vermeire et al 2008). However varying insertion depths, insertion placements and mismatched frequency to place stimulations can affect the accuracy of pitch perception (Baumann & Nobbe 2006, Boex et al 2006, Dorman et al 2007 and Vermeire et al 2008).

Cochlear Implant Input Frequency Range

Typically a CI input frequency range will not reach under 100Hz or above 8kHz therefore this will limit the range of achievable pitches that will be transferred especially for music where often a wider range of frequencies are present than what is observed in speech. This has greater impact when frequencies are then mismatched due to electrode placement (Baskent & Shannon 2004)

2.7.3 Combined Electric-Acoustic Stimulation

Combining electric and acoustic inputs for individuals with residual hearing in the low frequencies gives the potential for better sound localisation, improved speech in noise and greater perception of music (Ching et al. 2009; McDermott 2011) because fine structure information is provided in the low frequency region where there is good residual hearing (Smith et al. 2002). In cases with this natural residual hearing, improvements in binaural hearing abilities and reduction of auditory deprivation are reported (Ching et al. 2009).

There are two approaches to providing bimodal stimulation, the first by combining a CI with a HA on the contra-lateral ear (Kong et al. 2005); the second by using a modified shortened electrode array with acoustic amplification in the same ear (Gantz et al. 2005) known as electro-acoustic (EAS) or hybrid stimulation. EAS devices aim to amplify sounds in the low frequencies acoustically, as a HA would and to stimulate higher frequencies electrically, through CI electrical stimulation.

2.7.3.1 Pitch Perception with Combined Electric-Acoustic Stimulation

The limitations associated with pitch processed through CIs have been discussed previously; however there is evidence that combining electrical stimulation with acoustic hearing could improve outcomes (Dorman et al. 2008; Gfeller et al. 2006; Kong et al. 2005; McDermott 2011) although this is not always demonstrated (Cullington and Zeng 2011; Looi and Radford 2011). The two may provide complimentary auditory cues for pitch perception as CIs provide high frequency information and HAs give more reliable fundamental frequency information (Looi 2008).

In 2005 a group of researchers investigated the melody recognition skills of five adult BMS users (a CI on the ipsilateral ear with a HA on the contralateral ear) (Kong et al. 2005). Participants were asked to perform tasks with each device alone and then combined so that they received sound stimulation bimodally. Results showed that better performance was achieved for the melody recognition tasks with bimodal stimulation than either mode alone. The results were attributed to the potential of the acoustic HA to provide cues for pitch perception. It is important to note that these individuals were experienced users of bimodal stimulation and therefore this factor could have had an effect on results when using the modes separately. The study was also conducted on a small number of adult subjects (n=5) which may not be representative of a larger sample.

By contrast a later study conducted by Looi and Radford (2011) assessed the pitch ranking abilities of four different groups of children aged between six and 16 years old (NH listeners, unilateral CI users, bilateral HA users and BMS users). They did not observe a significant difference between the bimodal and unilateral CI participants for the pitch ranking task. They attributed the lack of measurable benefit by their bimodal group to the fact that children may have been experiencing conflicts in pitch changes between their devices or that lack of maturity meant that they were unable to utilise the information as well as post-lingually deafened adults. There were differences between the groups in terms of aetiology of HI, with a larger portion of the bimodal group being born prematurely and/or or suffering with hypoxia or anoxia at birth and also a significant age difference between BMS and CI users (with BMS users being significantly younger than the CI users) which may of contributed to the results obtained. Cullington and Zeng (2011) added further support to these findings because their study showed no significant bimodal advantage in pitch perception tests either. They tested 13 BMS users and 13 bilateral CI users on four pitch related tasks: the hearing in noise test (HINT) (Nilsson et al. 1993), the Montreal battery of evaluation of amusia (Peretz et al. 2003), the aprosodia (prosody deficit) battery (Ross et al. 1997) and talker identification. Their results showed no significant differences between the bimodal and bilaterally implanted children on any of their measures. Their adult groups were matched in age, duration of deafness and speech perception performance however the BCI group had significantly longer length of cochlear implant use (7.2 years) than the BMS group (2.6 years) which could have had influence over the results. A lack of measurable difference could also be attributed to the test battery sensitivity. Based on these two studies it cannot be concluded that acoustic input from a HA is not beneficial for pitch perception due to the group differences.

Two studies on use of EAS devices (ipsilateral acoustic and electric stimulation) are reported by Gfeller and colleagues; one conducted in 2006 and the other in 2007. In the first study, a group of adult EAS device users were compared to a group of adult conventional CI users for song recognition and instrument identification. The later study compared EAS and CI users (all adults) on pitch-ranking abilities. The results obtained on both studies demonstrated that EAS device users had superior ability in these tasks with a significant difference between the groups in all tasks completed (Gfeller et al 2006; Gfeller et al 2007). Results were also compared to a third normal hearing group, who had significantly higher scores than both HI groups. This indicated that although the EAS device shows musical/pitch advantages it is not to the level of NH pitch perception. A study by Golub et al (2012) also demonstrated that adult EAS users performed better in musical tasks. They conducted a study using EAS and conventional CI users (all adults) and they were compared on measures of spectral and temporal sensitivity (spectral-ripple discrimination, temporal modulation detection, Schroeder-phase discrimination andclinical assessment of music perception (Kang et al. 2009)). For spectral-ripple discrimination 500ms stimuli were generated either in standard or inverted ripple form. In order to determine spectral-ripple resolution threshold an adaptive forced choice paradigm was used. Temporal modulation detection was attained by asking participants to choose the interval containing modulated noise in a forced choice procedure. For the Schroeder-phase discrimination test, positive and negative Schroeder-phase stimuli pairs were created at two frequencies (50 and 200Hz) these were presented to participants again in a forced choice procedure. The subject was asked to discriminate test from reference stimuli in this adaptive task. The clinical assessment of music perception was used to assess melody, timbre and pitch recognition. Participants underwent three forced choice tasks; for pitch a complex tone pitch discrimination test was administered at three different frequencies (262, 300 and 391Hz). Participants were asked to select the highest frequency in a 1-up and 1-down tracking procedure; for timbre a musical instrument identification test was undertaken, instruments included piano, guitar, clarinet, saxophone, flute, trumpet, violin and cello; and for melody participants were asked to discriminate different familiar melodies e.g. “twinkle twinkle” in a 12 forced choice task. Their results showed that EAS users’ performance on clinical assessment of music perception pitch test and spectral-ripple discrimination was significantly better than the CI alone group. The temporal modulation detection, melody and timbre clinical assessment of music perception tests and Schroeder-phase discrimination test showed no significant difference between groups (Golub et al. 2012). These results suggest that some benefit may be observed for BMS users for spectral discrimination but not for temporal discrimination.

Current research suggests that bimodal stimulation (BMS and EAS devices) could be beneficial for musical tasks associated with pitch perception. There are, however, few studies on pitch perception for children.

2.8 **Singing with Hearing Impairment**

The issues discussed in the previous sections not only affect direct perception of sound but also the auditory feedback process, which has an impact on monitoring and adjusting production (Murbe et al 2002). It is therefore logical to assume that these factors may in turn affect singing abilities.

Xu et al. (2009) demonstrated that cochlear implantees perform significantly poorer than NH matched peers on singing skill. They assessed 7 children with CIs aged between 5 and 12 years old against a control group of 14 NH children aged between 4 and 8 years old. They asked all children to sing a song of the child's choice and recorded the production. The fundamental frequency (F0) of each note in the recorded songs was extracted for acoustic analyses. The children with CIs showed significantly poorer performance in the pitch-based singing assessments compared to the NH children. They attributed this lack of ability to the unsatisfactory perception of musical pitch. One limitation of the study was that children were asked to select the song they wanted to sing which led to a variety of different songs being chosen. Therefore variation in song choices meant musical structures were inconsistent across the whole sample which could have influenced the accuracy of evaluation.

A later study conducted by Wang and Huang (2010) compared the pitch perception and pitch production of 14 CI children aged between 2 and 9 years of age. The children's perception was assessed through a same-different task; and their production was assessed by asking them to vocalise the musical tones after listening to the same notes vocalised by a female speaker. The results suggested that the CI children were able to discriminate musical notes two or more semitones apart. However their musical production showed significantly lower fundamental frequency than the original sounds heard. Subjective analysis of vocal production also showed poor pitch contour recognition. This therefore suggests that CI children's pitch production does not necessarily reflect their perceptual ability. This study was conducted on a small sample of mandarin speakers which could have influence on interpreting and comparing results to western children who are not regularly exposed to tonal language.

On the basis of these studies, it could be suggested that individuals using HAs or BMS may have better singing abilities than individuals using just electric stimulation via CIs. Direct evidence could not be found within the literature to support this with the paediatric population. Ching et al. (2007) predicted that BMS stimulation would lead to a group of adult users demonstrating a better voice quality. Nittrouer and Chapman (2009) predicted improvements in speech and language development for the paediatric population using BMS.

Psychoacoustic experiments can give insights into actual perception and production skills, but there is also the important psychological component of musical appreciation and enjoyment.

2.9 **Musical Behaviours and Appreciation with Hearing Impairment**

By observing enjoyment and appreciation of music it can give an insight into patient perspectives on how devices process musical elements such as pitch. Typically this data is collected in questionnaire format but is therefore susceptible to bias and participant influence.

Results from a study by Gfeller et al. (2000a) suggest that HI adults' level of musical enjoyment is not directly comparable to NH matched controls. There are a variety of findings when comparisons are made across the different intervention methods for HI. Findings from Looi et al (2008) indicate that music appreciation for HA users are similar to that of cochlear implantees. They conducted a study with 30 hearing-impaired adults matched on level of hearing loss (15 aided and 15 implanted). They rated and compared their appreciation of musical sounds. Their results indicated that cochlear implantees rated the musical sounds as more pleasant however the difference between the groups was not significant. The comparison to NH subjects was not made within this study and these findings were based on a relatively small number of adult users.

Results from adult questionnaire data suggests that combined electric and acoustic hearing could provide some advantages in music perception (Kong et al. 2005). One may assume that better music perception may increase musical listening and participation (Fitzpatrick 2009) although this has not been confirmed (Gfeller et al 2008). Gfeller et al (2008) conducted a study with 209 adult CI users to assess whether there were predictors of musical perception and musical appraisal. Their results showed that significant predictors of percept accuracy were not predictors of appraisal. This study suggests that perceptual skill may have little effect on involvement and appreciation although specific studies directed at musical behaviours, appreciation and enjoyment with combined electro-acoustic stimulation have not been reported in the literature especially with paediatric populations.

2.10 Effects of Musical Training on Pitch Perception and Production with Hearing Impairment

There are investigations into the potential benefits of musical training for HI individuals. Studies in this area have primarily assessed cochlear implantees due to their musical difficulties. It is known that the processing and transmission of certain musical parameters such as pitch are limited based on device coding strategies. However studies over the past ten years have promoted music listening and training packages to assist adult CI users in a variety of musical tasks, some designed specifically for pitch perception (Galvin et al. 2007; Gfeller et al. 2000b; Gfeller et al. 2001). Results from these studies indicate that despite device limitations, training packages can improve musical perception for cochlear implanted individuals.

A few studies of musical training effects have also been undertaken with children showing positive results (Abdi et al. 2001; Rocca and Boyle 2011; Yucel et al 2007; Yucel et al. 2009). Two studies were specifically designed to assess whether training improvements singing skills of CI children are of particular relevance for this research (Rocca and Boyle 2001; Yuba et al.

2009). Yuba and colleagues recorded the singing voices of 8 CI children, letting them sing the melody from the first two bars of the ‘‘Frog Chorus’’ (a well known Japanese song) before and after instruction. The instruction given was focused on the falsetto voice by letting each subject listen individually to the instructor’s model singing, and electric piano sounds. The participants were asked to imitate what they heard as part of the instruction. Comparisons were made of fundamental frequencies before and recorded after instruction. Significant differences were recorded between time-point 1 and 2. Rocca and Boyle (2011) monitored children’s development when undertaking a musical training programme – “A musical journey” in a pilot study. Children were assessed using tests of pitch development, vocal training and the singing and recognition of melodic sequences. Video recordings were graded by blind analysis in relation to a target series of intervals and melodic sequences based on these assessments. Rocca and Boyle’s (2011) results indicate that musical habilitation can enhance the ability to repeat intervals, or melodic sequences and to sing in tune.

2.11 **Gaps in Research Evidence**

Through review of the literature, gaps have been identified where further exploration would be beneficial for better understanding of the pitch perception and production in HI children. These include areas associated with the normally functioning auditory system, such as gaining a greater understanding of the perceptual mechanisms associated with pitch perception; and gathering further evidence of links between musical and cognitive processes. In addition a greater literature base is required specifically focussed on HI populations, for example, which intervention devices provide optimal auditory conditions for musical perception and production for certain individuals, how much residual hearing and fine structure preservation is necessary to see binaural improvement with combined electric-acoustic stimulation, and what effects HA signal processing features and CI mechanisms have on musical signals (e.g. compression systems, feedback cancellation systems, NFC technology). Further investigation into the musical appreciation of HI children and the effects of training would also be of interest.

These areas require further exploration because of the critical role that pitch has with respect to musical enjoyment and speech and language development. The outcomes could have an impact on clinical choices for children with cochlear HI.

As noted above the current literature base does not present comparisons between intervention devices (CI, HA or BMS/EAS) associated with HI, with respect to both musical pitch perception and production. This gap in the research literature forms the basis of the current primary research aim. In order to investigate this area, validated measures of pitch perception, production and musical ability are preferable. Within the next chapter validation of the chosen parental questionnaire is presented.

CHAPTER 3 : THE OPTIMISATION, VALIDATION AND NORMATIVE DATA COLLECTION FOR THE MUSICAL STAGES PROFILE (MSP) QUESTIONNAIRE

3.1 Introduction

Music forms an integral part of our modern society (Trehub 2003). As children develop, there are many opportunities for involvement in music, within the family and wider social interactions. Within the UK the benefit from music for learning is underpinned by the inclusion of music within the National Curriculum for children and adolescents aged from 5 to 16 years old (Department of Education 2013). The curriculum framework is built upon the assumption that the level of musical ability will increase as children progress through the educational "key stages". It is helpful therefore to have methods of monitoring children's musical development; however at present this is not carried out in a formalised way. The lack of coherent and validated assessment gives rise to variability across schools and teachers in comparing musical ability for both NH and HI children at different stages of development (Scattergood and Limb 2010).

Musical enjoyment is acknowledged as being a holistic experience with different individuals liking a diverse range of music. However, it is easier to assess overall musical ability if music is broken down into key elements that can be measured and evaluated separately however these cannot be assumed to be linked with musical enjoyment. These can include aspects of pitch, rhythm and timbre perception as well as emotional interpretation. When dissected in this way individual perceptual skill levels can be derived to give an indication of ability in each area as well as for overall musical development. This is particularly relevant when assessing populations with possibilities in different sound processing abilities such as those with dyslexia, auditory processing disorders or HI. Children with these difficulties have perceptual constraints arising from distortion in hearing or central processing of sound. For some of the HI children additional difficulties may also arise due to signal processing within their hearing devices. This study is focussed on HI because that was the particular population of interest in the main study phase, but the work has relevance for the wider population of children with sound processing difficulties.

Hearing loss can be responsible for a number of changes that effect representation of sound and therefore perception of music signals in the auditory system (Moore 2008). Commonly this is attributed to damage to the sensory hair cells within the cochlea affecting musical perception in varying ways as described in Chapter 2. As a result listeners suffering with hearing loss can experience poor frequency selectivity (Moore 1995), reduction in the precision of phase locking (Woolf et al. 1981), loudness recruitment (Moore 1995) and reduction in temporal processing and integration (Carlyon et al. 1990). All of which can be responsible for poor performance in music perception tasks. Individuals with cochlear hearing loss are offered a range of intervention devices, their goal being to improve listening and communication. The choice of interventions is often governed by level of HI, as well as individual characteristics such as health, duration of deafness, aetiology of deafness and preference. The most common forms of intervention offered are HAs, CIs or devices combining acoustic and electrical stimulation (BMS or hybrid devices). Within each of these areas there are differences in the approaches to sound delivery due to different manufacturers using their own approaches to process sound for optimal listening. The way in which these intervention methods affect perception and production in musical contexts differ (Chasin & Russo 2004), it is therefore likely that different signal processing and fitting strategies of hearing devices will vary the listeners' perception, production, and appreciation of music. One example of this is for children who use CIs. Paediatric cochlear implantees are likely to perform more poorly in pitch and timbre perception tasks than children using HAs or NH children. However rhythmical perception is likely to be equivocal between the different groups (Limb & Rubinstein 2012; McDermott 2004). The possible reasons for these differences have been described in Chapter 2.

At present there are few validated measures for assessment of musical ability for young children; particularly measures which can be used for both children with NH and HI (Kang et al. 2009). Young children can be challenging to assess behaviourally, but by using subjective parental evaluation, insight into the perceptual abilities could be gained prior to the age when a child is developmentally appropriate for behavioural testing. This is important for special populations, where the emergence of musical abilities may develop later than expected based on chronological age.

There are questionnaires that have been developed to assess musical aspects in adults with HI (Gfeller et al 2000; Gfeller and Lansing 1991;Leal et al 2003; Looi et al 2008; Looi and She 2010; Mirza et al 2003; Veekmans et al 2009) but at present there are very few used for assessing overall musical ability level in young HI children. Questionnaires have been developed to quantify music exposure and enjoyment for HI children but do not offer a means of specifically assessing perceptual or production skills (Gfeller et al. 1998; Mitani et al. 2007; van Besouw et al. 2011). Two of the studies cited here are of interest because they document their validation processes.

Gfeller et al. (1998) developed a questionnaire to assess musical background and appreciation for children with CIs. This questionnaire was adapted from a previous questionnaire for adults (Gfeller et al 1998b). The validity of the questionnaire was assessed by a panel of four professionals with experience of working with HI children. The expert recommendations were taken into account and modifications made prior to the questionnaire being distributed. Van Besouw et al (2010) reported the development of a parental questionnaire looking at CI children's music exposure and appreciation. In the process of development this questionnaire was reviewed by parents of CI children to determine the feasibility of the questionnaire. Although the questionnaires mentioned here have undergone some degree of validation, they have not been through a full standardisation process to determine the normative ranges of performance for NH and HI children.

In order to develop a musical ability measure with norms for children from birth to nine years of age, the Musical Stages Profile (MSP) questionnaire was developed and assessed in a pilot study (Vickers et al. 2007). The MSP is a parent interview questionnaire looking at the development of musical skills in young children. The MSP was developed by a collaboration of professionals in the fields of music education, music therapy and cochlear implantation. Questions were based on their joint experience of the emergence of musical skills as a child develops from birth up to nine years of age. The format of the MSP is similar to the Meaningful Auditory Integration Scale (MAIS) (Robbins et al 1999), a parental interview scale in which parents provide information on their child's listening skills using a five point scale (1. Never, 2.Rarely, 3.Occasionally, 4.Frequently, 5.Always). As with the MAIS questionnaire, the MSP was designed to measure emerging abilities in different skill areas. Questions in the original MSP questionnaire were categorised into domains which were rated as integral to musical development by professionals working with both NH and HI children. These included: sound awareness and general reaction to sound, exposure to music, melody and dynamic changes, rhythmical changes and emotional aspects. Each question is answered following observation of the child's behaviour with the same five point scale as the MAIS. A score is calculated for each individual question (out of five), sum of all questions in a domain, as well as a sum of all the questions on the MSP. The scores were intended to reflect a child's current musical ability, with a higher score indicating a higher level. The questionnaire has been designed to cover a wide age range in children (0-9 years old), to allow the assessment of children's musical skill as abilities develop. The limitation of such a wide age range is that parents completing the questionnaire may encounter particular difficulties answering questions at particular stages e.g. having knowledge of musical activities and behaviours undertaken at school when they are not present. However within this current research the wide age range is particularly relevant as HI children are unlikely to develop musical skill levels equivalent to a NH child of the same chronological age and both are to be included in the main study phase. The version of MSP questionnaire cited in Vickers et al (2007) has been used in studies assessing the impact of musical training for children with CIs in Turkey (Yucel et al. 2007; Yucel et al. 2009). Yucel et al (2009) reported significant differences using the MSP, between a group of children with CIs that received musical training and a control group of implanted children that did not receive training. This suggests that the MSP may be sensitive differences in musical ability shown between CI children.

The aim of the current study was to optimise the content of the MSP and to determine the reliability and validity of the MSP for use in assessment of musical ability in groups of children with NH and with HI; with the goal of determining how effective and sensitive it is for children with different profiles of hearing loss in the emergence of musical abilities. The optimisation and validation of the MSP questionnaire was considered important for this research as it ensured the questionnaire provided reliable data in which to draw suitable conclusions from for future studies. The validation approach was conducted using an approach outlined by Jackson & Furnham (2000).

The MSP was chosen because it subjectively quantifies music perception and production skills as well as other emotional aspects relating to musical appreciation and enjoyment. This is important for this research because the test population of HI and NH children may have very different patterns of emerging musical skills. A questionnaire was selected because it is a useful measure for assessing young children prior to an age when they are developmentally capable of undertaking assessments of ability. This may also be true for special populations with development delays.

3.2 **Methods**

Ethics approval was given by the UCL ethics committee (UCL Ethics Project ID Number: 1927/001) prior to data collection for this study.

There were three main phases to the study. Phase One was an expert panel review of the MSP. The expert opinion given in this phase was used to make amendments to the questionnaire by improving the clarity of the wording and by moving questions to different sections of the MSP where they were considered to be more appropriate. Phase Two was a pilot study to assess the validity and reliability of the newly optimised MSP questionnaire. In phase Three, normative data was collected for the MSP and reference centile charts created.

3.2.1 Phase One- Expert Review:

A group of 14 experts in the field of musical development and hearing were recruited to review the MSP for its validity and appropriateness, following email invitation. Their opinions were used to determine which critical questions within each domain were useful to understand the development of key skills for musical ability. The panel was made up of two professionals in fields of audiology, three speech and language therapists, three CI audiologists, and six specialists in music development and music education.

The MSP was supplied to each expert in an online form using a web-based questionnaire package (Opinio 1998) with all domain headings removed. After each question a drop down menu was provided with a choice of domain headings from the questionnaire. These headings were –"sound awareness and general reaction to sound", "exposure to music", "melody and dynamic changes", "rhythmical changes" and "emotional aspects". The experts were also provided with a comments box after each question to allow them to make additional suggestions or comments.

Experts were asked to review each question for clarity (noting suggestions for improvement within the comments boxes) and then to allocate each item to a particular domain that they felt it belonged to from the drop down menu. They were also asked to add additional comments on the general characteristics of each question if they felt it was appropriate e.g. language use, time taken to answer, and clarity. Validity was assessed by looking at which domain the experts selected for each item and calculating the domain percentage agreement between experts.

The MSP questionnaire was amended so that items that were identified as ambiguous by the expert review panel were changed or moved into different domains to improve clarity. The optimised version of the MSP questionnaire is presented in Appendix 1.

3.2.2 Phase Two- Pilot Study:

A random opportunity sample of parent participants was recruited from local nurseries, schools and play groups in and around London. The study was advertised on notice boards and through letters sent home to children's carers. The only inclusion criterion was that children needed to be within the age range 0-9 years of age. Each questionnaire related to one individual child; although some parents completed more than one questionnaire if they had more than one child. Parents/guardians were asked to complete the MSP questionnaire based on their observation of their child's current behaviour concerning music, for example: "when singing a song will your child vary loudness appropriately?". The questionnaire was delivered as an online survey (Opinio 1998) and took approximately fifteen minutes to complete (measured between start and stop times).

MSP questionnaires were completed by parents for 60 children. There was incomplete information in eight of the questionnaires collected, so a total of 52 of the questionnaires were used in the analyses (relating to 52 children).

The mean age of the children was 53 months and the age range was from 6 to 108 months. The gender distribution was 42.3% male to 57.7% female. This data collected was analysed to evaluate the questionnaire's validity and reliability.

Two weeks after completing the first online survey, a second identical questionnaire was given to the parent respondents to complete. These data were used to give an indication of the questionnaire's repeatability (test-re-test reliability). A two week break between the first and second questionnaire was chosen so that respondents would not remember responses given in the first completion but also to ensure the child's ability level had not changed between the two time intervals. 36 parents (69% of sample) repeated the questionnaire for a second time.

3.2.3 Phase Three– Age Appropriate Normative Data:

To collect normative data for the MSP questionnaire a random opportunity sample of respondents (parents/carers of children) were recruited from nurseries, schools, play groups and internet sites with agreed access. Once recruited the questionnaire was distributed in an online form (Opinio 1998). Parents/guardians were asked to complete the questionnaire at their convenience. The survey remained open for 10 months.

The exclusion criteria were parents/guardians of children who fell outside the age range set by the limits of the MSP questionnaire (children between 0-9 years of age) and children who had known HI or other difficulties which would suggest potential atypical development (no children fell within this category from parents that had completed the questionnaire).

324 questionnaires were fully completed in this phase of the study. The ages of the children reported in the MSP responses ranged from 2 to 108 months with a mean of 48 months (see figure 5 for age distribution) and there was an even gender distribution (Males 48.5% Females 51.5%). Data was analysed and smoothing reference centile curves were generated using the LMS method (Cole and Green 1992). A method which summarises changing distribution of three curves L- coefficient of variation, M- median, S- skewness. The centile curves were generated for each domain and also the total MSP score.

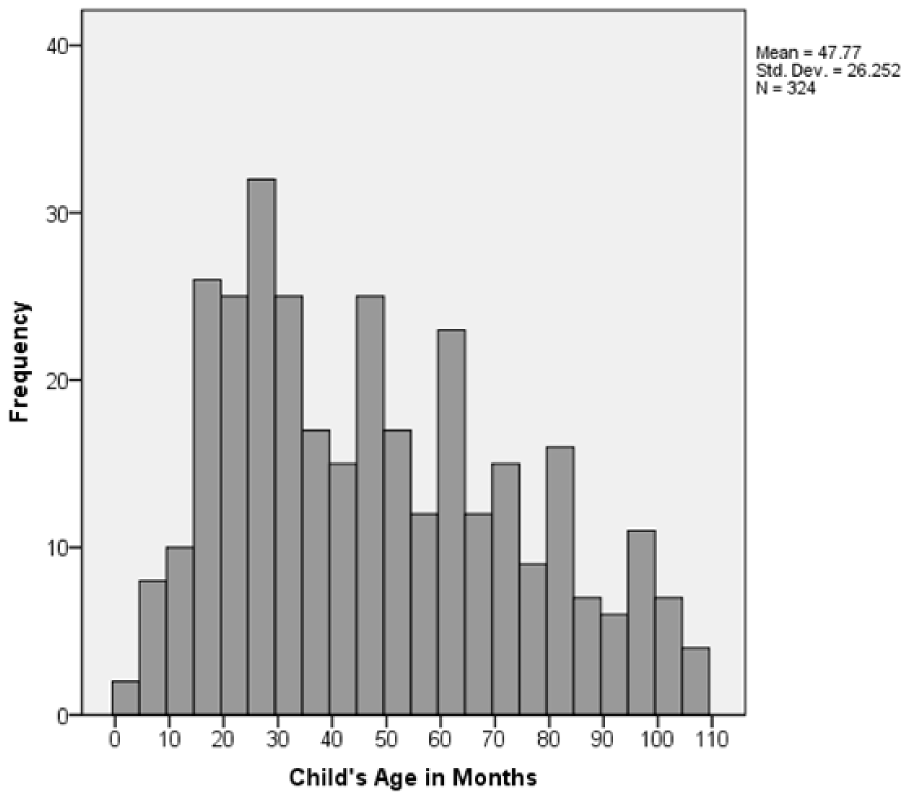


Figure 5. Distribution of ages for the 324 children for which MSP questionnaires were completed in phase three

3.2.4 Analysis

All data were entered into a database in accordance with the Data Protection Act (Data Protection Act 1998) and analysed using the SPSS 14 and LMS chartmaker software packages.

3.2.4.1 Validity analysis

Validity was assessed through two different methods within the study. Initially validity was examined by calculating percentage agreement between experts in question domain allocations (Phase One). Following questionnaire modification, Phase Two of the study asked for parental opinion. The statistical techniques chosen were based on the methodology reported by Jackson & Furham (2000) and in previous studies (Gfeller et al 1998a; Van Besouw et al 2010).

3.2.4.2 Reliability analysis

Reliability was assessed through measures of test-retest and internal consistency. Test-retest reliability measures stability of scores at repeated occasions and was evaluated via within-subject standard deviation, σ_ω(Bland and Altman 1996) after the assumption of normality was assessed and met. The calculation of within-subject standard deviation σ_ω involves computing the variance of scores for each respondent, and then taking the square root of the mean variance for the group of respondents. Lower values of σ_ω indicate better reliability. An individual's score is expected to lie within

±1.96σ_ω of their true score for 95% of observations. Therefore σ_ω can also be used to calculate the repeatability of a measure by using data from this formula, $\sqrt{2}$*1.96σ_ω (Bland and Altman 1996). The difference between two measurements from the same respondent is expected to be less than $\sqrt{2}$*1.96σ_ω for 95% of pairs of observations when completed under the same conditions.

Internal consistency was assessed with a Cronbach alpha coefficient, α(Cronbach 1951). A Cronbach alpha coefficient,α is used to measure multiple-item measurements to give an averaged correlation between the items. The coefficient indicates the reliability of the items within the questionnaire for measuring a common concept or theme. A measure is considered reliable when the index is greater than 0.7.

3.2.4.3 Statistical techniques used to create age appropriate centile curves

Age appropriate smooth centile curves were created through the LMS chartmaker software package via the LMS method. The LMS method summarises the changing distribution of three curves. The three curves represent the data sets' median, coefficient of variation and skewness. Through a method of maximum penalised likelihood (Green 1987) the three curves are fitted and smoothed to create reference centile charts (Cole and Green 1992). Reference centile charts are used widely in medical practice especially for measures such as height and weight (Cole et al. 1988) in order to identify subjects who may be unusual (Cole and Green 1992). The intention is that the MSP centile charts will also be used for this purpose with future populations, in particular assessing HI children against normative values.

3.3 **Results**

3.3.1 MSP Questionnaire Validity

In phase one the expert panel reviewed 32 questionnaire items (contained within the original MSP questionnaire). Demographic questions were removed for this process. The experts selected the domain (sound awareness and general reaction to sound, exposure to music, melody and dynamic changes, rhythmical changes and emotional aspects) that they considered each question had addressed from the drop down menu supplied after each item. They also supplied comments on each questionnaire item. Based on comments received the separate ‘exposure to music’ domain was deemed inappropriate to include within a calculation of musical ability. Those four questions were put together with the demographic information to form a general information section; those values were not included in the total MSP score. Three items in the sound awareness section were also deemed confusing in terms of why they were included within a musical questionnaire so were removed completely. The three removed questions were: Does your child react when a) a dog barks?, b) a glass falls?, or you knock a glass with a spoon and c)a car horn sounds?.

The expert’s domain allocations of the remaining items (25 questions) were grouped and a percentage agreement between the experts was calculated for each question/item. It was decided that items that achieved less than 65% agreement would be reconsidered (Jackson and Furnham 2000).

Agreement above this criterion was achieved for 14 items (56% of the remaining questionnaire items). This is an indication that the items fell into a specific domain of the questionnaire and thus remain within the same domain in the resulting optimised MSP. The comments for the remaining 11 showed that there was disagreement between experts as to which domain the questions should fall into. These are presented in Table 1. These 11 questions were reconsidered and some were adapted using comments from the expert panel to improve clarity of the questions and to ensure that the questions fell within the appropriate domain. Some of the 11 items remained unchanged because the highest scoring domain allocation was for the domain that they originally were assigned to and it was considered appropriate when domain headings were visible. An optimised MSP questionnaire was created from this data (Appendix 1).

A comment section was included both within Phase One and Phase Two to gather information on the questionnaire's validity. On review of these subjective comments, common themes were noted and the general opinion was that the questionnaire was measuring what it was intended to within each domain and the overall MSP was appropriate for following emerging skills just as long as the music exposure domain was removed from the overall score.

Table 1. MSP Items falling below 65% agreement criteria in expert review domain allocation

Item no	Item	% agreement for correct domain	Other domains selected
4	Does your child start clapping when they hear a song or music being played?	28.6% (SA)	42.9% (R), 7.1% (EA), 14.3% (EM). 7.1% (MD)
8	Does your child start moving or dancing when there is some music being played (radio, tv,...)?	35.7% (SA)	35.7% (R), 14.3% (EM), 14.3% (EA)
9	When you listen to music or you hum the melody, does your child try to vocalise?	35.7% (MD)	42.9% (SA), 14.3% (EM), 7.1% (EA)
10	Does your child sing the correct tune and all the words to any songs?	35.7% (MD	42.9% (EM), 21.4% (SA)
13	When listening to a song will your child start to sing words at the ends of the phrases?	35.7% (MD)	35.7% (SA), 28.6% (EM)
14	Does your child ever spontaneously: a) clap hands to music? b) drum a beat on something (drum, pot, ...) to music?	64.3% (R)	28.6% (SA), 7.1% (MD)
16	Does your child spontaneously try and sing a familiar melody (like nursery rhymes or lullabies he/she has heard)?	42.9% (MD)	35.7% (EM), 21.4% (SA)
22	Does your child ever spontaneously ask you to sing or play music?	50% (EA)	42.9% (EM), 7.1% (SA)
25	Does your child react to lively music?	35.7% (EA)	35.7% (SA), 14.3% (EM), 7.1% (R), 7.1% (MD)
28	Does your child ever ask to listen to a particular CD or tape?	50% (EA)	50% (EM)
29	Can your child say when a favourite song is being played?	21.4% (EA)	28.6% (EM), 28.6% (SA), 21.4% (MD)

SA – Sound Awareness, EM – Exposure to music, MD – Melody and dynamic changes, R - Rhythmical changes, EA – Emotional Aspects

3.3.2 MSP Questionnaire Reliability

3.3.2.1 Test-retest

A two tailed paired-samples t-test was used to indicate whether there was systematic variation between scores at the two time points. This was included within the analysis to confirm there had not been a learning effect between the two occasions the MSP was completed by parents. T-test results showed that there was no significant difference ($t = -0.091$, $df = 30$, $p = 0.928$, $r = -0.06$) between MSP total mean scores obtained from the two occasions when the MSP was completed by parents. There were also no other significant differences found between the two time points for all separate domain scores contained within the questionnaire (at the $p < 0.05$ level) (see Table 2).

Table 2. Paired Samples t-test results comparing each separate domain in the MSP for questionnaires completed at the two time points

Test-retest	t	Df	Sig. (2-tailed)	Effect size (*r*)
Pair 1- Sound Awareness	0.4	30	0.7	0.02
Pair 2- Melody & Dynamics	0.8	30	0.5	0.02
Pair 3- Rhythmical Changes	-0.9	30	0.4	-0.04
Pair 4- Emotional Aspects	-0.6	30	0.6	-0.03

The selected measure of reliability (within-subject standard deviation, σ_ω) was also conducted after assumption of normality was met and results are presented in Table 3. Low values indicate good test-retest reliability.

Table 3. Measures of test-retest reliability

Test-retest	MSP Total Score	Sound Awareness Score	Melody & Dynamics Score	Rhythm Score	Emotional Aspects Score
Within-subject standard deviation, σ_ω	4.1	1.2	2.2	1.8	1.8
Repeatability, $\sqrt{2}*1.96\sigma_\omega$	11.4	3.3	6.1	5.0	5.0

3.3.2.2 Item reliability index

A Cronbach alpha coefficient, α was used to determine internal consistency on the phase two data and was above 0.7 (0.92) indicating strong internal reliability.

3.3.3 Phase Three - Age appropriate reference centile curves

The normative ranges of each domain and total MSP score were calculated using the optimised MSP questionnaire (following Phase One & Two). The LMS chartmaker software package was used to fit reference centile curves using the LMS method (Cole and Green 1992). A set of 7 centiles were included on each chart (3^{rd}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th} and 97^{th}), each centile being equally spaced two-thirds of a Z score apart. MSP score centile charts are shown in Figure 6 & 7.

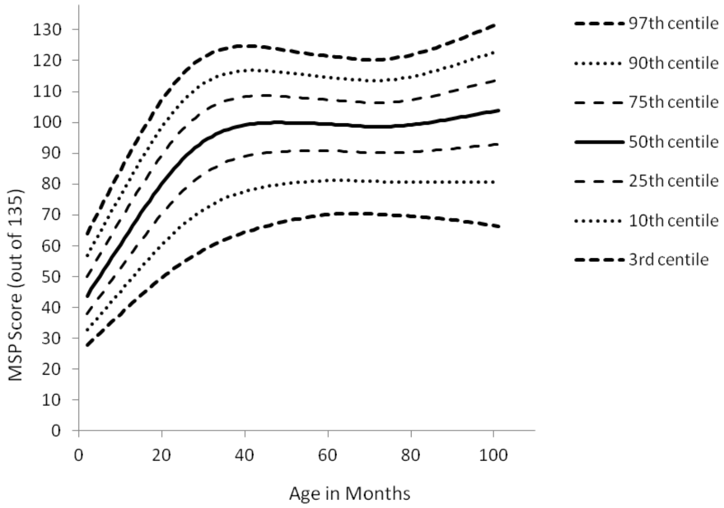


Figure 6. Seven centiles of MSP total score from age 2 to108 months, based on the LMS curves generated by LMS method in LMSchartmaker

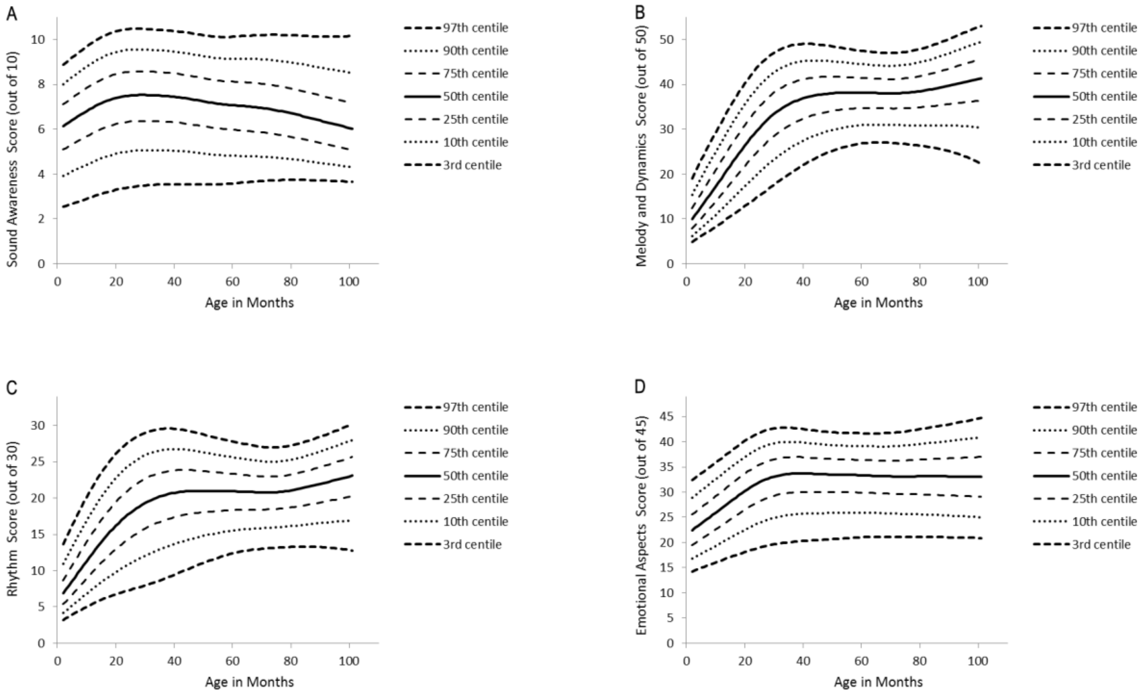


Figure 7. Centile charts for each separate domain (A Sound Awareness, B Melody & Dynamics, C Rhythm and D Emotional Aspects) contained within the MSP questionnaire from age 2 to 108 months, based on the LMS curves generated by the LMS method in LMSchartmaker

3.4 **Discussion**

The MSP questionnaire was optimised, validated and its reliability determined through phase one and two of this study. In addition, developmental age-appropriate centile charts were created in order to compare future populations to normative values (Phase Three).

Data collected from the expert review (Phase One) was used to assess validity in a similar approach to that reported by Gfeller (1998a). The data collected suggested modifications were necessary, because some questions were ambiguous as to which musical domain they belonged to in the experts' opinion and others were considered not useful for a musical development measure. These particular questions were reviewed separately and some were deleted completely (3) and some were moved (4). Of the 11 questions that did not meet the 65% criteria 8 weremodified based on comments received, the remaining three questions were left unchanged as they were deemed appropriate when domain headings were present . A newly optimised version of the MSP questionnaire was created for future use (see Appendix 1). Examination of the MSP questionnaire validity and reliability followed the optimisation phase.

Phase two data showed the MSP questionnaire to be a valid and reliable measure in its optimised form. In Van Besouw et al's (2011) musical questionnaire study they assessed face validity by asking likely respondents (parents) to review questionnaire items. This information was collected by parent review of the questions in the current study and the review demonstrated strong face validity of the MSP questionnaire. This strong face validity could however lead to social desirability bias. This is not considered likely for this questionnaire due to there being little personal gain to be achieved by “faking” answers for the questionnaires intended future use.

Small σ_{ω} values (total MSP = 4.1) confirmed strong test-re-test reliability for the MSP questionnaire. A Cronbach alpha coefficient α over 0.7 also confirmed good internal reliability of the MSP questionnaire.

Phase three of the study was used to generate reference centile curves for the MSP questionnaire score domains and total. This process is very common when considering health related scales, but is not available for the other questionnaires directed at this area of interest. Observation of the centile charts demonstrated that there was an increase in MSP score with age for NH children showing the emergence of musical abilities over time. However at approximately 44 months of age the rate of change of the function slows down dramatically and plateaus suggesting that the MSP is unlikely to be sensitive to developmental changes beyond this age for a typically-developing NH child. It may therefore be more appropriate to use a different measure beyond this stage to assess musical development. Children beyond a developmental age of 44 months should be able to complete musical behavioural assessments accurately (Trainor 2005), so the MSP would provide a resource to allow monitoring of development for the stages when the child is too young or developmentally delayed to complete formal assessments. In addition to the plateau observed at 44 months there is also a dip is observed at the age of 77 months which is explained by the unfortunate lack of questionnaires completed by parents with children of this age group. Due to the fact that the data surrounding this time period fell on the plateau of the function it can reasonably be assumed that this time period should also fall at the plateau level.

3.5 **Conclusion**

Results obtained from this study show that the original MSP questionnaire (Vickers et al. 2007) required adjustments as a result of expert feedback. Once in the optimised form, validation and reliability measures show that the MSP questionnaire is suitable for use in the assessment of musical ability of normally developing children; and is most sensitive to development up to the age of 44 months old. The questionnaire would still be considered valuable to use with older normally developing children so that comparisons can be made using the same scale to age-matched HI children who may have developmental delay based on their hearing loss. This has particular relevance to this research. Future work to collect MSP data from HI groups and establishing reference centile curves for these populations would also be valuable.

It is acknowledged that the sample used in all three phases of the study were small especially to create normative centile charts in phase three. The researcher was limited by time and this influenced recruitment, therefore it would also be beneficial to continue to collect normative responses to add into the reference centile charts as a future direction.

CHAPTER 4 : PILOT STUDY

4.1 Introduction

Prior to conducting the main study phase of the research a pilot study was undertaken to ensure the selected test materials and procedures intended for the main study phase were appropriate. The purpose of the study was to trial the test protocol with a group of NH children and assess whether adaptions were necessary.

It is advisable to conduct a pilot study to reduce the chance of failed trials within a large scale study, which is particularly important when testing children and difficult to recruit populations. For such groups the test sessions need to be optimised for effective data acquisition and the pilot study allows problems to be identified and resolved to ensure a more streamlined process.

The primary role of a pilot study is to examine the feasibility of an approach intended for a larger scale study (Porta 2008). The approaches chosen to be incorporated in the pilot study should be selected based on theory or similar studies in the same subject area. The feasibility covers recruitment, assessment procedures, new methods and novel interventions. Pilot studies also provide opportunity for the experimenter to train and strengthen the competencies required for accurate and precise data integrity and the protection of human subjects (Leon et al. 2011).

Well implemented pilot studies provide useful information on the sample, testing procedures and materials, and the need for modification of protocol. A pilot study will not however provide a means for hypothesis testing (Leon et al. 2011). Hypothesis testing is not appropriate because there is limited knowledge of the methods or interventions; and sample size is normally small.

The aim of this pilot study was to assess the appropriateness of the test protocol and trial the selected testing materials (MSP questionnaire, Primary Measures of Musical Audiation (Gordon 1979) and the National Singing Programme Child Singing Assessment (Welch et al. 2009)) (See section 4.2.2) with a group of typically developing NH children of the same age group as the population of interest for the main study phase (4-9 years old). The intention was to highlight any problems with the test protocol and assess whether the instructions and training for the use of the tests and the laryngograph was sufficient. In addition the results recorded were compared to materials normative values to ensure they follow the same pattern in terms of development with age. Additionally the time taken to administer the full test battery was recorded and the quality of the laryngograph recordings were analysed to determine if the procedure was effective.

The pilot study was not conducted with HI children because participant recruitment was difficult and all the HI children were required for testing in the main study phase.

4.2 **Methods**

4.2.1 Participants

Following ethical approval 14 children aged between 4 and 9 years of age were recruited from a primary school in North London, where the researcher had agreed access. The inclusion criteria was that children were aged between the selected age range, had English language understanding (in order to undertake the tests involved) and had hearing level of 20dBHL or less in both ears. Of the 14 children, one child fell outside the NH range and therefore was excluded from further testing. The remaining children were aged between 58 and 95 months, with a mean age of 72.5 months (SD 10.9).

4.2.2 Materials

Wherever possible materials selected for the main study phase of the research had previously been validated and normative values were available. Due to the subjective nature of the Child Singing Assessment scoring, additional validation was sort by making comparisons to electrolaryngography recordings (laryngograph) made while the child completed the assessment.

4.2.2.1 Musical Stages Profile (MSP) Questionnaire

The MSP questionnaire was designed to measure emerging abilities in different skill areas for children aged between birth and nine years of age. The MSP was validated and normative values collected as part of an earlier study (see Chapter 3). Questions in the MSP questionnaire were categorised into domains considered to be integral to musical development for both NH and HI children. These included: sound awareness, melody and dynamic changes, rhythmical changes and emotional aspects. Each question was answered following observation of the child's behaviour with one of the following responses 1. Never, 2.Rarely, 3.Occasionally, 4.Frequently, 5.Always. A score was calculated for each individual question (out of five), each domain, as well as a total MSP score by summing the scores across all domains. The total scores were intended to reflect a child's musical ability, with a higher score indicating a higher level. This questionnaire was chosen for the research because it was validated, had normative reference centile curves (see Chapter 3) and it permitted collection of data related to perceptual and production skills, which is particularly useful for children who are developmentally unready to perform behavioural assessment. The MSP questionnaire used in the pilot study and main study phase can be found in Appendix 1. The MSP questionnaire was chosen for this research to allow different groups of children (both HI and NH) to be assessed subjectively for musical ability on the same scale. It is acknowledged that within the earlier validation study (Chapter 3) lack of sensitivity to changes beyond 44 months of age was found for the group of NH children used to create the MSP reference centile curves; however it is likely that HI children will not sit at the same developmental stage as their chronologically age matched NH peers. Therefore the MSP questionnaire allows data to be recorded from both HI and NH children of an older age within this research and is still considered valuable especially where children may not be developmentally ready to complete behavioural assessments.

4.2.2.2 Primary Measures of Musical Audiation (PMMA)

The PMMA is a measure used in the field of music education to determine the ability level of children with respect to pitch and rhythm perception. It was developed for kindergarten aged children (4-5 years old) up to Grade 3 aged children (8-9 years old).

The PMMA was selected because it is a well-established validated test battery with normative values for comparison purposes. It is a simple test to administer and has been specifically designed for use with children of the appropriate age. The PMMA has also been shown to be sensitive for detecting perceptual differences with HI and CI children and adults (Gfeller et al. 1997; Gfeller and Lansing 1991; McDermott 2004), the population of interest in this work.

It uses a same-different task where children respond (by clicking the associated box) to say whether two musical note sequences are the same or different in terms of “tone” (pitch perception) or “rhythm”. There were forty questions with two practice examples for each test (pitch and rhythm). The stimuli ranged from notes C4 (261.3Hz) to C5 (523.3Hz) and the testable range is between one and 12 semitones. It took the children between 40-50 minutes to complete both the tone and rhythm tasks in the PMMA. The PMMA computerised version (1.0) was used for this research. The program was run on a laptop (Samsung NI30 with realtek high definition audio card); with stimuliplayed through a loudspeaker at 65dBA (Behringer MS20 active loudspeaker) at a distance of one meter in front of the child's seated position. The child's head movements were not restricted.

4.2.2.3 National Singing Programme (NSP) – Child Singing Assessment recorded with Laryngograph

The children's singing production was assessed using the "National Singing Programme Child Singing Assessment" (Welch 2009). The NSP forms part of a UK government initiative aimed at assessing the development of musical and singing activities within schools as well as providing singing activities within the curriculum, under a programme known as "sing-up" (Sing up 2013).

As part of the NSP programme, baseline singing skills of children in primary schools prior to using sing-up and also following sing-up intervention were assessed. The Child Singing Assessment was developed as a means of conducting these evaluations (Welch et al. 2009). The NSP baseline data was used as a comparison in this study and was derived from over 13,000 child singing assessments.

The Child Singing Assessment consists of three aspects of children's vocal behaviour:

i. Children's habitual speech pitch centre - (achieved by asking the child to count backwards from 10)

ii. Comfortable singing range – (achieved by the child producing the highest and lowest tones that they can using pitch slides)
iii. Normalised singing score (NSS). A measure of singing accuracy based on the child singing two well-known songs (usually. “Happy Birthday to You” and “Twinkle, Twinkle Little Star” unless unknown by the child).

The scoring method used within the Child Singing Assessment was created from a combination of scoring schemes based on singing development models by Rutkowski (1997) and Welch (1998). The scoring sheet is presented in Appendix 6. The NSP was selected for the main study phase because it had been shown to be sensitive to differences between groups for the age range of interest, and contained a comprehensive range of tasks.

The utterances produced in the NSP Child Singing Assessment by the children were recorded using the electrolaryngograph Speech Studio Software (Laryngograph 2013). This produced both speech audio recordings and Laryngograph traces to be able to conduct acoustic analyses to quantitatively assess voice fundamental frequency and efficiency of vocal fold closure. These measurements were made using a USB electroglottograph (model: EGG-D200, serial no:100220) with the Speech Studio software program run on a NI30 samsung laptop. A pair of medium laryngograph electrodes was placed on the child’s neck to record vocal fold closure. A Labtec over ear microphone (model:Axis-002) was used to create audio recordings. Within the pilot study the audio recordings were used to score the NSP child singing assessment and the Larynograph traces were used to validate the subjective scores assigned in the NSP analysis.

It was considered important that the NSP Child Singing Assessment values obtained in the current research were comparable to data collected by the NSP team at the Institute of Education (IoE). The researcher was trained but not experienced in scoring the NSP Child Singing Assessment. Therefore in order to remove this margin of error between researcher scoring and IoE staff scoring, an audio recording of the assessment for each participant was sent, analysed and scored by members of the NSP IoE team. The analysis of the NSP scores were carried out by trained listeners at the IoE. The listeners were musically trained and had many years of experience conducting the NSP Child Singing Assessments using subjective judgement of pitch accuracy. The IoE listener assigned singing behaviour scores based on singing quality and accuracy of the production. To avoid any bias the trained listeners from the IoE were blind to the hearing status of the individual children; they scored recordings and the results were stored with a code number for each child.Audio recordings were sent rather than live scoring as NSP IoE staff were not available to attend the current study test sessions.

Within this pilot study audio and laryngograph recordings were reviewed by the researcher and IoE NSP staff to ensure that they were of sufficient quality for use in the main study phase. They were also used as a means of ensuring validity of the IoE subjective scoring method.

4.2.3 Procedure

Testing took place in a in a small quiet room (ambient levels were lower than the 40dBA criterion level) in a primary school in North London. The hearing status of every child was assessed by the researcher using pure tone audiometry screening at 20dBHL at octave frequencies between 250-8000Hz. This was undertaken on a Maico MA41 portable audiometer. Children who failed the screening test were excluded from the study and the school advised parents to visit their GP for further testing and management. All remaining children undertook the full test battery (PMMA tone and rhythm tasks and NSP Child Singing Assessment recorded with laryngograph). Within the test session children were given one hour and 30 minutes to complete the full test battery and hearing screening. The MSP questionnaire was sent home for parents to complete and return on the day of the test session.

Throughout the test session, notes were taken of subject compliance, time taken for assessments and the child's reaction to each task. Following the test session the NSP Child Singing Assessments were sent to staff at the IoE and recording quality was subjectively assessed.

4.3 **Results**

The time values noted for the duration of testing ranged from 40-65 minutes to complete the test battery, excluding hearing assessment. Hearing assessment was not included in the time recordings because it was not part of the protocol for testing the HI children in the main study phase. All of the 13 children tested were keen to participate in all of the tests. Only six MSP questionnaires were returned by parents, indicating that it was important for the main study phase that the parents completed the MSP at the time of testing, wherever possible, to reduce the amount of missing data. All of the13 children completed all the other tests in the test battery so their results have been included as part of those analyses.

All children demonstrated a good understanding of the instructions and all tests were completed correctly. All of the children did, however, report boredom during the PMMA test due to the length but both tone and rhythm sequences were completed successfully. This indicated that it may be appropriate to break up the testing sequence and provide breaks during testing in the main study phase.

A range of total MSP scores were obtained from the pilot participants and they fell within the age appropriate normative range (see Figure 8). Examination of individual scores indicated that the sample was a typically developing group falling on and above the 50^{th} centile of normative range.

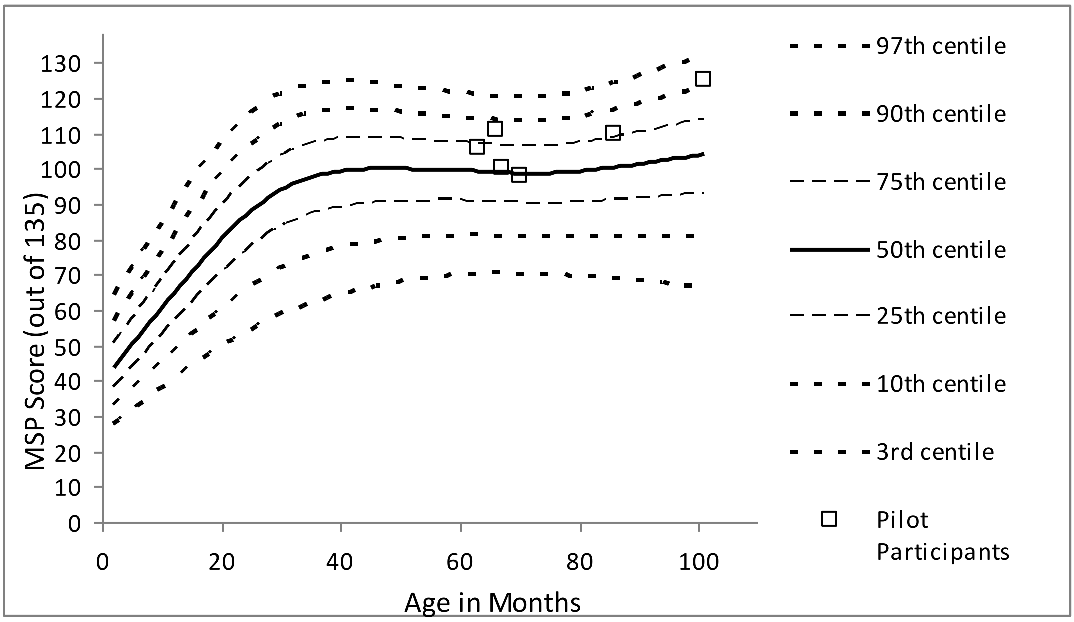


Figure 8. Total MSP score for respondents on reference centile chart

To examine the PMMA test results, children were split into three groups based on age so that relationships to previous normative data could be viewed. Mean scores were generated for each age group and the musical domain (pitch or rhythm) (see Table 4). Difference in raw scores between the age ranges was examined through a two-tailed one-way ANOVA with ‘Grade’ (Kindergarten, Grade 1, Grade 2) as a factor. There was a statistically significant main effect of Grade at the $p<0.05$ level for both Pitch raw scores ($F_{(2-10)}=59.5$, $p=0.03$, eta squared=0.5) and Rhythm raw scores ($F_{(2-10)}=47.2$, $p=0.03$, eta squared=0.5). Least Significant Difference (LSD) Post hoc tests showed the Grade 1 group (M=28.7, SD 3.1) scored significantly higher than the Kindergarten group (M=26.6, SD 3.8) for Pitch raw score. For Rhythm raw score the Grade 2 group (M=31, SD 1.4) scored significantly higher than the Kindergarten group (M=25.9, SD 3.4). No other significant differences were observed between the groups.

Table 4. Raw mean scores (out of 40) for each age group on PMMA tasks

	Pitch mean raw score	Rhythm mean raw score
Kindergarten (age 48 – 72 months old) N= 8	26.8 (SD 3.8)	25.9 (SD 3.4)
PMMA Normative value	24.7 (SD 5.28)	22.3 (SD 3.74)
Grade 1 (age 73 – 84 months old) N= 3	28.7 (SD 3.1)	31.7 (SD 2.5)
PMMA Normative value	29.8 (SD 5.0)	25.8 (SD 4.3)
Grade 2 (age 85 – 96 months old) N=2	35.5 (SD 2.1)	31 (SD 1.4)
PMMA Normative value	32.0 (SD 4.6)	27.7 (SD 4.6)

All age groups of children in the sample (noted in Table 4) were within plus or minus one standard deviation from the normative mean values given in the PMMA test manuals indicating that the participants had typical development with respect to pitch and rhythm development. The user manual further splits the normative ranges into different levels of musical aptitude based on raw scores (L-Low aptitude, A- Average aptitude and H-High aptitude). The percentage distribution of levels for this pilot group is shown in Table 5. The percentage distribution shown indicates that children within the sample fell towards the top of the normative range because the highest proportion of children was grouped into the high aptitude category.

This result in aptitude grouping shows that the PMMA test materials would be most suitable and sensitive for children of this ability level and lower.

Table 5. Percentage distribution of aptitude levels (Low, Medium and High) assigned by PMMA test materials based on normative values for total pilot sample

	Low Aptitude	Average Aptitude	High Aptitude
Pitch	7.7%	38.5%	53.8%
Rhythm	0%	46.2%	53.8%

For the assessments of singing ability some children felt inhibited and required encouragement to participate. However a number of participants stated that the singing assessment was their favourite task from the entire test battery after completing it (n=7). The quality of recordings generated by the laryngograph and the audio recordings were reviewed by both by the researcher and a National Singing Programme co-ordinator based at the IoE. The recordings were considered to be of a sufficiently high standard for later analysis and scoring.

In order to validate the IoE NSP child singing assessment scoring method, the scores obtained from the IoE assigned habitual speech pitch centre were correlated with laryngograph traces made from the same recorded sample using a Pearson Product-Moment correlation coefficient (see Figure 9).

There was a strong positive correlation between average fundamental frequency from laryngograph trace and assigned IoE habitual speech pitch centre (n=13, r=0.87, p=0.00) indicating that the subjective method for scoring singing assessments was strongly related to the laryngograph measurements. There was one outlier (P14) where IoE assigned habitual speech pitch centre was lower in frequency than average fundamental frequency. This recording was reviewed, and this child showed large variation in pitch when the child counted backwards from 10. Therefore it was difficult to obtain a sustained vowel sound which would provide an accurate acoustic analysis within the laryngograph recording.

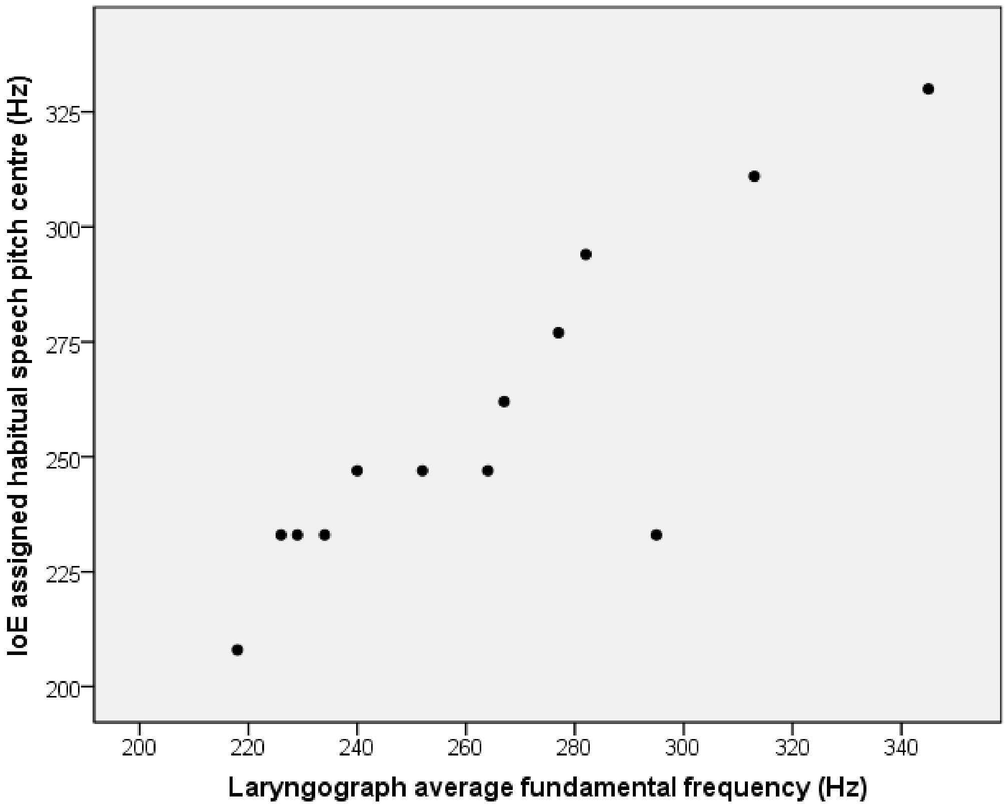


Figure 9. Relationship between average fundamental frequency from Laryngograph trace (Hz) and IoE assigned habitual speech pitch centre

4.4 **Discussion**

Results showed the method and materials used within the pilot study were suitable for typically developing children in the 4-9 years age group. The instructions were clear and understood by all the participants. Boredom was reported by children when completing the PMMA test battery, therefore within the main study phase adequate breaks would be included and pitch and rhythm tasks would not be undertaken in succession of each other. Time taken to administer all the tests in the battery fell under 1 hour 30 minutes (including hearing tests and breaks). This indicates testing sessions selected for main study phase would allow sufficient time to compete the full test battery inclusive of breaks.

MSP results showed that the pilot sample were age appropriate with the individual scores falling between the 50^{th} and 97^{th} percentile of the MSP reference centile chart. No children scored the maximum value for the test. However based on the high scores obtained by the NH pilot group, results indicate that the MSP would be most suitable for children who score the same or lower than this group otherwise ceiling effects may be observed. The MSP is considered appropriate for the main study phase of this research as HI children are to be investigated. As described in Chapter 2 HI children are unlikely to perform better than a NH sample when considering musical aspects due to limitations associated with their HI and the intervention devices they have to manage it.

Musical perception for the sample was shown to fall within the one standard deviation from the mean normative score for pitch and rhythm scores on the PMMA assessment. PMMA test sensitivity was examined through comparisons between age groups (Kindergarten, Grade 1 and Grade 2). Significantly better scores were shown for older children in comparison to the younger children for both pitch and rhythm raw scores. This result indicates that the PMMA test materials were sensitive enough for detecting developmental differences in pitch and rhythm perceptual domains within this NH sample. PMMA aptitude rankings indicated that a large proportion of NH pilot sample scored in the highest ability range for both pitch and rhythm tasks (set out by the PMMA test manual), although none scored the maximum of 40. As was described above this is not considered an issue for the main study phase as groups of HI children are to be tested.

NSP Child Singing Assessment recordings made using the laryngograph were reviewed by both the researcher and IoE NSP staff. The recordings were useable for both IoE scoring and voice quality analysis via laryngograph speech studio software. A strong positive correlation between the IoE assigned habitual speech pitch centre and average fundamental frequency validates the subjective pitch matching technique used in scoring the NSP Child Singing Assessment. Slight discrepancies observed between the two values assigned can be attributed to the fact that IoE allocations are given as musical notes which have been converted to equivalent frequencies (Hz). There was one outlier identified, this child had a lower IoE assigned habitual pitch centre than was recorded by laryngograph recording analysis.

This result can be attributed to the pitch variations displayed by the child when counting backwards from ten (which made it difficult to gain an accurate sustained vowel sound to conduct analysis on), rather than inaccuracy of IoE pitch allocations.

4.5 **Conclusion**

The purpose of the pilot study was to investigate the feasibility of the test protocol and testing materials. Results indicated that the protocol was appropriate for the age range of interest (4-9 years). The tests do not suffer from floor and ceiling effects and that there was a wide range in test scores for the typically developing population, indicating that the tests should be sufficiently sensitive to pick out perceptual differences between different groups of children, which are important for the main study phase.

Results indicated that the testing time of 1 hour and 30 minutes is appropriate; and that the quality of recordings for the singing assessments and laryngograph measurements is accurate and sufficiently clear for analysis.

CHAPTER 5 : PITCH PERCEPTION, PITCH PRODUCTION AND MUSICAL ABILITY OF HI CHILDREN

5.1 **Introduction**

For HI children the primary focus of intervention with a hearing device is to optimise speech perception. However very little is known about the impact this could have on music and pitch perception, which is now acknowledged to be beneficial not only for music enjoyment but also for the impact that it has on speech, reading and language development and other cognitive areas (Anvari et al. 2002; Costa-Giomi 1999; Gromko and Poorman 1998; Hurwitz et al. 1975; Rauscher et al. 1997; Rauscher and Zupan 2000; Schellenberg 2004). It is expected that HI children will perform more poorly than NH children in certain domains of music perception due to perceptual limitations associated with their HI (Moore 1996). However all aspects of music perception will not necessarily be equally affected. Based on the dominance pitch has within musical signals, and the different pitch signal processing approaches within hearing devices, the primary focus of the current research has been on pitch perception and production.

<u>The Impact of Hearing Devices on Pitch Perception</u>

The most common forms of intervention offered to HI children are HAs, CIs or BMS devices. EAS devices are currently available but are not routinely fitted to children. Within each device category there are differences in approaches to sound delivery due to manufacturers using various processing schemes and different hardware to achieve satisfactory results primarily for speech. The processing in both HAs and CIs will therefore affect perception differently, especially with respect to musical elements such as pitch (Chasin and Russo 2004; Scattergood and Limb 2010).

As was described in Chapter 2, HA prescriptions are based on speech spectra to optimise audibility of the critical speech frequencies (Dillon 2001) rather than focussing on music signals. Therefore the dynamic variability, restricted bandwidth of the device, and additional front end processing systems may have detrimental effect on musical signals. CIs have the same primary function as HAs in that enhancement of speech perception is the main aim. Speech in noise, tonal language perception and musical perception has been shown to be challenging for implant users (McDermott 2004). This is attributed to degraded pitch representation due to the loss of fine structure information within CI processing and the status of the cochlea. The fine structure information is beneficial for good pitch perception and is responsible for delivering the fundamental frequency (F0) in NH subjects (Smith et al. 2002; Wilson et al. 2004), the perception of which is often poor for CI users (Yucel et al. 2007; Moore and Carylon 2005a; Moore and Carylon 2005b).

A combination of electric and acoustic inputs (with BMS or EAS devices) have the potential for better delivery of pitch and melody information for individuals with residual hearing in the low frequencies (Ching et al. 2009). This is due to the acoustic signal helping to deliver the fine structure information. The two devices provide complimentary auditory cues for pitch perception because CIs provide place pitch information and high-frequency content and HAs supply the low frequency F0 information (Smith et al. 2002). There is evidence to demonstrate that this configuration of electric and acoustic inputs can improve perception of pitch elements (Dorman et al. 2008; Gfeller et al. 2006; Kong et al. 2005) although this has not been demonstrated for children (Looi and Radford 2011).

The Impact of Hearing Devices on Pitch Production/Singing

For success in musical production auditory feedback is required to monitor and adjust productions (Murbe et al 2002). Due to the importance of auditory feedback on both speech and singing production it is therefore logical to assume that HI and the use of hearing devices (HAs, CIs, and BMS) that limit or modify the auditory signal could in turn affect singing abilities.

Evidence has shown that CI users perform poorer that NH matched peers when singing skills were analysed in terms of accuracy of fundamental frequency (F0) (Xu et al. 2009).This was attributed to the unsatisfactory delivery of musical pitch with CIs. On the basis of this study individuals using HAs or BMS may have better singing abilities with respect to melody production than individuals using purely electrical stimulation via CIs but there is little evidence to support this hypothesis.

Music enjoyment and Involvement

Musical aptitude is important from many perspectives including musical enjoyment and involvement. Gfeller et al (2000a) suggested that HI individuals' level of musical enjoyment is not as high as NH matched controls. When comparing across intervention devices for HI findings from Looi et al (2007) indicated that music appreciation for HA users was similar to that of cochlear implantees. The comparison to NH or BMS subjects was not made within this study. Further investigation, particularly with paediatric populations, is required because devices have improved and become more prevalent since Gfeller and colleagues (2000a) conducted the study against NH participants, which could have an impact on results. In addition comparisons between adults' and children's musical enjoyment with CIs show differences between the populations suggesting children enjoy music more than adults (Trehub et al. 2009). Possible explanations for the difference between the adult and paediatric populations are that pre-lingually HI children may encode sounds differently to post-lingually HI adults (Vickers et al. 2007) or that pre-lingually HI children have no or little prior familiarity of music through a NH mechanism unlike post-lingually HI adults (Gfeller et al. 2000a). Adult questionnaire data suggests that combined electric and acoustic hearing could provide some advantages for musical appreciation (Kong et al. 2005) and therefore increase musical listening and participation (Fitzpatrick et al. 2009); however, little evidence exists to support this finding for children with BMS or EAS devices.

There are clear perceptual limitations associated with HI and the intervention methods offered to HI children for musical perception, singing and enjoyment and involvement in music. To accurately assess those factors, both behavioural and subjective evaluations are necessary. A combination of assessments can then give valuable information on the impact of HI and the associated interventions.

The aim of this research was to determine whether there are differences in general musical ability (including musical involvement and enjoyment), pitch perception and singing ability between children using different amplification methods (BCI, BHA and BMS) and also whether HI children have different competency and ability levels when compared to NH children and normative or baseline data associated with the selected test materials.

Research Questions

- Do differences exist between different groups of HI children using different amplification devices for their hearing loss in terms of general musical ability, pitch perception and singing ability?
- Are there differences in general musical ability, pitch perception and singing ability between HI and NH children?

5.2 **Methods**

The research protocol for the main study phase is shown in Figure 10. All participants followed the same protocol regardless of their hearing devices (BCI, BHA, or BMS). There were a number of participants unable to complete parts of the full test battery; in these cases data from the completed tasks were collected and used within the analyses. Participants' demographic information is provided for each test material, as well as overall, so that information of the sample that completed that test is given.

One child was unable to complete the full battery of tests in one session due to time constraints, so a second session was arranged within two weeks of the original test session to ensure that all tests could be conducted. A NH group were also recruited, so that the scores from the HI children could be compared to NH children tested with exactly the same test set up, as well as to test material normative values. The NH group included within the main study phase were the same 13 children who completed the pilot study. They repeated the test session for the main study phase approximately five months after being tested within the pilot study. It is acknowledged that this NH group may have additional advantage over the other experimental groups due to practice effect experienced by repeating the test battery but including a NH group was deemed valuable to provide additional comparisons with the same experimental conditions.

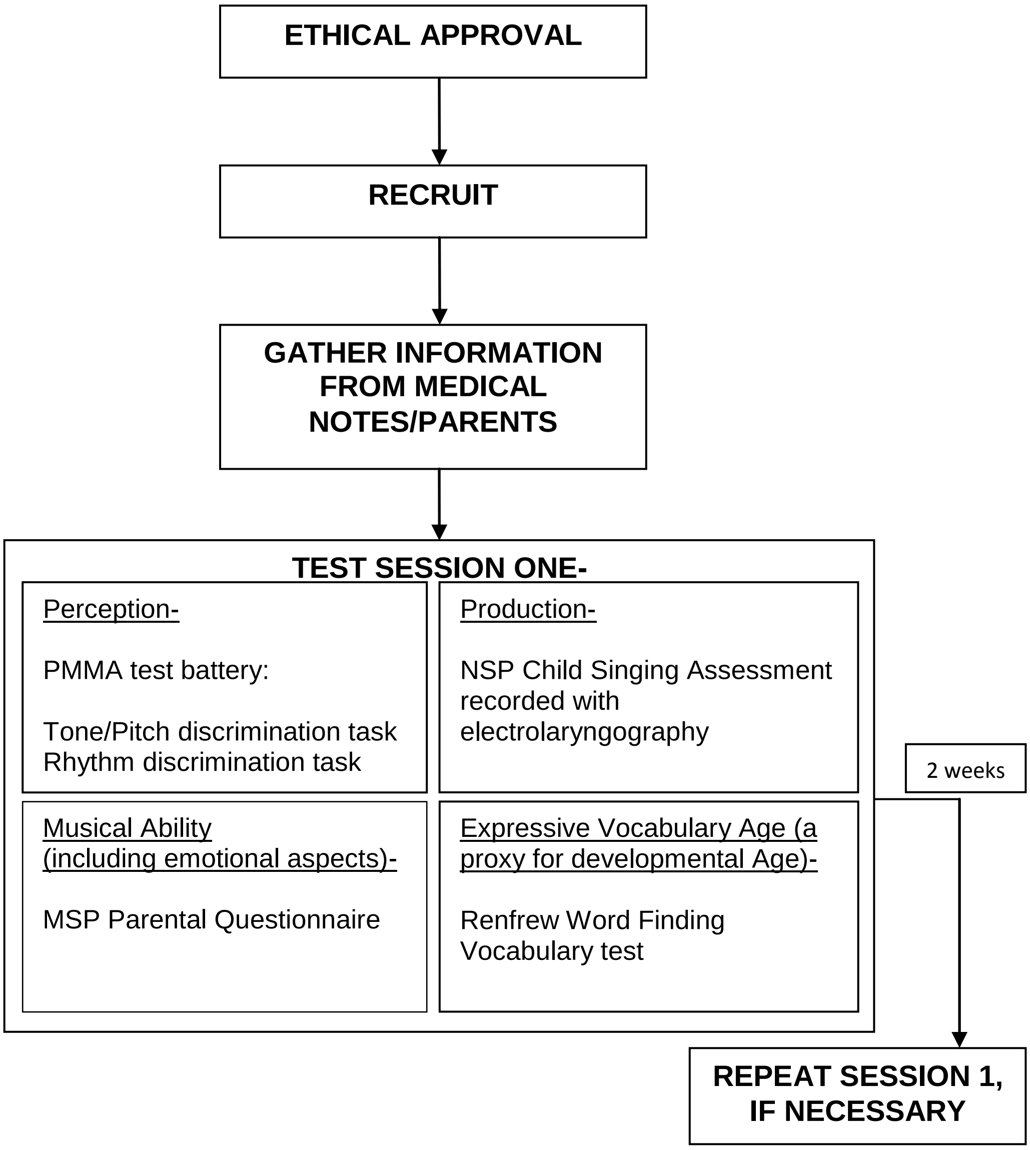


Figure 10. Research stages and study protocol for the main study phase.

5.2.1 Ethics approval

Ethical approval for the research was obtained from the NHS London REC 2 committee after review of the research protocol (REC reference: 11/LO/0236). Approvals were also gained from research and development departments at each hospital trust involved with the project prior to recruitment. This approval covered recruitment from charities and schools.

5.2.2 Recruitment

There were two methods of recruitment for the research:

a) A member of the child's healthcare team or school sent a letter of invitation to the child's parents, along with the postal information sheet (Appendix 2). If the parents wished to take part, they returned a tear-off slip to the researcher. Consent was obtained by the researcher at the start of the first testing session using the consent form (Appendix 3).

b) Adverts were published in newsletters of schools and charities such as the Cochlear-Implanted Children's Support Group (CICS), National Deaf Children's Society (NDCS) and Ear Foundation. Interested parents were then sent a copy of the postal information sheet (Appendix 4). If the parents wished to take part, they returned a tear-off slip and full consent was obtained at the start of the first assessment session with the consent form.

5.2.3 Gathering of information

After the parents had given consent, the direct healthcare team consulted the child's medical notes to provide researcher with demographic details, audiological status and test results. If recruited through a charity or school parents and teachers provided the necessary information at test session one.

5.2.4 Test Session One

Test sessions took place in a quiet room (under 45dBA measured with a sound level meter) at the UCL Ear Institute or in the participant's own home or school. The parent and child were greeted and a review of parental information and completion of consent forms took place. The child also had the research study explained to them with assistance from children's information sheet (Appendix 5). During the session participants completed pitch and rhythm aspects of the PMMA test battery, the NSP Child Singing Assessment (recorded with a laryngograph) and an expressive vocabulary test (Renfrew Word Finding Vocabulary test; Renfrew,2010; fourth edition) to determine the child's expressive vocabulary age (a proxy for developmental age) (Bloom 1993; Hoff 2005). This was considered an important component of the research because large differences in developmental stage could have an impact on performance and therefore needed to be accounted for in the analysis. In the Renfrew test the children had to identify and name the pictures presented on individual cards and a score was calculated based on the amount of correctly identified pictures. The score was compared to tables of developmental age. This test was not included within the pilot study as participants should not complete the Renfrew within six months of first completing it and therefore the gap between test sessions would not have sufficient in order to use the Renfrew in both.

While each child completed the test battery parents were asked to complete the MSP questionnaire in a separate room. Where children were tested within school, the MSP questionnaire, study information and consent forms were sent home, completed and returned on the day of the test session.

5.2.5 Participants

57 participants were identified and recruited from paediatric Cochlear Implant and Audiology departments, charities and schools in and around the London area. The NHS recruitment sites are listed in Table 6. In addition to NHS sites, participants were recruited through the NDCS, CICS, The Ear Foundation, Cowley Hill Primary School, Darrick Wood Primary School and Maple Primary School.

Table 6. NHS recruitment sites for the study

NHS Hospital	Recruiting Department(s)
Royal National Nose, Throat and Ear Hospital – London	Paediatric Audiology & Cochlear Implants
Great Ormond Street Hospital – London	Paediatric Audiology & Cochlear Implants
Bedford Hospital – Bedford	Paediatric Audiology
Peace Children's Centre – Watford	Paediatric Audiology
Royal Berkshire Hospital – Reading	Paediatric Audiology

Children were grouped according to the device used to manage their HI. Of the 57 participants13 had NH. There were four groups in total – Bilateral cochlear implantees (BCI), bilateral hearing aided participants (BHA), bimodal stimulation users (BMS), and normally hearing participants (NH).

Inclusion and Exclusion criteria for the research were set out to ensure that each participant was able to complete the intended test battery successfully and allow accurate comparisons across groups. The criteria for the HI participants are listed in Table 7. Inclusion criteria for the NH group was to have hearing thresholds 20dBHL or better (at 500Hz, 1kHz, 2kHz and 4kHz) and having good English language knowledge defined as children having been within mainsteam UK education since aged four.

Table 7. Inclusion and exclusion criteria for HI children included in study

Inclusion Criteria	Exclusion Criteria
• Aged 4-9 years • Moderate to profound hearing impairment (better hearing ear 0.5-4kHz average) • Using either CI's, HA's or BMS • Have used intervention for at least 6 months • Hearing loss diagnosed under 2 years of age • Have good English language knowledge (due to test materials involved) • Primarily an Aural Communicator	• Cases where there was a conductive/fluctuating element to hearing loss • Asymmetrical losses (average 0.5-4kHz to be within 20dBHL between right and left ears)

5.2.5.1 Demographic summary

The children's mean chronological age was 82.12 months (SD 15.8) and the gender distribution was 25 male to 32 female. Four children could not complete the Renfrew Word Finding Vocabulary Test due to cognitive development issues so these children could not be controlled for in terms of developmental age. The vocabulary age of the remaining sample was 76.9

months (SD 17.2). Differences between chronological and developmental age for the sample was investigated through two one-way ANOVAs. No significant differences were shown between the groups (BCI, BHA, BMS, NH) at the $p<0.05$ level. The sample included 13 children from minority ethnic backgrounds (Group split: BCI=5, BHA=7,BMS=1,NH=0). Every child had English as their primary language with no parents reporting that their child was bilingual. However 13 children within the sample spoke additional languages (Group split: BCI=4, BHA=4, BMS=4, NH=1). Reported additional languages were Lithuaiuian (n=1), BSL (n=2), Italian (n=1), Urdu (n=3), Arabic (n=1), Hebrew (n=2), French (n=1), Cantonese (n=1- within BCI group) and Japanese (n=1- within BMS group).Each child's special educational needs (SEN) status was obtained from their school records and it was confirmed that all of the children with SEN status had been categorised based primarily on their permanent hearing loss. Parental questionnaires were completed by either the mother or father of the child. The sample was split based on the intervention device used for HI (BCI, BHA, BMS and NH). Demographic information for each separate group is shown in Table 8.

Table 8. Demographic information for groups included in the study

Group N=57	BCI	BHA	BMS	NH
Number of subjects	15	21	8	13
Mean Age (months) (SD)	80 18.1	83.2 13.8	91.3 20.4	77.2 11.9
Mean Expressive vocabulary Age (months) * N=53 (SD)	76.1 20.1	72.9 17.8	84.3 15.4	80.6 12.8
Gender Distribution (percentage)	Male= 40 Female= 60	Male= 52 Female= 48	Male= 38 Female= 62	Male= 39 Female= 61
4 Frequency Average (0.5-4kHz) Hearing Threshold (dBHL)	104	68	98.3	Under 20**
Year group distribution (percentage)	Rec = 13.3 Year 1= 20 Year 2= 46.7 Year 3= 13.3 Year 4= 0 Year 5= 6.7	Rec = 4.8 Year 1= 19 Year 2= 42.9 Year 3= 19 Year 4= 14.3 Year 5= 0	Rec = 12.5 Year 1= 12.5 Year 2= 12.5 Year 3= 25 Year 4= 25 Year 5= 12.5	Rec = 7.7 Year 1= 46.2 Year 2= 38.5 Year 3= 0 Year 4= 7.7 Year 5= 0
Special Educational Needs Status (SEN) (percentage)	None = 13.3 School Action= 0 School Action Plus= 0 Statemented = 86.7	None = 9.5 School Action= 9.5 School Action Plus= 9.5 Statemented = 71.4	None = 0 School Action= 0 School Action Plus= 12.5 Statemented = 87.5	None = 100 School Action= 0 School Action Plus=0 Statemented = 0
Aetiology of HI (no.)	Genetic = 6 Cytomegalovirus = 0 Jaundice = 1 Meningitis = 2 Unknown = 6 Syndrome = 0	Genetic = 7 Cytomegalovirus = 2 Jaundice = 0 Meningitis = 0 Unknown = 11 Syndrome =1	Genetic = 3 Cytomegalovirus = 1 Jaundice = 0 Meningitis = 0 Unknown = 2 Syndrome =2	N/A
Manufacturer of HI management devices (no. of children with devices)***	Advanced Bionics = 1 Cochlear = 13 Med-el = 1	Oticon = 5 Phonak = 16	Advanced Bionics & Phonak = 4 Cochlear & Phonak = 4	N/A

* Four children (of the 57) were not included in these figures because they were unable to complete the Renfrew test (BCI11, BHA10, BMS 8 & NH4)

** NH children all had their hearing screened at a level of 20dBHL (500Hz, 1kHz, 2kHz and 4kHz) within pilot study

*** All children had bilateral devices

5.2.6 Data collection and analysis

Data was collected and stored in accordance with the Data Protection Act (1998). Data scoring was calculated based on the published assessment manuals. Child Singing Assessment audio recordings were sent to the IoE and scoring was undertaken by a member of the IoE NSP team. The Child Singing Assessment scoring sheet is presented in Appendix 6. Larynograph traces were analysed using the Speech Studio software program (Laryngograph 2013).

Statistical analyses were carried out using the SPSS 21 software program. Group comparisons were made using two-tailed one-way between-subject analysis of variance (ANOVA) and Welch ANOVA measures with least significant difference (LSD) and Games-Howell post-hoc tests using a criterion significance level of $p<0.05$. Differences between chronological and developmental age for the sample was investigated through two one-way ANOVAs. No significant differences were shown between the groups at the $p<0.05$ level so this variable was not explored further for each separate test sample.

5.3 **Musical Development Measured using the MSP**

5.3.1 Method

50 parents of the 57 recruited undertook the MSP while their child completed the other measures in Test Session One. Parents were in a separate room

from their child while completing the questionnaire. The children in this sample had a mean chronological age of 82.8 months (SD 16.4) and the gender distribution was 22 male to 28 female. Completed parental questionnaires were split into groups based on the mode of intervention that the child had. The expressive vocabulary age for each child was also determined using the Renfrew Word Finding Vocabulary Test (Renfrew 2010). The average difference between estimated vocabulary age and chronological age was -7.4 months (M=76.4 months, SD=17.7). Demographic information for each separate group is presented in Table 9.

Table 9. Demographic information for groups where parents had completed the MSP

Group	BCI	BHA	BMS	NH
Number of subjects N=50	15	21	8	6
Mean Age (months) (SD)	80 18.1	83.2 13.8	91.3 20.4	77 14.5
Mean Expressive vocabulary Age (months) * N=47 (SD)	76.1 20.1	72.9 17.8	84.3 15.4	79.8 14.4
Gender Distribution (percentage)	Male= 40 Female= 60	Male= 52.4 Female= 47.6	Male= 37.5 Female= 62.5	Male= 33.3 Female= 66.7
4 Frequency Average (.5-4kHz) Hearing threshold (dBHL)	104	67.9	98.3	Under 20**

* 3 children from the 50 were excluded from this calculation as they were unable to perform or complete the Renfrew Vocabulary test (BCI 11, BHA10 & BMS8)

** All NH children had their hearing screened at 20dBHL (at 500Hz, 1kHz, 2kHz and 4kHz) within pilot study

Two-tailed one-way ANOVAs with between-subjects factor of HI group were conducted and the LSD test for pairwise comparisons was used when a significant main effect was found. Individual scores were compared to the normative values for the MSP by referencing against centile curves created from over 300 completed MSP questionnaires (see Chapter 3). Fishers exact tests, a version of the 2 X 2 Chi-square test were used to assess whether there were differences between groups for the proportion of participants with scores above and below the 50th percentile. Groups were compared in a pairwise fashion because of the limitation of the Fishers exact test only allowing 2 X 2 comparisons. Fishers exact tests were chosen because when the counts of participants in different percentile groups were collated some of the cells had counts less than five. In this situation Chi-square would not be suitable because low cell counts can lead to erroneous results due to the approximation calculations. Comparisons between the NH, BCI, BHA and BMS groups were examined with two-tailed one-way ANOVAs with LSD post-hoc tests after checking the assumptions were met.

5.3.2 Results

5.3.2.1 Participant Variables

Level of HI was assessed by comparing the three HI groups' four frequency (500Hz, 1kHz, 2kHz and 4kHz) better hearing ear average. This was conducted for each separate measure so that differences could be established where sample size changed. The two-tailed one-way ANOVA with group as a factor revealed that there was a significant difference shown between the three HI groups at the p<0.05 level ($F_{(3-46)}$=89.8, p=0.00, eta squared=0.9) for the 50 participants. LSD post-hoc tests revealed the BHA group had significantly lower four frequency better hearing average (M=67.9dBHL, SD=13.9) than both the BCI (M=104dBHL, SD=9.9) and BMS (M=98.3dBHL, SD=11) groups. The BCI and BMS were not significantly different from each other. This is expected based on criteria of candidacy for provision of CIs for children in the UK (NICE 2009).

5.3.2.2 Musical Ability Level Group Comparisons

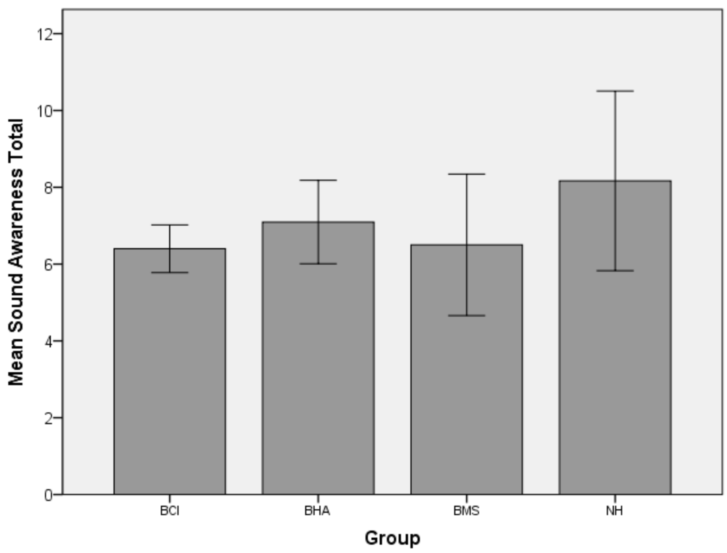
A two-tailed one-way ANOVA with group (NH, BHA, BCI, BMS) as a factor was conducted to explore the impact that the three different hearing devices had on musical development, as measured by the MSP parental questionnaire. There was a statistically significant main effect of group at the p<0.05 level for MSP total scores ($F_{(3-46)}$=3.3, p=0.03, eta squared=0.18). Group scores are shown in Figure 11.

Figure 11. Mean total MSP scores for each intervention group (BCI, BHA, BMS and NH)

Post-hoc comparisons using the LSD test indicated that the mean total MSP score for the NH group (M=108.3, SD=9.7) was significantly higher than all three HI groups (BCI: M=84.1, SD=15.6; BHA: M=84.3, SD=19.8; BMS:

M=83.5, SD=19.8). But that the HI groups were not significantly different from one another.

Comparisons were also made for the separate domains (sound awareness, melody & dynamic changes, rhythmical changes and emotional aspects) contained within the MSP using two-tailed one-way ANOVA tests. Group mean scores are shown in Figures 12,13, 14 and 15. No significant differences were found between any of the groups for the sound awareness and the emotional aspects domains at the $p<0.05$ level. There was a statistically significant main effect of group for the melody & dynamic changes (MD) domain ($F_{(3-46)}=3.6$, $p=0.02$, eta squared=0.19) and the rhythmical changes (R) domain ($F=_{(3-46)}3.2$, $p=0.02$, eta squared=0.17).



Error Bars: 95% Confindence Intervals

Figure 12. Mean scores for MSP Sound Awareness Domain across the four groups (BCI, BHA, BMS, NH)

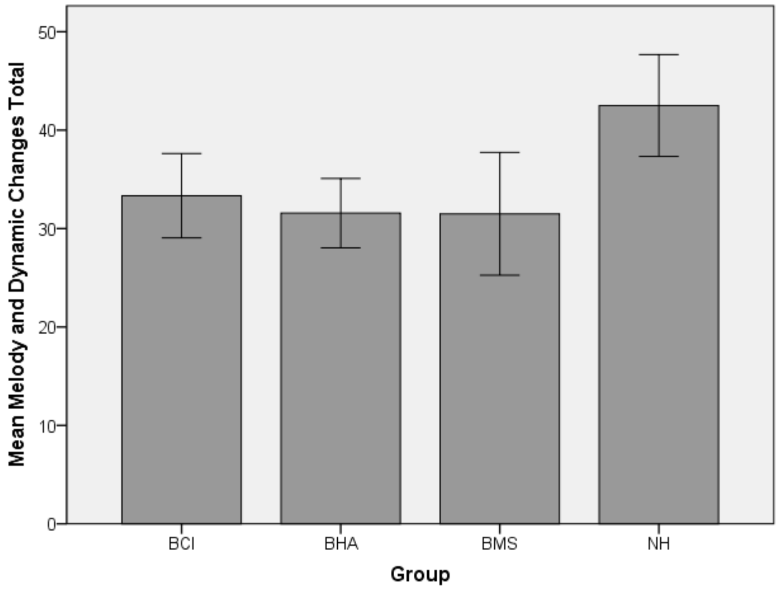


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Figure 13. Mean scores for MSP Melody & Dynamics Domain across the four groups (BCI, BHA, BMS, NH)

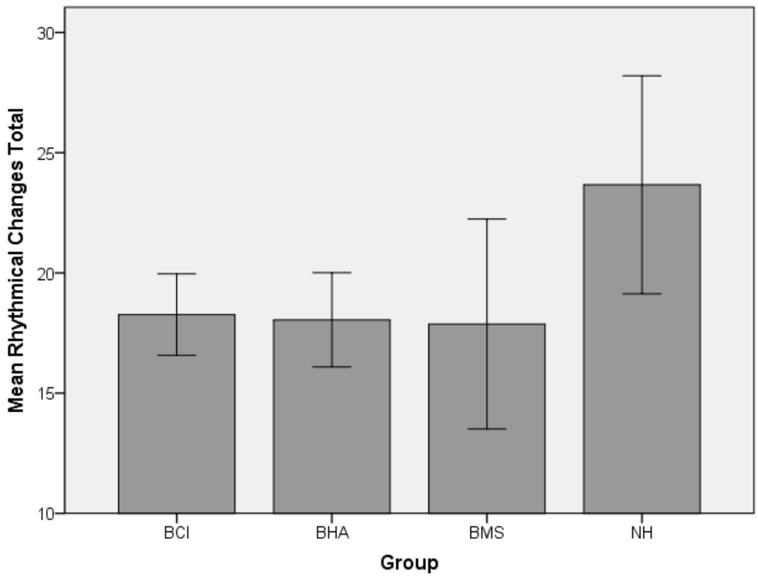

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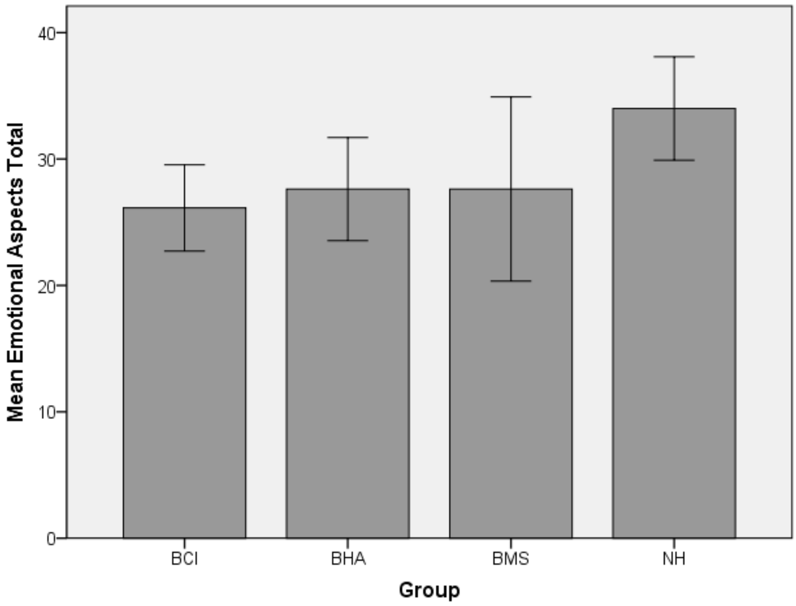
Figure 14. Mean scores for MSP Rhythmical Changes Domain across the four groups (BCI, BHA, BMS, NH)



Error Bars: 95% Confindence Intervals

Figure 15. Mean scores for MSP Emotional Aspects Domain across the four groups (BCI, BHA, BMS, NH)

Post-hoc LSD comparisons for the two significant domains (M&D and R) indicated that mean M&D score for the NH group (M=42.5, SD=4.9) was significantly different from all three HI groups (BCI: M=33.3, SD=7.7; BHA: M=31.5, SD=7.7; BMS: M=31.5, SD=7.5). The mean R score for the NH group (M=23.7, SD=4.3) was also significantly different from all three HI groups (BCI: M=18.3, SD=3.1; BHA:M=18.0, SD=4.3; BMS:M=17.9, SD=5.2). No other significant differences were seen between the groups within these domains.

5.3.2.3 Comparisons to MSP Reference Centile Charts (for Child's Chronological Age)

Individual participant scores were plotted on MSP reference centile charts so that comparisons could be made to normative data previously collected from over 300 NH children. Respondents' total MSP scores as a function of chronological age are presented on the reference centile curves in Figure 16. When examining the groups visually on Figure 16 in terms of individual total MSP scores, it can be observed that the majority of the NH group included in this sample scored from the 50th centile upwards in comparison to the normative values; whereas the majority of HI respondents fell below the 50th centile irrespective of their method of intervention. The NH subjects' data points are similar to pilot study results indicating that subjects had not developed significantly since their parents completed the MSP questionnaire five months before. The distribution of respondent scores in each centile is shown in Table 10. Fishers exact tests were performed relating to the distribution of centiles for total MSP score based on group. Results showed a significant difference between distribution of centile scores (above 50th centile versus below 50th centile) for the NH group and all the other HI groups (BHA $p=0.01$, BMS $p=0.03$ and BCI $p<0.01$). No significant differences were shown between the pairings of different HI groups on this measure indicating no overall intervention advantage for musical ability.

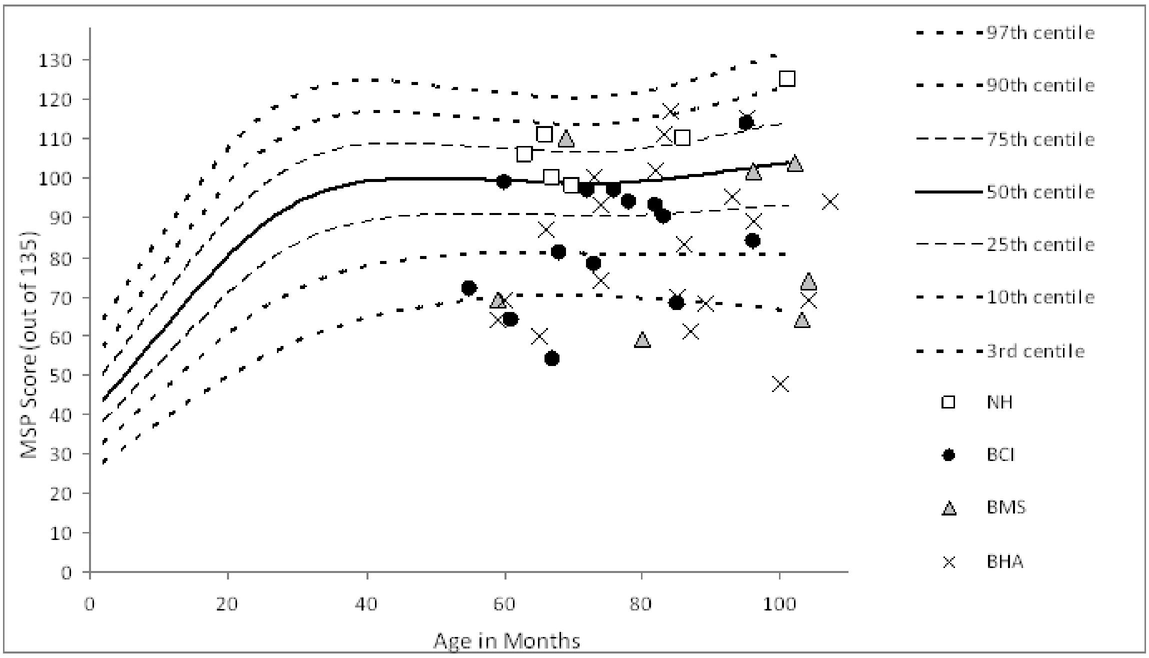


Figure 16. Respondent MSP total scores related to chronological age on reference centile chart. The lines depict different centile levels and the symbols relate to individual children from each of intervention groups (NH, BCI, BMS and BHA)

Table 10. Distribution of respondent total MSP scores within each centile of the MSP reference centile chart (for child’s chronological age)

Groups/ Domains Total MSP Score		Centile							
		<3	3-10	10-25	25-50	50-75	75-90	90-97	>97
NH	Count %	0 0	0 0	0 0	1 16.7	2 33.3	2 33.3	1 16.7	0 0
BCI	Count %	3 20	4 26.7	2 13.3	5 33.3	0 0	1 6.7	0 0	0 0
BHA	Count %	6 28.6	3 14.3	4 19	3 14.3	2 9.5	2 9.5	1 4.8	0 0
BMS –	Count %	3 37.5	1 12.5	1 12.5	2 25	0 0	1 12.5	0 0	0 0

Individual domain scores for the MSP questionnaire were also examined against corresponding reference centile charts. These are presented in Figure 17. Distribution of respondent scores for each domain contained within the MSP questionnaire in each centile are presented in Table 11. In terms of sound awareness and emotional aspects there was a wide spread across the centile chart with no particular pattern in terms of intervention method for hearing loss. Fishers exact tests between the groups and distribution of centiles (above versus below 50th centile) showed no significant differences between any pairing of the included groups at the $p<0.05$ level for either of these domains. Across the other domains (melody & dynamics and rhythm) on inspection of Figure 17 the NH group appear to perform better than the other groups with the lowest scoring NH participant consistently falling above the 10th centile; whereas the lowest scoring participants within the HI groups fall below the 3rd centile of the normative values. Fishers exact tests comparing groups for the Melody & Dynamics domain show distribution of centiles are significantly different between the NH group and other HI groups (BHA $p=0.00$, BMS $p=0.03$ and BCI $p=0.04$). Within the rhythmical domain Fishers Exact tests only show a significant difference between the distribution of centiles for the NH and BHA groups ($p=0.02$), all other group comparisons are not significant at the $p<0.05$ level. Across the different intervention methods within the HI groups there is no distinguishable pattern and individual scores seem to be spread across the centile ranges, Fishers exact tests results confirm this because no significant differences between the HI groups were found for any of the domains included on the MSP questionnaire.

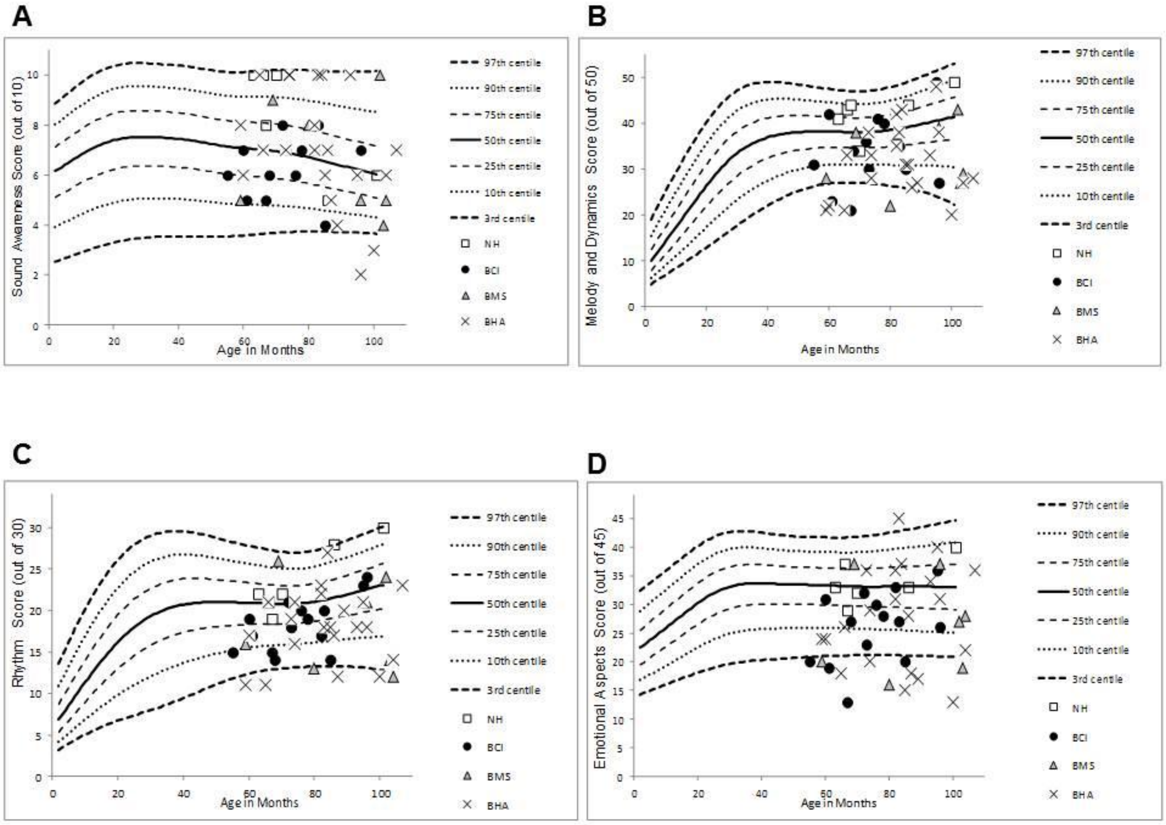


Figure 17. Respondent domain scores (A-Sound Awareness, B-Melody & Dynamics, C-Rhythmical changes and D- Emotional aspects) in relation to chronological age on reference centile chart. The lines depict different centile levels and the symbols relate to individual children from each of intervention groups (NH, BCI, BMS and BHA)

Table 11. Distribution of Respondent Scores in each MSP domain within each centile on the MSP reference centile chart (for child's chronological age). Count values and percentages are shown

Groups/ Domains		Centile							
		<3	3-10	10-25	25-50	50-75	75-90	90-97	>97
SA Score									
NH	Count	0	0	1	1	1	0	3	0
	%	0	0	16.7	16.7	16.7	0	50	0
BCI	Count	0	1	3	4	6	1	0	0
	%	0	6.7	20	26.7	40	6.7	0	0
BHA	Count	2	1	1	6	4	1	6	0
	%	9.5	4.8	4.8	28.6	19	4.8	28.6	0
BMS	Count	0	1	3	1	0	2	1	0
	%	0	12.5	37.5	12.5	0	25	12.5	0
M&D Score									
NH	Count	0	0	1	0	1	4	0	0
	%	0	0	16.7	0	16.7	66.7	0	0
BCI	Count	2	4	2	3	2	1	1	0
	%	13.3	26.7	13.3	20	13.3	6.7	6.7	0
BHA	Count	4	7	4	3	1	2	0	0
	%	19	33	19	14.3	4.8	9.5	0	0
BMS	Count	1	4	0	2	1	0	0	0
	%	12	50	0	25	12.5	0	0	0
R Score									
NH	Count	0	0	0	2	2	0	2	0
	%	0	0	0	33.3	33.3	0	33.3	0
BCI	Count	0	4	4	4	3	0	0	0
	%	0	26.7	26.7	26.7	20	0	0	0
BHA	Count	4	2	6	6	2	0	1	0
	%	19	9.5	28.6	28.6	9.5	0	4.8	0
BMS	Count	2	1	2	1	1	0	1	0
	%	25	12.5	25	12.5	12.5	0	12.5	0
EA Score									
NH	Count	0	0	1	3	0	2	0	0
	%	0	0	16.7	50	0	33.3	0	0
BCI	Count	4	1	5	4	1	0	0	0
	%	26.7	6.7	33.3	26.7	6.7	0	0	0
BHA	Count	6	4	2	2	4	2	0	1
	%	28.6	19	9.5	9.5	19	9.5	0	4.8
BMS	Count	3	0	2	0	2	1	0	0
	%	37.5	0	25	0	25	12.5	0	0

SA – Sound Awareness, M&D – Melody & Dynamics, R – Rhythmical changes, EA – Emotional Aspects

5.3.2.4 Comparisons to MSP Reference Centile Charts (for Developmental Age)

Due to the recognised developmental delays associated with HI described in Chapter 2, MSP individual scores were also plotted against as a function of each child's expressive vocabulary age (rather than chronological age) on the MSP reference centile curves for total MSP score (Figure 18) and for each separate domain score (Figure 19).

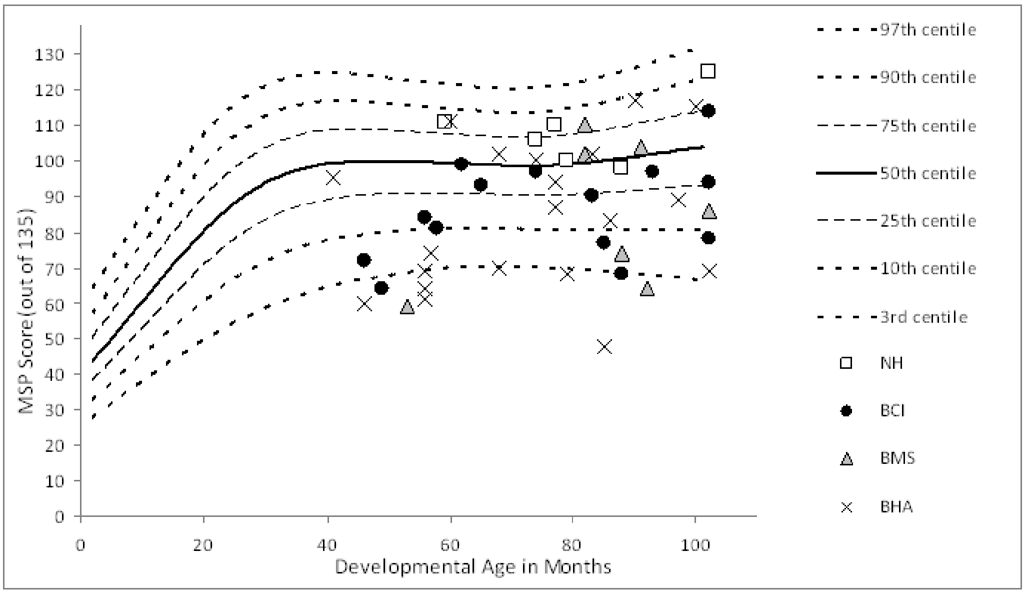


Figure 18. Respondent MSP total scores related to expressive vocabulary age on reference centile chart. The lines depict different centile levels and the symbols relate to individual children from each of intervention groups (NH, BCI, BMS and BHA)

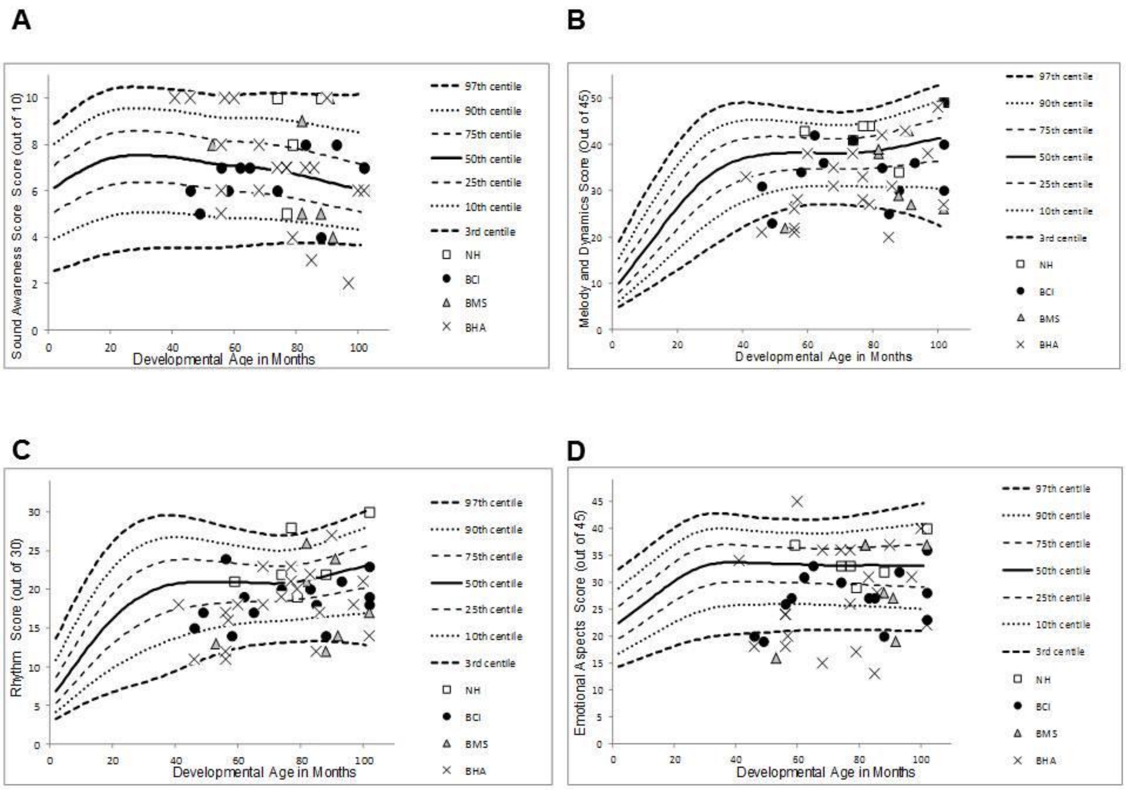


Figure 19. Respondent domain scores (A-Sound Awareness, B-Melody & Dynamics, C-Rhythmical Changes and D-Emotional Aspects) related to developmental age on reference centile chart. The lines depict different centile levels and the symbols relate to individual children from each of intervention groups (NH, BCI, BMS and BHA)

Visual examination of reference centile curves created for developmental age show similar results to chronological age. Actual distribution of respondent scores within each centile is shown in Table 12 for total MSP score and Table 13 for other MSP questionnaire domains. As reported for chronological age, difference in distribution of respondents in centiles (above vs below 50th centile) was investigated between pairings of groups included in the sample using Fishers exact tests. For total MSP score the only significant difference shown was between the NH and BCI group at the p<0.05 level.

For the separate domains included within the questionnaire there were significant differences shown between the NH group and all three of the hearing-impaired groups (BHA p=0.00, BMS p=0.03 and BCI p=0.02) in terms of Melody & Dynamics and no significant differences shown between any of the groups' distribution of scores for Sound Awareness and Emotional Aspects at the p<0.05 level. In contrast to what was reported for chronological age, centile distributions within the Rhythmical Changes domain showed a significant difference between the NH and BCI groups (p=0.01) but not any other group combinations at the p<0.05.

Table 12. Distribution of respondent total MSP scores within each centile of the MSP reference centile chart (for expressive vocabulary age – 47 respondents)

Groups/ Domains Total MSP Score		Centile							
		<3	3-10	10-25	25-50	50-75	75-90	90-97	>97
NH –	Count	0	0	0	1	2	2	1	0
	%	0	0	0	16.7	33.3	33.3	16.7	0
BCI –	Count	2	4	2	5	1	0	0	0
	%	14.3	28.6	14.3	35.7	7.1	0	0	0
BHA -	Count	7	2	3	2	3	3	0	0
	%	35	10	15	10	15	15	0	0
BMS –	Count	2	1	1	0	2	1	0	0
	%	28.6	14.3	14.3	0	28.6	14.3	0	0

Table 13. Distribution of Respondent Scores in each MSP domain within each centile on the MSP reference centile chart (for developmental age – 47 respondents)

Groups/ Domains		Centile							
		<3	3-10	10-25	25-50	50-75	75-90	90-97	>97
SA Score									
NH –	Count	0	0	1	1	0	1	3	0
	%	0	0	16.7	16.7	0	16.7	50	0
BCI –	Count	0	1	3	5	3	2	0	0
	%	0	7.1	21.4	35.7	21.4	14.3	0	0
BHA –	Count	2	1	2	3	7	0	5	0
	%	10	5	10	15	35	0	25	0
BMS –	Count	0	1	2	1	1	1	1	0
	%	0	14.3	28.6	14.3	14.3	14.3	14.3	0
M&D Score									
NH –	Count	0	0	1	0	1	4	0	0
	%	0	0	16.7	0	16.7	66.7	0	0
BCI -	Count	2	3	4	2	1	2	0	0
	%	14.3	21.4	28.6	14.3	7.1	14.3	0	0
BHA -	Count	5	6	3	3	2	1	0	0
	%	25	30	15	15	10	5	0	0
BMS -	Count	1	3	0	2	1	0	0	0
	%	14.3	42.9	0	28.6	14.3	0	0	0
R Score									
NH –	Count	0	0	0	2	2	0	1	1
	%	0	0	0	33.3	33.3	0	16.7	16.7
BCI –	Count	0	2	6	5	0	1	0	0
	%	0	14.3	42.9	35.7	0	7.1	0	0
BHA -	Count	3	2	6	5	3	0	1	0
	%	15	10	30	25	15	0	5	0
BMS –	Count	1	3	0	1	1	0	1	0
	%	14.3	42.9	0	14.3	14.3	0	14.3	0
EA Score									
NH –	Count	0	0	1	3	0	2	0	0
	%	0	0	16.7	50	0	33.3	0	0
BCI –	Count	3	2	4	4	1	0	0	0
	%	21.4	14.3	28.6	28.6	7.1	0	0	0
BHA –	Count	6	3	2	3	3	2	0	1
	%	30	15	10	15	15	10	0	5
BMS –	Count	2	0	3	0	1	1	0	0
	%	28.6	0	42.9	0	14.3	14.3	0	0

SA – Sound Awareness, M&D – Melody & Dynamics, R – Rhythmical changes, EA – Emotional Aspects

5.3.3 Discussion

The aim of the research conducted with the MSP questionnaire was to determine if there were differences in general musical development for different hearing device (BCI, BHA or BMS) users. Comparisons between the HI groups indicated that there were no significant differences between the groups across these intervention methods with respect to overall musical development level.

When considering the separate domains of the MSP questionnaire, results from the Melody & Dynamic changes domain showed no significant differences between intervention groups which is in contrast to the Looi and Radford (2011) study which also focussed on pitch perception. In that study, paediatric CI and BMS users scored significantly lower than HA users. The differences in results obtained could be attributed to the fact that the Melody and Dynamics section of the MSP relates not only to pitch perception but also to identification and discrimination of dynamic changes. Results from the rhythmical, sound awareness and emotional aspects domains also show no significant differences between device groups. An adult study using the Musical Sounds in Cochlear Implants (Mu.S.I.C) test battery support these findings because they also did not show significant differences between CI, HA and BMS groups for these perceptual areas (Brockmeier et al. 2010) although this could also be attributed to the test battery not being sensitive enough to detect differences.

Although no particular intervention method was shown to be advantageous for musical development the results showed that not surprisingly, all the HI groups scored lower than the NH group on the total MSP score. This was also demonstrated when comparing scores to the normative centile distributions across the groups. Respondents within the NH group performed in a higher percentile range than their HI counterparts. On further examination of the lower scores for the HI children it shows that they are heavily influenced by the perceptual domains of Melody & Dynamics and also Rhythm rather than the Sound Awareness and Emotional Aspects domains. These lower perceptual domain scores are expected based on the fact that HI individuals will have additional challenges with perception based on not only their hearing loss but also on the processing limitations of their different devices (Chasin and Russo 2004; Limb and Rubinstein 2012; Moore and Carlyon 2005; Scattergood and Limb 2010). These results are supported by studies demonstrating that CI children perform significantly worse than NH children in perceptual tasks (Vongpaisal et al. 2006; Vongpaisal et al 2009). The comparisons made with the NH group within this study should however be taken with caution as parents had previously answered the questionnaire (within the pilot study) and they also appear to be a high performing NH group compared with the normative data.

It is interesting to note that even though difficulties are reported in the perceptual domains for the HI groups, mean scores within the emotional aspects domain are not significantly lower than the NH group indicating that their enjoyment and appreciation may be not be considerably different to that of a NH child irrespective of their difficulties. These results are supported by findings from Stordahl (2002) where CI recipients performed similarly to NH participants in terms of self-reported musical involvement and music listening habits.

The numbers in this study were small (50 children) for separating into groups. However individual scores were compared against the centile charts for the children's developmental stage to be able to explore both group and individual levels of performance.

5.4 **Pitch Perception (measured via PMMA test battery)**

5.4.1 Methods

55 of the participants took part in the PMMA tone and rhythm tests. The 55 children's mean chronological age was 82.7 months (SD 15.8) and the gender distribution was 23 male to 32 female. The average difference between estimated vocabulary age and chronological age for children who could complete Renfrew (n=51) was -6.3 months (M= 77 months; SD= 17.2). All HI children were split into groups based on the mode of intervention (BCI, BHA & BMS). Of the 55 participants 13 of them were children with NH. Demographic information for each separate group is presented in Table 14.

Participant variables and grouping comparisons were examined with one-way between-subjects ANOVAs with LSD post-hoc tests after checking the assumptions were met.

Table 14. Demographic information for groups included in PMMA dataset

Group N=55	BCI	BHA	BMS	NH
Number of subjects	15	20	7	13
Mean Age (months) (SD)	80 18.1	83.7 14	95.9 16.9	77.2 11.9
Expressive vocabulary Age (months) * N=53 (SD)	76.07 20.1	72.9 17.8	84.3 15.4	80.6 12.8
Gender Distribution (percentage)	Male= 40 Female= 60	Male= 50 Female= 50	Male= 28.6 Female= 71.4	Male= 38.5 Female= 61.5
4 Frequency Average (.5-4kHz) Hearing threshold (dBHL)	104	67.4	98.6	Under 20**

* Two children (of the 55) were not included in these figures as they were unable to complete the Renfrew test (BCI11& NH4)

**All NH children had their hearing screened at 20dBHL (at 500Hz, 1kHz, 2kHz and 4kHz) within pilot study

5.4.2 Results

5.4.2.1 Participant Variables

The level of hearing (based on participants' better hearing ear 4 frequency average in dBHL) was analysed with a two-tailed one-way ANOVA with group as a factor. NH participants were not included when comparing level of HI. There was a significant difference at the $p<0.05$ level ($F_{(2,39)=}42.1$, $p=0.00$, eta squared=0.7). Post hoc comparisons using LSD test indicated the BHA (M=67.4, SD=14.1) group had a significantly lower mean hearing level to both the BCI (M=104, SD=9.9) and BMS (M=98.6, SD=11.9) groups. The BCI and BMS were not significantly different from each other.

5.4.2.2 Pitch Perception

Raw tone PMMA score was used as a measure of pitch perception. Group scores are shown in Figure 20. A two-tailed one-way ANOVA was conducted with group as a factor. There was a significant difference at the $p<0.05$ level ($F_{(3\text{-}51)}$=4.9, p=0.004, eta squared= 0.2). Post hoc comparisons using the LSD test indicated that the BCI group (M=24.4, SD=4.5) had a significantly lower score than the other three groups, including both HI groups (BHA M=28.6, SD=4.5; BMS M=29.14, SD=3.9; NH M=30.6, SD=4.5). No other significant differences are observed between the groups.

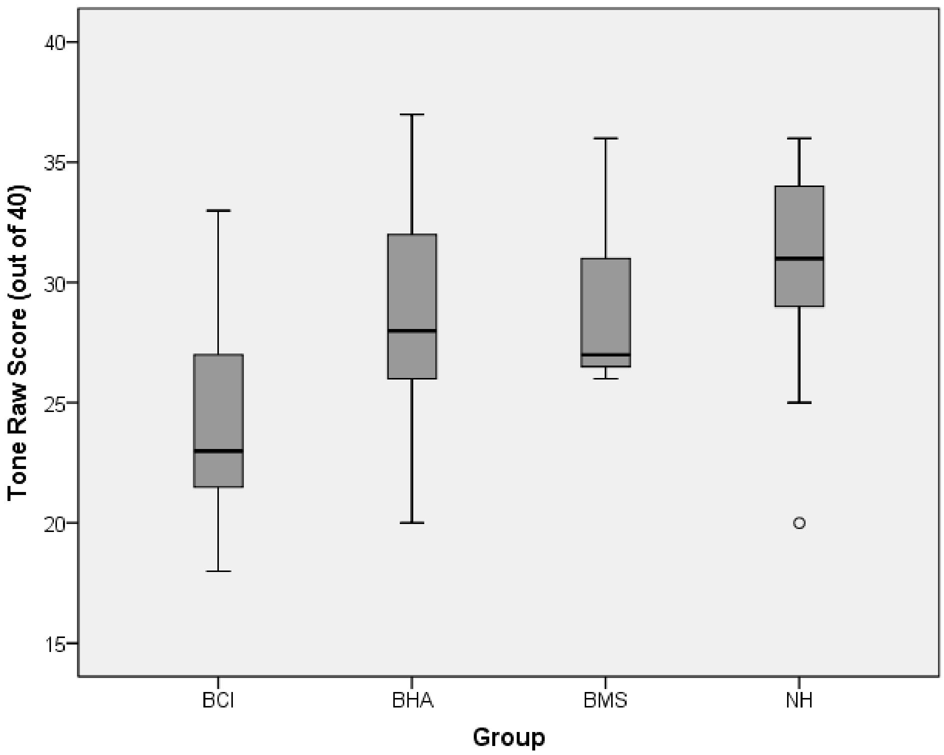


Figure 20. Mean tone raw score across the four groups (BCI, BHA, BMS & NH)

5.4.2.3 Comparisons to PMMA pitch normative data

Within each group (BCI, BHA, BMS and NH) participants were further split into four groups (Kindergarten, Grade 1, Grade 2, Grade 3) so that comparisons could be made with normative data. Mean raw pitch score based on these age groupings for chronological age is shown in Table 15 and developmental age in Table 16.The amount of standard deviations from the normative mean is indicated by colour coding.

Table 15. Raw mean pitch score (out of 40) for each age group (based on chronological age) on PMMA task

Age Grouping (based on chronological age)	Pitch mean raw score (out of 40)			
	BCI	BHA	BMS	NH
Kindergarten (age 48 – 72 months old)	23 (SD 5.2)	29 (SD 5.7)	26 (SD 0)	28 (SD 4.9)
Grade 1 (age 73 – 84 months old)	23.9 (SD 3.9)	28.1 (SD 2.0)	27 (SD 0)	29 (SD 0)
Grade 2 (age 85 – 96 months old)	28.5 (SD 6.4)	29 (SD 6.5)	27 (SD 0)	34 (SD 1.4)
Grade 3 (age 97 – 108 months old)	27 (SD 0)	26.8 (SD 5.1)	31 (SD 4.4)	36 (SD 0)

Within 1 SD above normative mean; Within 1 SD below normative mean; Within 2 SD below normative mean; Within 3 SD below normative mean

Table 16. Raw mean pitch score (out of 40) for each age group (based on developmental age) on PMMA task*

Age Grouping (based on developmental age*)	Pitch mean raw score (out of 40)			
	BCI	BHA	BMS	NH
Kindergarten (age 48 – 72 months old)	23.8 (SD 4.9)	27.1 (SD 4.2)	27 (SD 0)	31.5 (SD 3.5)
Grade 1 (age 73 – 84 months old)	26 (SD 7.1)	30.2 (SD 3.4)	26.5 (SD 0.7)	30.8 (SD 4.0)
Grade 2 (age 85 – 96 months old)	24.3 (SD 2.3)	27 (SD 1.7)	29.3 (SD 3.5)	31.25 (SD 2.9)
Grade 3 (age 97 – 108 months old)	27.5 (SD 7.8)	29.7 (SD 8.7)	36 (SD 0)	36 (SD 0)

Within 2SD above normative mean; Within 1 SD above normative mean; Within 1 SD below normative mean; Within 2 SD below normative mean

* Two children (of the 55) were not included in these figures as they were unable to complete the Renfrew test (BCI11& NH4)

All age groups of children in the sample (noted in Tables 15 and 16) were within plus or minus three standard deviations from the mean normative ranges outlined in the PMMA test manuals for pitch raw score.

Examination of colour coding shows that the majority of NH group scores fall above the normative mean, the only exceptions being the Grade 1 group for chronological age, and the Grade 2 group for developmental age that both fall less than one standard deviation below the normative mean.

When looking at the results for the HI groups they did not perform as well as the NH group. Their group mean scores ranged from within one standard deviation above the normative mean to three standard deviations below. Further investigation of the findings shows that when groups are corrected for developmental age all HI participants fall within the 95% confidence interval (defined by falling within 2 standard deviations of the normative mean), indicating that all HI groups are not significantly worse than the normative mean values. This however is not the case when chronological age is examined where both BCI and BHA Grade 3 groups are 3 standard deviations below the normative mean values.

5.4.2.4 Rhythm Perception

A two-tailed one-way ANOVA was conducted to explore whether differences were seen between the groups for rhythm raw score. No significant differences were shown between the four groups at the $p<0.05$ level ($F_{(3,51)}=0.4$, df=3, p=0.7, eta squared= 0.03). Mean Rhythm raw scores for each group are shown in Figure 21.

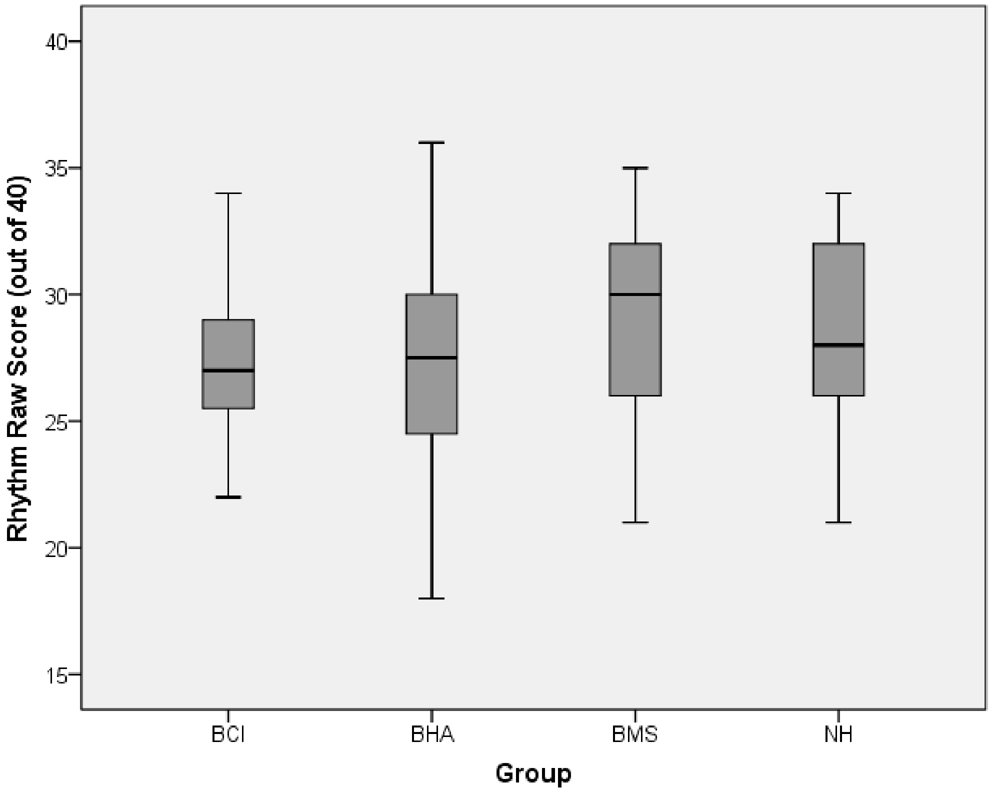


Figure 21. Rhythm raw score across the four groups (BCI, BHA, BMS& NH)

5.4.2.5 Comparisons to PMMA rhythm normative data

As was shown for pitch raw score, the relationship to rhythm normative data was explored by splitting each group (BCI, BHA, BMS and NH) into four further groups (Kindergarten, Grade 1, Grade 2, Grade 3). Mean raw rhythm score based on these age groupings for chronological age is shown in Table 17 and developmental age in Table 18.The amount of standard deviations from the normative mean is indicated by colour coding.

Table 17. Raw mean rhythm score (out of 40) for each age group (based on chronological age) on PMMA task

Age Grouping (based on chronological age)	Pitch mean raw score (out of 40)			
	BCI	BHA	BMS	NH
Kindergarten (age 48 – 72 months old)	27 (SD 2.6)	26.3 (SD 3.9)	31 (SD 0)	24.2 (3.0)
Grade 1 (age 73 – 84 months old)	25.9 (SD 2.9)	27.9 (SD 4.3)	21 (SD 0)	31 (4.2)
Grade 2 (age 85 – 96 months old)	30.5 (SD 5.0)	28.4 (SD 7.1)	30 (SD 0)	31.6 (SD 0.5)
Grade 3 (age 97 – 108 months old)	29 (SD 0)	27.3 (SD 3.0)	30 (SD 5.0)	34 (SD 0)

Within 3 SD above normative mean; Within 2 SD above normative mean; Within 1 SD above normative mean; Within 1 SD below normative mean; Within 2 SD below normative mean

Table 18. Raw mean rhythm score (out of 40) for each age group (based on developmental age) on PMMA task*

Age Grouping (based on developmental age*)	Pitch mean raw score (out of 40)			
	BCI	BHA	BMS	NH
Kindergarten (age 48 – 72 months old)	27.7 (SD 2.2)	24.8 (SD 3.7)	21 (SD 0)	24 (4.2)
Grade 1 (age 73 – 84 months old)	24 (SD 2.8)	31.8 (SD 2.8)	30.5 (SD 0.7)	28.6 (SD 3.3)
Grade 2 (age 85 – 96 months old)	25.7 (SD 3.5)	27.7 (SD 2.5)	28.3 (SD 4.5)	31.3 (SD 2.5)
Grade 3 (age 97 – 108 months old)	31 (SD 4.2)	28.7 (SD 6.4)	35 (SD 0)	34 (SD 0)

Within 3 SD above normative mean; Within 2 SD above normative mean; Within 1 SD above normative mean; Within 1 SD below normative mean; Within 2 SD below normative mean

* Two children (of the 55) were not included in these figures because they were unable to complete the Renfrew test (BCI11& NH4)

Examination of colour coding shows that all groups included within the sample range between three standard deviations above and two standard deviations below the mean normative value. In contrast to pitch results the rhythm results show no particular pattern between the different groups (BCI, BHA, BMS and NH).

5.4.3 Discussion

The aim of the research conducted with the PMMA test battery was to assess whether differences were found in pitch and rhythm perception between the four groups (BCI, BHA, BMS or NH).

Pitch perception results showed that the BCI group scored significantly lower than the other three groups (BHA, BMS and NH). These results are supported by studies which show combined electric-acoustic benefit in pitch perception with EAS devices (Gfeller et al. 2006; Gfeller et al. 2007; Golub et al. 2012). This pattern was also observed when comparing values obtain with chronological age to normative values for the PMMA. This effect was not shown when groups were controlled for developmental age. These results differ from results obtained via the MSP questionnaire within this current research (see section 6.3.2) where no differences were shown between the three HI groups. The discrepancy in results obtained with measures from the current study may be attributed to the fact that the MSP questionnaire has a combined melody and dynamics section so will not provide as refined result for primarily pitch perception as the PMMA pitch test material. No other significant differences were found between the groups for pitch perception suggesting that both the BHA and BMS groups perform equally well to each other as well as to the NH group.

In contrast to the pitch perception scores, PMMA rhythm perception scores showed no significant differences between any of the groups (BCI, BHA, BMS or BMS). This configuration of results is supported by previous literature using the PMMA test battery (Gfeller and Lansing 1997) and other methodologies (Kong et al 2004).

It was noted previously that the numbers in this study were small (55 children) for separating into groups. However scores were compared against PMMA normative values for both chronological and developmental age to reduce the impact that this might have on the analysis. It should also be acknowledged that the NH group within the study had previously completed the PMMA test battery within the pilot study and therefore may perform better based on this factor. They also appear to be a high performing group in comparison to the normative data so comparison of this group to the HI groups should be taken with care.

5.5 **Pitch Production (measured via Child Singing Assessment and Laryngograph)**

5.5.1 Method

53 children took part in the NSP Child Singing Assessment as part of the main study phase. Larynogograph traces obtained while recording the assessment were used to validate the IoE scoring (same method as described within pilot study in Chapter 4) and as a means of assessing singing voice quality through examination of spread of irregularity. The Larynograph analysis was carried out on the sustained spoken vowels from when the child was counting backwards from 10. The vowels were

concatenated and an average fundamental frequency value was measured. This then correlated to IoE assigned centre pitch frequency which was subjectively assigned based on the same section of speech. The frequency of successive vocal fold vibrations (Fx) and vocal fold contact timing (Qx) were also examined from the Larynograph traces within the singing section of the recording (e.g. Happy Birthday, Twinkle twinkle) to obtain an indication of spread and extent of voice irregularity. Irregularity of both Fx and Qx is generated by observing voice fold patterns (cycle by cycle), and plotting cycle by cycle variation on a grid of spaced lines that are separated by distances appropriate to connected speech (Cross-plot). The central diagonal core of this cross-plot contains only points where cycle pairs (either Fx or Qx) differ by less than a set value 1DL (DL=just noticeable change). Irregularity measures give the total of all the occurrences when a corresponding pair of values falls into a cell that is outside the main central diagonal (Fourcin 2009). In order to make visual comparisons between the voice irregularities for each group (BCI, BHA, BMS and NH) Laryngograph traces were appended together and cross-plots produced for the whole group collectively as well as individually. Of the 53 who completed the assessment five participants did not have larygograph traces due to subject compliance.

The children’s mean chronological age was 82.4 months (SD 16.0) and the gender distribution was 25 male to 28 female. The average difference between estimated vocabulary age and chronological age of children that were able to complete the vocabulary assessments (n=49) was -5.9 months

(Mean= 77.8 months; SD= 16.95). Demographic information for each separate group is presented in Table 19.

Table 19. Demographic information for groups who completed the NSP Child Singing Assessment

Group N=53	BCI	BHA	BMS	NH
Number of subjects	14	18	8	13
Mean Age (months) (SD)	78.9 18.2	85.1 13.6	91.3 20.4	77.2 11.9
Mean Expressive vocabulary Age (months) * N=49 (SD)	77.6 20.1	73.2 17.6	84.3 15.4	80.6 12.8
Gender Distribution (percentage)	Male= 42.9 Female= 57.1	Male= 61.1 Female= 38.9	Male= 37.5 Female= 62.5	Male= 38.5 Female= 61.5
4 Frequency Average (.5-4kHz) Hearing threshold (dBHL)	104	66	98	Under 20**

* Four children (of the 53) were not included in these figures because they were unable to complete the Renfrew test (BCI11, BHA10, BMS 8 & NH4)

** All NH children had their hearing screened at 20dBHL (at 500Hz, 1kHz, 2kHz, 4kHz) within the pilot study

In order to compare results to the baseline data collected by the IoE NSP two extra participant groups from the IoE normative data were included in the analysis. These groups (sing up and non-sing up) were created from the baseline dataset and are categorised based on whether they attend a participating sing-up school or not. The data collected in this research was compared to baseline data from 9,494 assessments in the IoE dataset. These assessments were selected from the IoE baseline dataset and only children in the same age range as the main phase study group were included. The full IoE database contained children from cathedral schools but these were not included in the analysis because they were not considered to be typical with respect to singing ability for their age.

Participant variables (hearing level) were examined with two-tailed one-way ANOVA with LSD post-hoc tests after checking the assumptions were met. For group comparisons for singing data, the IoE National Singing programme baseline data was also included so that additional comparisons could be made. This was achieved using two-tailed one-way ANOVA Welch tests with Games-Howell post-hoc tests. This form of ANOVA and post-hoc testing was selected because the data contained groups that were unequal in size and variance when the additional IoE data groups were added into the dataset. Group comparisons for singing voice quality were made with two-tailed one-way ANOVAs with LSD post-hoc tests.

5.5.2 Results

5.5.2.1 Participant Variables

The level of hearing (based on participants better hearing ear 4 frequency average in dBHL) of each HI group was analysed with a two-tailed one-way ANOVA. There was a significant difference at the p<0.05 level ($F_{(2,37)=}$48.8, p=0.00, eta squared=0.7, p<0.001). Post hoc comparisons using LSD test indicated that there was significant difference between the BHA group (M=65.9, SD=12.7) and both the BCI (M=104.1, SD=10.3) and BMS groups

(M=98.3, SD=11.03). The BCI and BMS were not significantly different from each other.

5.5.2.2 Habitual Speech Pitch Centre

Habitual speech pitch centre score was generated by each child counting backwards from 10. As a method of validation of the IoE scoring, sections of each participant's larynograph traces were examined. These were the same sample sections that the IoE staff used to determine participants' habitual centre frequency estimates. An average speech fundamental frequency was determined using the speech studio software program. The result was correlated to the IoE assigned habitual centre frequency (based on a musical note) using two-tailed Pearson Product-Moment correlation coefficient. There was a strong positive correlation between the two variables (r=0.87, n=48, p=0.00). The relationship between these frequencies is shown in Figure 22.

A two-tailed one-way ANOVA Welch test found no significant differences between the groups for habitual speech pitch centre at the p<0.05 level. IoE scorings were used for the group comparisons (rather than laryngograph trace average fundamental frequency scores) so that all 53 participants' scores would be included within the analysis along with data from IoE baseline groups (laryngograph traces were not available for five participants or any of the IoE baseline datasets).

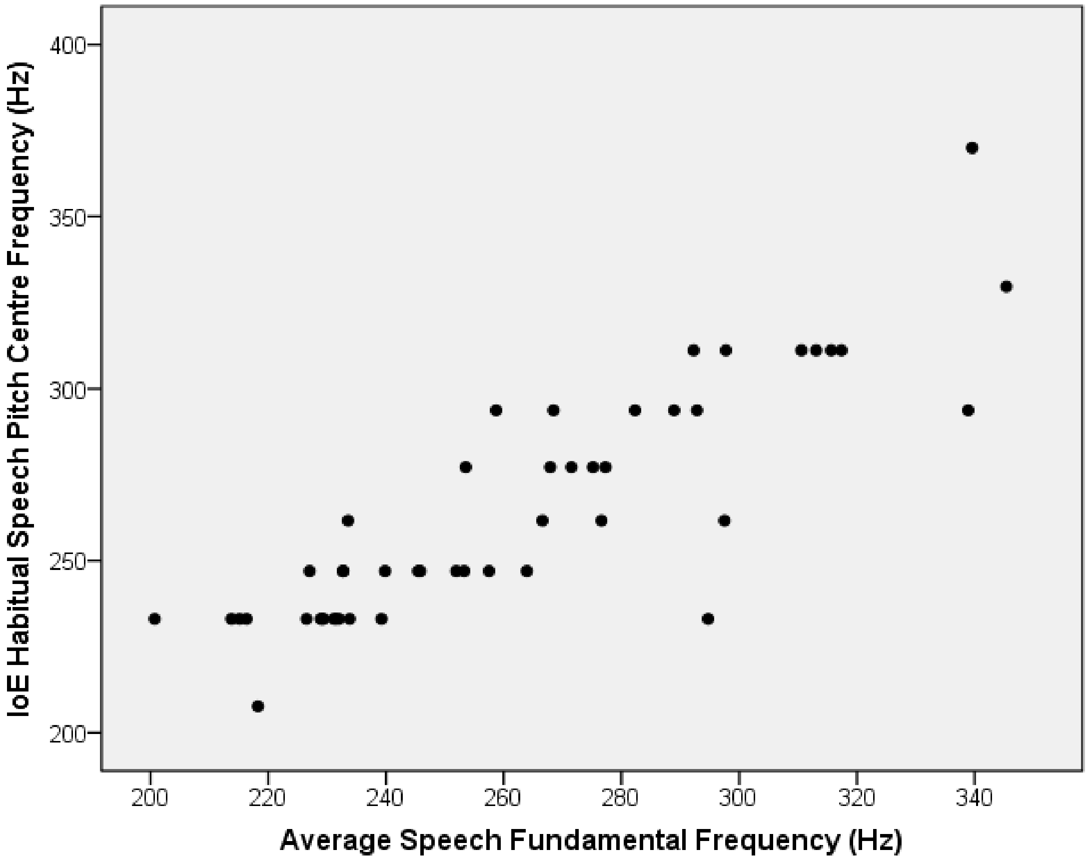


Figure 22.Relationship between IoE assigned habitual speech pitch centre frequency and average speech fundamental frequency obtained from Laryngograph traces. Both taken from a section of children counting backwards from 10 as part of the NSP child singing assessment

5.5.2.3 Comfortable Pitch Range

Comfortable pitch range was taken from the participants' pitch slides within the NSP assessment. Groups were compared in terms of comfortable pitch range (in semitone) using a two-tailed one-way ANOVA Welch test. There was a significant difference shown between the groups ($F_{(5-32.67)=}$4.48, p=0.07, eta squared=0.001) (see Figure 23). Games-Howell post-hoc tests showed that the only significant differences were between the BCI group

(M=10.57, SD=3.65) and both the IoE sing up group (M=14.18, SD=5.13) and IoE non-sing up group (M=13.84, SD=5.08).

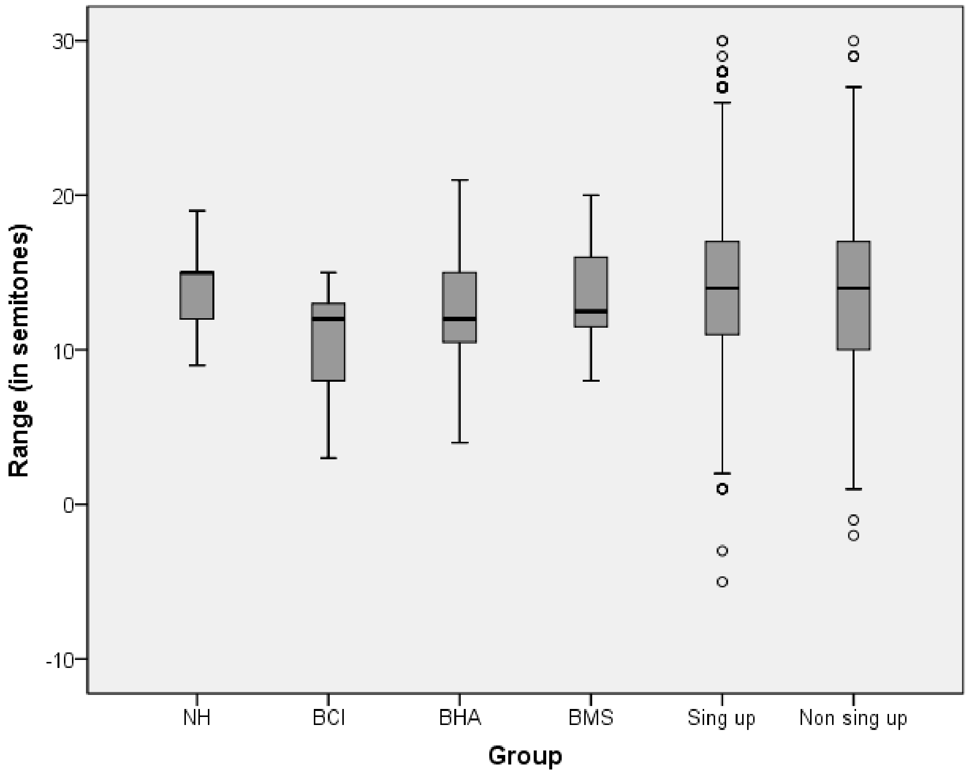


Figure 23. Comfortable Singing Range (in semitones) across the groups

5.5.2.4 Normalised Singing Score (NSS)

NSS scores were generated based on participants' singing behaviour to two well-known songs (e.g. Happy Birthday and Twinkle twinkle). NSS scores were analysed with a two-tailed one-way ANOVA Welch test with factor of "group". A significant difference between groups was shown ($F_{(5-32.6)=}3.53$, p=0.00, eta squared=0.02)(see Figure 24). Games-Howell post-hoc tests revealed significant differences between the NH group (M=81.06,SD=11.20) and the three HI groups (BCI M=54.20, SD=14.7; BHA M=61.25, SD=17.19;

BMS M=47.81,SD=18.09). There was no significant difference observed between the NH group and both the Sing up and Non-sing up IoE baseline dataset groups. There were also no significant differences shown between the three HI groups.

Examination of IoE groups revealed that the IoE sing up group had a significantly better NSS score (M=77.01,SD=17.83) than the three HI groups and the IoE non-sing up group (M=71.47, SD=20.06). The non-sing up group however only scored significantly higher than the BCI group.

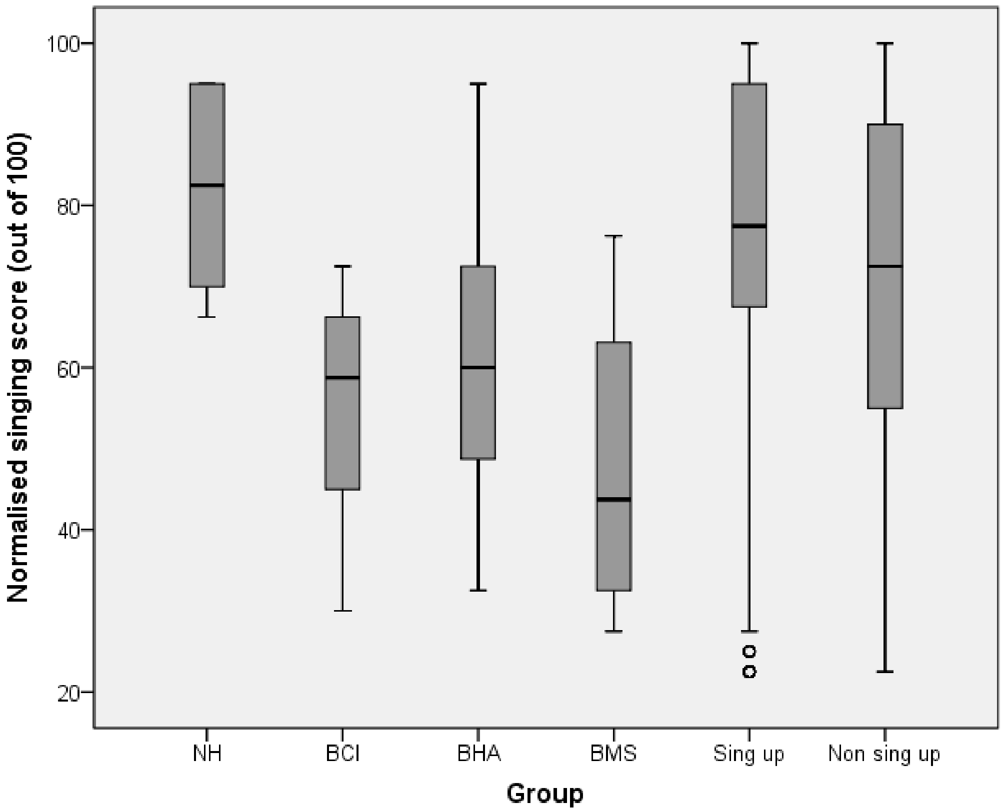


Figure 24. Normalised singing score (NSS) for the different groups of children

5.5.2.5 Singing Voice Irregularity

Singing voice irregularity was examined using laryngograph trace recordings of each child singing two well-known songs (“Happy Birthday” and “Twinkle twinkle”). IoE data groups are not included within these analyses. Recordings were analysed based on irregularity of successive vocal fold vibrational frequencies (IFx) and vocal fold contact phase (IQx). Figure 25 and 26 show the average cross-plots for Fx (CFx) and Qx (CQx) for each group of participants. These show the spread of irregularity shown by each group collectively as individual participant recordings for each group have been appended together into a string and analysed as a whole.

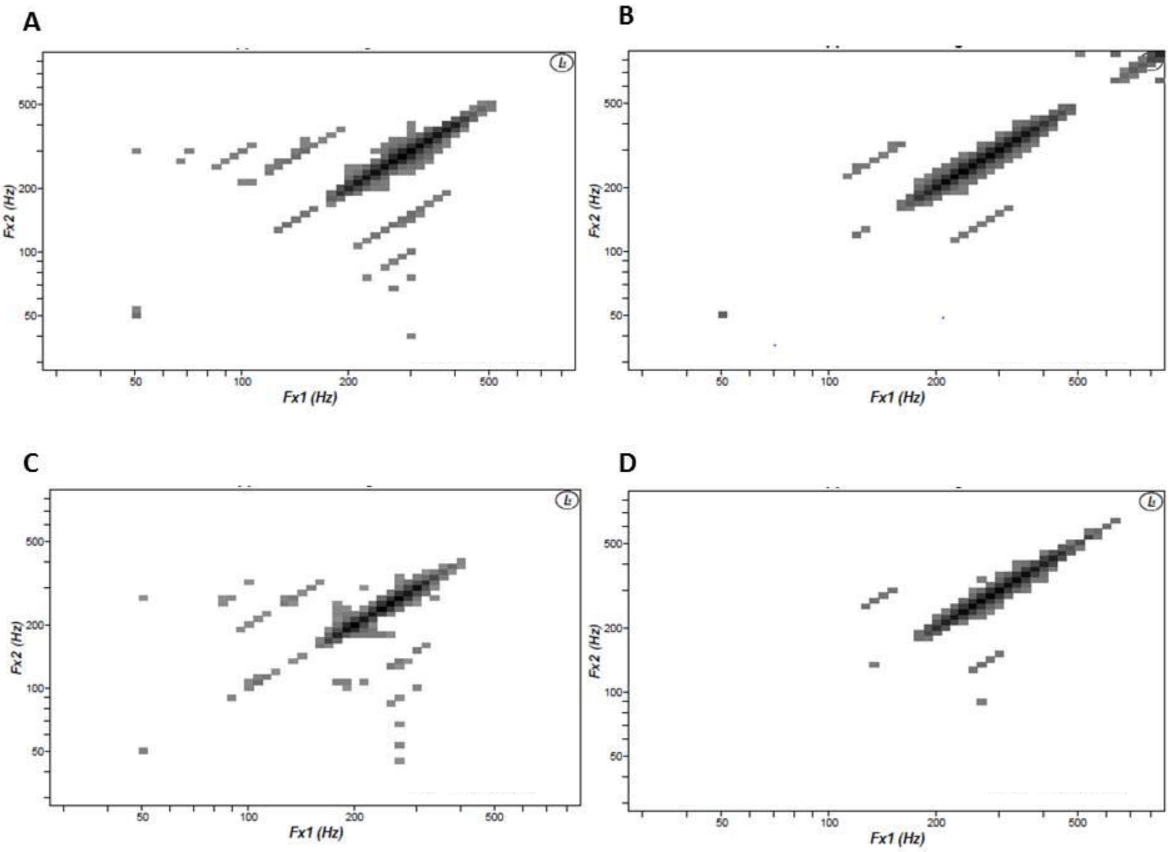


Figure 25. CFx showing spread of IFx for each separate group (A-BCI, B-BHA, C-BMS and D-NH)

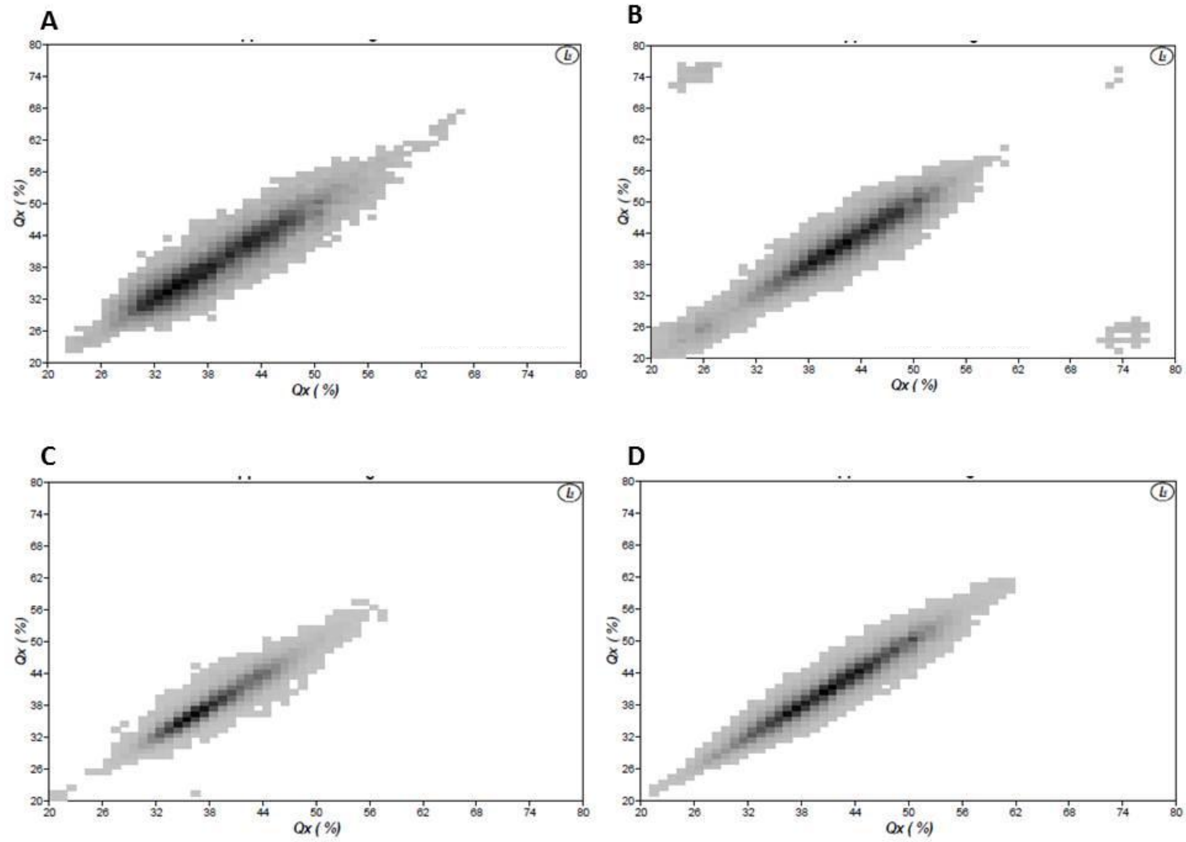


Figure 26. CQx showing spread of IQx for each separate group (A-BCI, B-BHA, C-BMS and D-NH)

The cross-plots showed that both BCI and BMS groups had the worst voice quality in terms of IFx due to their marked bimodal configuration. Qx is worst for the BCI group indicating that this group had the greatest irregulairity in terms of vocal fold contact.

Individual participant’s recording results were also used to compare the groups in terms of voice irregularity (IFx and IQx) using a two-tailed one-way ANOVA test. A significant difference between groups was shown at the $p<0.05$ level for IQx ($F_{(3-44)=}4.1$, $p=0.01$,eta squared=0.2) however not for IFx (see Figures 27 and 28). LSD post-hoc tests indicated the IQx percentage was significantly lower for the NH group (M=50.1%,SD=17.6%) in comparison to both the BCI group (M=68.1%,SD=12.8%) and the BHA group (M=63.5%, SD=11.7%) but not BMS group (M=50.0%, SD=21.8%).

When comparing the three HI group mean values, the BMS group had a lower irregularity percentage than the other two groups, however, there was only a significant difference between that group and the BCI group at the $p<0.05$ level.

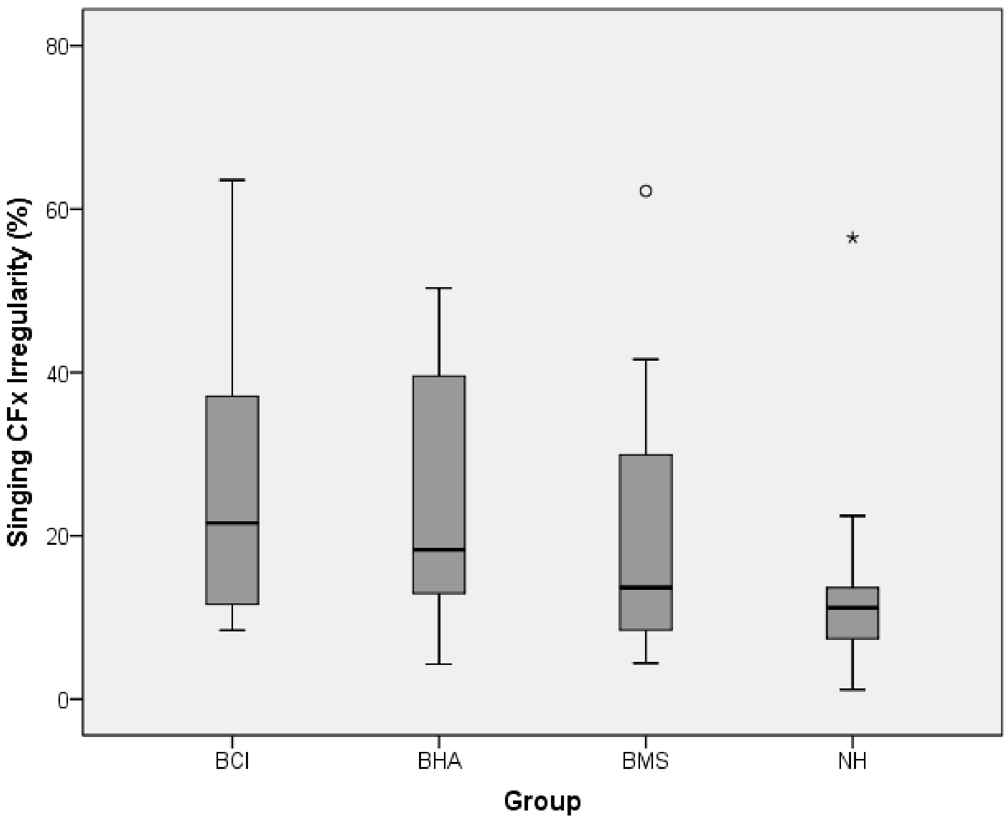


Figure 27. IFx (%) across the four groups (BCI, BHA, BMS and NH)

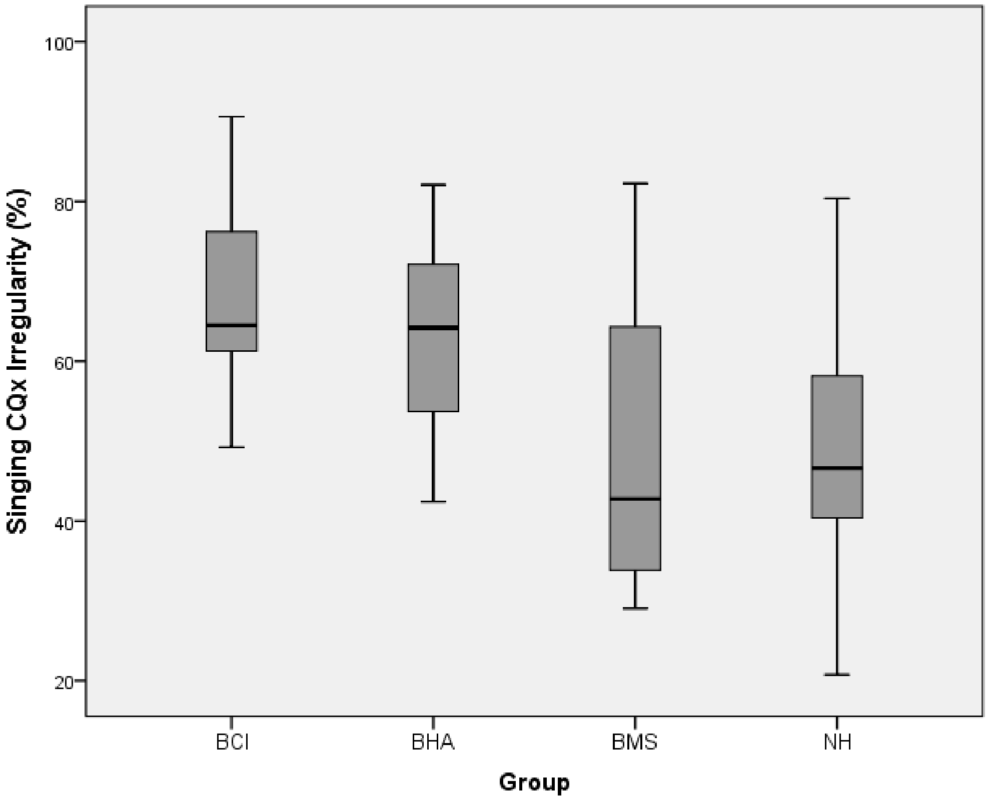


Figure 28. IQx (%) across the four groups (BCI, BHA, BMS and NH)

Due to the small number of participants, group spread of irregularity could be highly affected by individuals who have greater spreads than what would be expected. Figure 29 and 30 show Q-Q plots for IFx and IQx, here individual participant data points and individual data points with those that might be expected from normal distribution can be compared. A small amount of deviation from the line would suggest that the data point would be close to normality and therefore fit with the majority of the group. Small departures from the straight lines depicted indicate there is a tendency to normality for the majority of children within each group. Observation of the Q-Q plots show that some participants deviate more than others from the line indicating those participants show a greater spread of irregularity than is expected from the rest of the group.

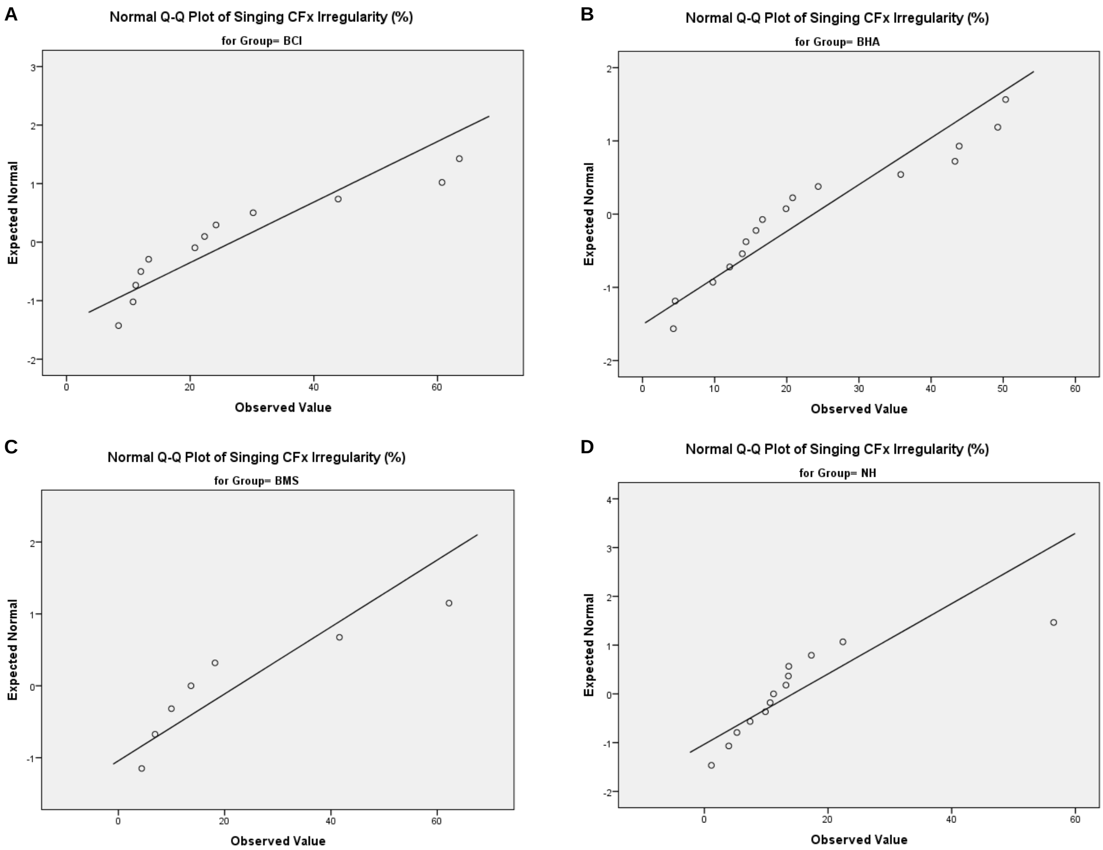


Figure 29 .Q-Q plots comparing observed IFx data points to expected probabilities for each group (A-BCI, B-BHA, C-BMS and D-NH)

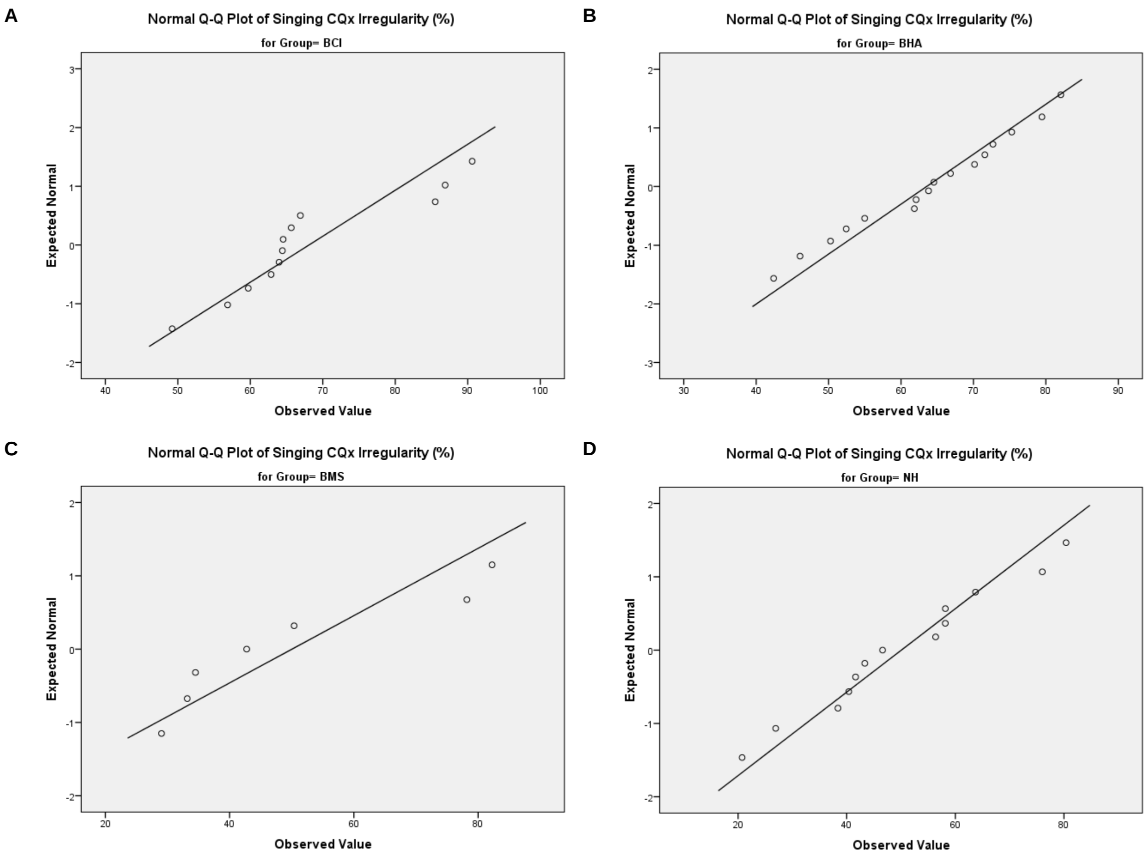


Figure 30.Q-Q plots comparing observed IQx data points to expected probabilities for each group (A-BCI, B-BHA, C-BMS and D-NH)

5.5.3 Discussion

The aim of the research conducted with the NSP Child Singing Assessment (recorded with a laryngograph) was to assess whether differences are found in singing competency between the four groups (BCI, BHA, BMS or NH). Singing competency was assessed through examination of Habitual Speech Pitch Centre, Comfortable Singing range, Normalised Singing Score and Singing Voice Irregularity (Fx and Qx).

Prior to examination of results connected to these singing competency areas the IoE NSP scoring technique validity was examined by comparing average F0 obtained from laryngograph recordings to IoE assigned habitual speech pitch centres. A similar pattern of results was observed as seen in the pilot study. There was a strong positive correlation between the two measures of habitual pitch indicating that the subjective estimates used in the IoE scoring were accurate.

Results comparing the four experimental groups (BCI, BHA, BMS and NH) habitual speech pitch centre and comfortable pitch range showed that there were no significant differences between the groups. However when compared to the IoE dataset the BCI group had a significantly smaller comfortable singing range (in semitones). This result may be expected based on the range of accessible frequencies represented by a CI. Based on recognised auditory feedback mechanisms one would assume that a child will only produce pitches in the range of what they perceive (Murbe et al. 2002). The perceivable pitch range will be constraint by a number of factors. These include electrode insertion depth and placement relating the place pitch perception; CI frequency input range which will typically be limited (between 100-800Hz) and based on electrode placement often be mismatched to corresponding neurons; and by the fact that temporal pitch perception is only represented by phase locking to the envelope of a signal (Macherey et al. 2011). These factors will lead to poorer pitch representation and resolution. .

NSS scores gave an indication of singing behaviour and competency. As might be expected, results indicated that the NH group had a significantly higher score than all three HI groups and the NH group was not significantly different to the IoE dataset groups. These results concur with other studies which also found poorer vocal pitch abilities in CI children compared to NH groups (Nakata et al. 2006; Xu et al. 2009). The results from this current research differ from these cited studies, as groups of HA and BMS children are also included for comparison against NH groups. This comparison between NH and HI groups should however be taken with caution as the NH group had previously undertaken the singing test battery within the pilot study and therefore there may be some practice effect observed.

When considering NSS scores for HI groups separately, no significant differences were shown between the three groups. Based on the theoretical knowledge of pitch representation within these different intervention devices (discussed in Chapter 2) it may be expected that the HA and BMS groups would perform better than the BCI group due to acoustic signal providing better F0 information, this is not however, confirmed by the current results. However, when singing irregularity was examined, the CI groups (BCI and BMS) showed marked diplophonia indicating poor voice quality (known as creaky voice) in terms of IFx. This was shown by interactions of different pitches within simultaneous voice being observed within the CFx cross-plot for those groups. This finding could be attributed to the degraded pitch representation cochlear implantees experience via CI signal processing (Moore 2003). Differences between the groups were not found to be significant for IFx. When considering IQx, the BCI group showed a high spread of irregularity, suggesting that participants were not operating well in regard to vocal fold contact control compared with the other groups and this was confirmed by the BCI group having significantly higher IQx than both NH and BMS groups. Again this finding may be attributed to degraded pitch perception based on CI processing and hardware limitations. The link between CI perception and vocal voice control has been demonstrated by a study showing that young CI participants (aged between 11 and 15 years old) perform better with regard to voice pitch range, pitch regularity, vocal fold contact phase range and contact regularity when they have access to processing of their devices (rather than when they are switched off, meaning they have no auditory feedback available) (Fourcin et al. 2011).

5.6 **Relationships between Results**

5.6.1 Methods

The relationship between the results using the different outcome measures (MSP questionnaire, PMMA test battery and NSP Child Singing Assessment, Laryngograph measurements) were correlated to identify associations between different attributes or tests using a Pearson Product-Moment correlation following exploration of data to ensure that the normality assumptions were met. Data from the whole sample was used for the correlation analysis; however, due to potential differences between the groups for certain outcome measures (BCI, BHA, BMS or NH) the influence of ‘group’ was also controlled for through partial correlation with group as a factor. Data was analysed using the SPSS 21 and Excel 2010 software programs.

5.6.2 Results

Relationship Between Subjective and Behavioural Scoring for Pitch and Rhythm Perception

The relationship between measures of subjective and behavioral pitch and rhythm perception were investigated (see Figure 31 and 32). There was a medium positive correlation shown between MSP melody and dynamic changes domain score and PMMA tone raw score ($r=0.4$, $n=48$, $p<0.05$). This finding was also shown when group was controlled for ($r=0.3$, $n=45$, $p<0.05$). MSP rhythmical changes domain score and PMMA rhythm raw score were also correlated both when group was not controlled for ($r=0.4$, $n=48$, $p<0.05$) and when it was ($r=0.4$, $n=45$, $p<0.05$). This indicates that as subjective scores increase behavioural scores increase. As both measures (MSP and PMMA) aim to quantify the same or similar musical attributes this finding gives an indication of the validity of the measures.

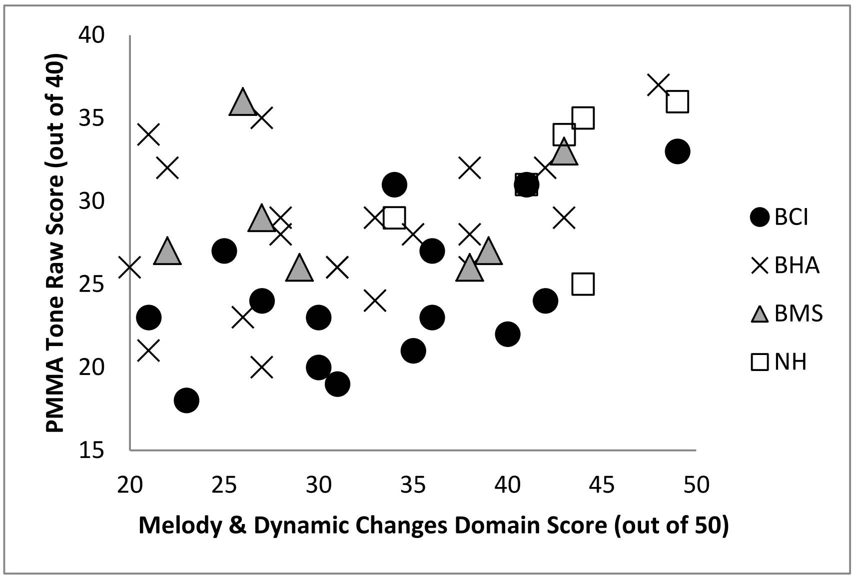


Figure 31. Relationship between MSP Melody and Dynamic changes domain score and PMMA Tone Raw score.

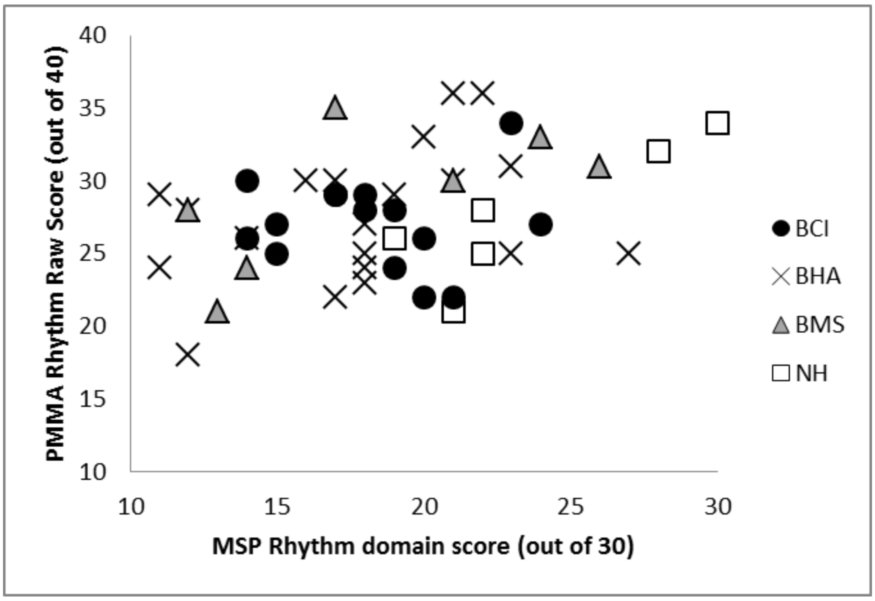


Figure 32. Relationship between MSP rhythmical changes domain and PMMA rhythm raw score

Relationship Between Emotional Aspects and Pitch Perception

The relationship between emotional aspects and pitch perception ability was examined by correlating scores from the emotional aspects domain of the MSP questionnaire with PMMA tone raw score. There was a medium positive correlation between the two variables ($r=0.4$, $n=48$, $p<0.05$) (when group was controlled for ($r=0.4$, $n=45$, $p<0.05$)), with higher levels on perceptual test being associated with higher score on the emotional aspects domain within the MSP questionnaire. Examination of the scatterplot (Figure 33) shows this association appears to be stronger for the BCI and NH groups rather than for all groups.

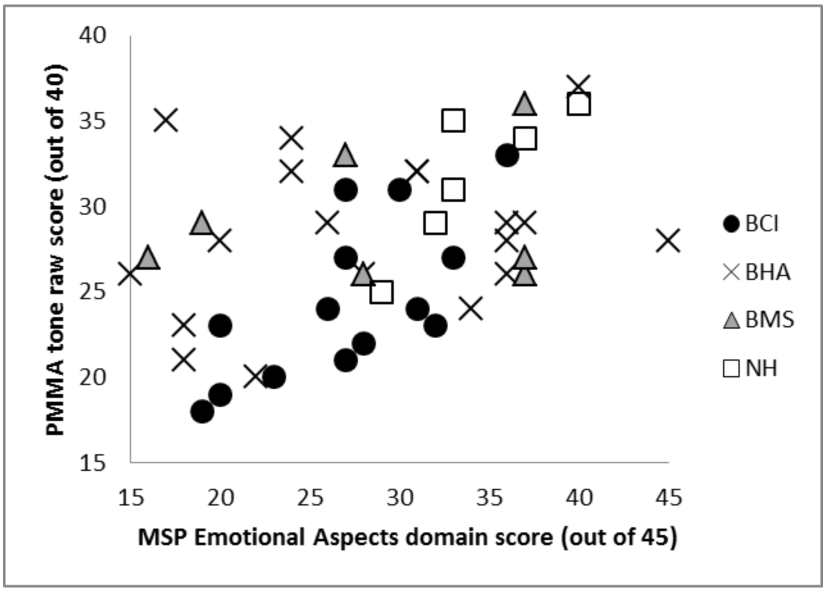


Figure 33. Relationship between MSP Emotional Aspects domain score and PMMA tone raw score

Relationship between Pitch Perception and Production

The association between pitch perception ability and singing competency was investigated by correlating both the MSP Melody and Dynamic changes domain score (see Figure 34) and the PMMA tone raw score (see Figure 35) with NSS score obtained through the NSP Child Singing Assessment. A medium positive correlation between variables was shown between NSS and both MSP Melody and Dynamic changes domain score (r=0.4, n=48, p<0.05) ((r=0.3, n=45,p<0.05) when group was controlled for) and PMMA tone raw score (r=0.5, n=53, p<0.05) ((r=0.3, n=50, p<0.05) when group was controlled for). This indicates that as perceptual ability increases so does singing competency.

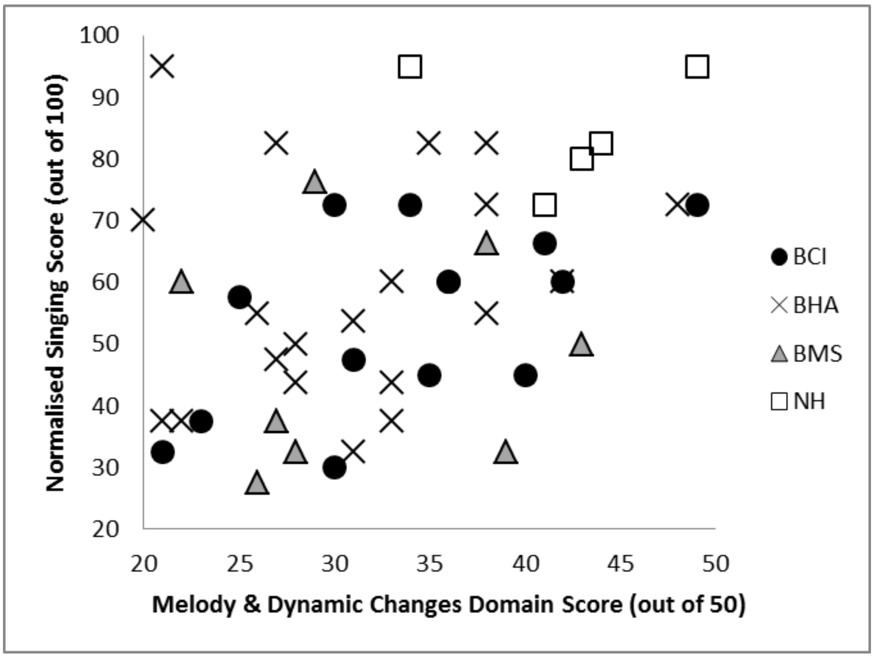


Figure 34. Relationship between MSP Melody and Dynamic changes domain score and NSP Child Singing Assessment Normalised Singing Score

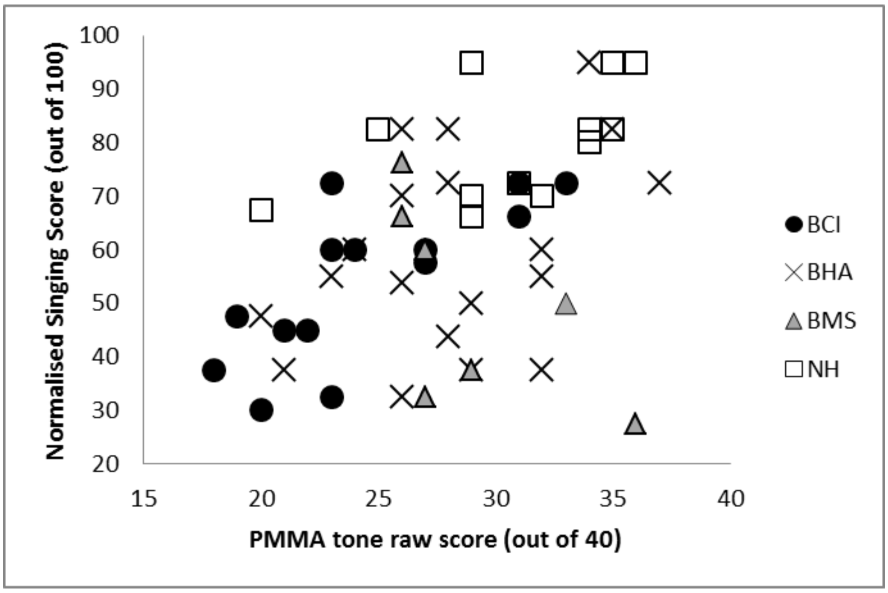


Figure 35. Relationship between PMMA tone raw score and NSP Child Singing Assessment Normalised Singing Score

<u>Relationship between Voice Irregularities (Fx and Qx)</u>

The relationship between voice irregularity measures of successive vocal fold frequency and vocal fold contact phase was examined. There was a strong positive correlation shown between to two variables (r=0.8, n=48, p<0.05) ((r=0.8, n=45, p<0.05) when group was controlled for) indicating that large irregularity in one will often indicate large irregularity in the other. Observation of the scatterplot in Figure 36 indicates that this pattern is common to all separate groups but greater spread is seen from the HI groups.

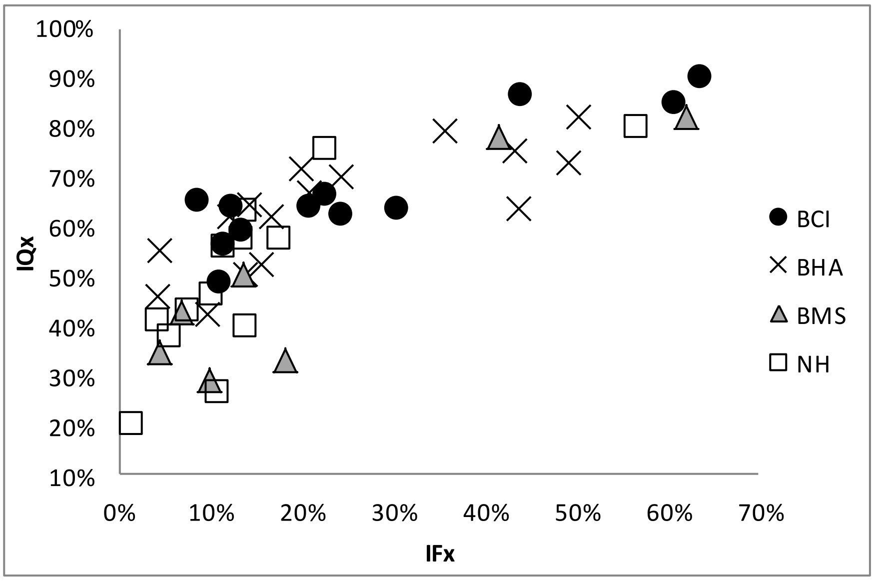


Figure 36. Relationship between successive vocal fold vibrational frequency irregularity (IFx) and vocal fold contact phase irregularity (IQx)

5.6.3 Discussion

Investigation of the correlation between the outcome measures used in the research shows a number of positive associations between different variables. Although not the primary aim of the current research, these additional results indicate validation of the test material by showing positive correlation of measures related to the same musical attributes i.e. pitch and rhythm. They also provide links between some of the different attributes and skills displayed by the participants.

The MSP questionnaire is intended to be a parental questionnaire to collect subjective data on various musical skills and behaviors. The questionnaire provided an overall score of musical ability (total MSP score) as well as a total score for each separate domain. Two domains contained within the

MSP were focused on measuring perceptual abilities (melody & dynamic changes and rhythmical changes). Correlations shown between these domain scores and behavioral pitch and rhythm perception tests measured using the PMMA test battery indicated that subjective evaluations can provide a reliable way of predicting behavioral perceptual outcome. This would be beneficial when testing younger or developmentally delayed children where behavioural measures are unsuitable.

The MSP questionnaire also includes a domain focused on emotional aspects associated with music. A positive correlation in this domain and PMMA tone raw score indicated that children who have better pitch perception show a higher emotional reaction to musical signals. These results are supported by studies showing children with pitch perception deficits due to CI processing will show less music appreciation (Galvin et al. 2007; McDermott 2004).

In Chapter 2 the importance of auditory feedback mechanisms for voice production was highlighted. It was be assumed that musical pitch perception would therefore be linked with vocal pitch production (singing). Results in this current study support this assumption because of the correlations between pitch perception assessments (PMMA tone raw score and MSP melody and dynamic changes domain score) and singing competency (NSP Child Singing Assessment Normalised Singing Score). A study of the relationship between auditory feedback and singers' pitch production demonstrates a strong link between pitch perception and production (with relation to singing) which supports the correlation observed from the current research (Murbe et al. 2002). Inspection of scatterplots (Figures 29 and 30) show a spread of data points with some children performing better or worse than the main cluster. This result is expected based on the diversity of children recruited in terms of age, level of HI, musical experience; and the known variation of singing development amongst children (Welch 2006).

Voice irregularity in terms of Fx and Qx has been previously discussed (see section 4.2.2.3) as a means of assessing singing voice quality. Correlation between these two variables in the normal voice would be reasonable to observe because the mucosal layers that are so crucial to vocal fold contact protection would have an influence on both IFx and IQx. It is however common with voice pathology to have low IFx and high IQx (Fourcin 2009). As none of the children who undertook the test battery had known vocal fold pathology the strong positive correlation observed would therefore be expected.

CHAPTER 6 : DISCUSSION AND CONCLUSIONS

6.1 Discussion

This research was comprised of a series of studies investigating the musical abilities of HI children using different intervention devices for their hearing loss. They were assessed using validated measures with normative ranges. The project had a focus on pitch perception and production due to the recognised importance of pitch within musical signals, and the impact that the different methods of sound processing employed by the different intervention devices may have, as was described in Chapter 2.

6.1.1 Test Battery Selection

There are a number of different test materials available for assessment of musical skills in children which date back over the last 60 years (Bentley 1966; Gordon 1979; Gordon 1990; Karma 2007; Seashore et al 1960; Wing 1948). The test materials selected for this research were based on the primary aim of the research which was to determine if there were differences in pitch perception, production and general musical ability of 4-9 year old HI children using different intervention devices. Test materials were selected that had previously been used with children of the appropriate age, been validated and had normative data available. If they were not validated this was carried out along with collection of norms within the research. This was considered important for the reliability of results to ensure that group and individual results could be explored. This is important when testing HI children because there is often variability across individuals and it is challenging to recruit large sample sizes to overcome this difficulty. This was especially evident in this research because the group of HI children was separated into three intervention groups (CI, HA and BMS). To reduce the variance a restricted age group was used but by having normative ranges for many of the tests it meant that the age appropriate level of performance could be established and used for comparison in the analysis. By looking at values with reference to normative ranges as a function of vocabulary age it gave an opportunity to reduce the effect of developmental delay being the cause of poorer scores for some individuals.

Three separate test materials were used within the project to answer the research question. These were the MSP questionnaire, the PMMA test battery and the NSP Child Singing Assessment (with laryngograph measurements). As outlined in Chapter 4, both the PMMA test battery and the NSP Child Singing Assessment had previously been used with large numbers of children of the appropriate age and had large normative databases with which to make comparisons to (Gordon 1979; Welch et al. 2009). Unfortunately, prior to this research project the MSP questionnaire had not undergone a validation process nor did it have associated normative values. The MSP questionnaire was considered valuable to include within the main study phase of this research because it provided a means of collecting information on emotional factors associated with music, as well as providing subjective assessment of perceptual skills (pitch and rhythm). This was an important component of this research project because two participants (BHA 10 and BMS 8) were unable to complete behavioural PMMA assessments due lack of co-operation or cognitive understanding. Therefore, prior to use within the pilot study (Chapter 4) and main study phase (Chapter 5), the MSP questionnaire underwent validation, normative data was collected and percentile charts created (Chapter 3).

Although some previous questionnaires directed towards music appreciation and musical exposure of HI children provide results on validity similar to what is described for the MSP (Gfeller et al. 1998; van Besouw et al. 2011); the important and distinctive feature of the present research was the collection of normative data from over 300 typically developing children, and the generation of reference centile curves for both the individual perceptual areas and also the overall MSP score. Validation results and normative data collected and reported in Chapter 3 were not only considered valuable within the current research project, but also for future research studies where subjective assessment of musical development is required.

The feasibility of using the test materials selected was examined in a pilot study (Chapter 4). The purpose of the pilot study was to trial the research protocol and test materials with a small sample of NH children to ensure that they would be appropriate for the main study phase. Due to recruitment challenges HI children were not included in the pilot study. Pilot study results showed that the intended test protocol and materials were appropriate for use with children of the selected age range (4-9 years old) and that the testing could be conducted within one hour.

Another pilot study aim was to investigate the method of recording and scoring the NSP Child Singing Assessment. This was undertaken to ensure assessments completedwithin this research were comparable to the NSP IoE normative data; to judge the validity of the NSP subjective scoring technique for accurate pitch production assessment; and to ensure that the quality of the laryngograph recordings were sufficient for acoustic analyses. The acoustic analyses were used as a method of quantifying singing voice quality in terms of irregularity of successive vocal fold frequency and vocal fold contact phase.

A high correlation ($r=0.87$, $p<0.005$) was demonstrated between NSP IoE subjective frequency estimations of the habitual speech pitch centre and acoustic frequency measurements obtained using the laryngograph trace analysis of F0 average value for the same section of speech analysed by the IoE. This correlation demonstrated that the subjective scoring method used by NSP IoE staff was sufficiently accurate. This correlation of variables was repeated in the main study phase of the research and again a high correlation was found adding further support to the pilot study results.

The Renfrew Word Finding Vocabulary test (Renfrew 2010) was added to the selected test materials to be undertaken by participants within the main study phase of the research as a mean of establishing developmental age. The addition of this test was thought to be necessary so that developmental age could be controlled for between the HI groups where chronological and developmental ages may differ due to developmental delay.

6.1.2 Pitch Perception in musical contexts for HI Children

Results reported in Chapter 5 display comparison of pitch perception ability between the four groups using both behavioural (PMMA tone raw score) and subjective (MSP Melody and Dynamic changes domain score) assessment methods. The results not only built on the current research evidence for the perceptual skills of different groups of HI children; but also provided evidence that could impact on clinical choices for HI children.

Based on the literature discussed in Chapter 2 one might expect children with BMS to have an advantage over the other HI groups for musical pitch perception, due to the complimentary auditory cues given by both the acoustic and electric signals. The difference in hearing level does however need to be considered. Past research studies have not be able to demonstrate a BMS benefit (Looi & Radford 2011; Cullington & Zeng 2011); however, PMMA results from the current study have. PMMA tone raw score was shown to be significantly lower for the BCI group in comparison to both other HI groups (BHA and BMS). These results indicate that the participants within both HA and BMS groups have advantage over the BCI group for pitch discrimination; and this could be attributed to a number of factors such as degree and type of hearing loss, level of residual hearing as well as to better fine structure representation through use of acoustic information from their HAs. Although past studies do not concur with this finding (for children using

BMS), support is provided when studies of combined electric and acoustic stimulation through EAS devices are considered (Gfeller et al 2006, Gfeller et al 2007 and Golub et al 2012). These studies have shown better pitch discrimination in individuals with EAS compared with conventional CI users.

Current NICE guidance recommends that suitable children with bilateral severe-profound HI are offered BCIs (NICE 2009). BCIs have been shown to be beneficial for children's speech perception (both in noise and in quiet) (Galvin et al. 2007; Steffens et al 2008; Wolfe et al. 2007) and sound localisation (Grieco-Calub et al. 2008; Grieco-Calub & Litovsky 2010; Steffens et al. 2008; Van Deun et al. 2009). However, based on this recommendation children with useable residual hearing who undergo conventional bilateral cochlear implantation may forfeit the potential benefit for pitch perception achieved through a BMS configuration (CI with HA in contralateral ear). A benefit which has be demonstrated by the current pitch discrimination results. A potential solution to this issue would be to have enhanced surgical techniques in order to preserve residual hearing so the bilateral EAS devices can be used. There are studies which show benefit of EAS devices over conventional CIs for adult populations with regard to pitch perception (Gfeller et al 2006, Gfeller et al 2007 and Golub et al 2012); however currently fitting of EAS devices for paediatric populations is rare.

In contrast to the PMMA results shown in the current research, MSP scores were not significantly different between the three HI groups, suggesting that all groups of children performed at the same level for melody and dynamic perceptual abilities. The discrepancy shown within the current study between MSP and PMMA results could be attributed to the fact that the MSP domain used to make comparisons also contains items directed at dynamic changes. Therefore the results obtained using the MSP melody & dynamic changes domain will not be as focused on purely pitch perception (pitch discrimination) as a behavioral pitch discrimination test such as the PMMA tone task. Another reason for the discrepancy observed could be that parents may be inaccurate at judging their child's ability subjectively especially when compared to a direct behavioural measure. Behavioural results obtained in the current study are further supported by other studies which show better pitch discrimination demonstrated by HA users than CI users (Looi et al 2008; Looi & Radford 2011).

Differences in pitch perception between NH and HI children were also investigated through in the current study group comparisons. These results should be interpreted with caution as the NH group had previously undertaken the test battery within the pilot study and therefore there may be some practice effect observed. They also appear to be a high performing NH group in comparison to the normative data. MSP results showed significantly better perception for the NH group compared to all three HI groups. This result is expected based on the pitch processing limitations HI listeners experience (Moore 1995) however could also be attributed to the group having advantage in terms of practice effect. PMMA tone results showed that the NH group performed significantly better than the BCI group, however differences between the NH and both the BHA and BMS groups did not reach the significance level of $p<0.05$. Inspection of the results obtained show that one child within the NH group performed particularly poorly in comparison to the rest of the group on the PMMA tone task, therefore this child could have had influence over group mean score. This make comparison to normative data even more valuable. The results obtained by both subjective and behavioural measures were in agreement with other studies showing that pitch discrimination is poorer for CI users than groups with NH (Lee et al 2002; Looi et al 2008; Wang et al 2012).

It is well documented that even though CI users experience difficulty in pitch perception, the same effect is not observed for rhythm perception (McDermott 2004). Current research results with both subjective (MSP rhythmical changes domain) and behavioral (PMMA rhythm score) rhythm assessments further confirm this, because there were no significant differences between the HI groups. These results indicate that although the BCI group had poorer pitch perception than the BHA and BMS groups, rhythm perception ability was similar across intervention groups. This configuration of results is supported by previous literature using the PMMA test battery (Gfeller and Lansing 1997) and other methodologies (Kong et al 2004).

6.1.3 Pitch Production in Musical Contexts for HI Children

There is a recognised association between auditory perception and production abilities, especially with respect to pitch (Murbe et al. 2002). This has been further confirmed by current results showing medium positive correlations between both behavioural and subjective pitch perception measures and NSP Normalised Singing Score. This indicated that children with better pitch perception skills may have better singing competency. One would therefore assume that limitations associated with degraded pitch perception (such as CI pitch representation) would have direct impact on vocal pitch production. Theoretical knowledge might lead one to assume that differences in pitch production would be observed between different groups of HI listeners (using CIs, HAs or BMS/EAS) based on differences in pitch representation within their intervention devices. However, at present there are no published studies making such comparisons. The importance of this current research is therefore apparent in terms of adding to the current insufficient research literature and offering results which could also inform clinical practice.

Singing competency and voice irregularity were measured as an indication of vocal pitch production accuracy and overall voice control within the current research. There were no significant differences between participant groups (NH, BCI, BHA and BMS) with respect to the habitual speech pitch centre or comfortable singing range used. Comparisons were also made with the normative values obtained in the IoE dataset. These comparisons were made because the intention was always to compare scores to the normative values for an assessment because that would be a better representation of the normative range than the sample tested within the study. When the groups were compared to NSP IoE normative data the BCI group had a significantly smaller comfortable singing range than both the NSP IoE Sing up and Non Sing up groups. This may be expected based on the cochlear implantees' perceivable pitch range being constraint by electrode insertion depth and input frequency range relating the place pitch perception; and that temporal pitch perception is only represented by phase locking to the envelope of a signal (Macherey et al. 2011). This poor fine structure delivery of the CI will lead to poorer pitch representation and resolution.

For the singing behaviour and competency, NSP normalised singing score results showed that the NH group scored significantly higher than the three HI groups. This result is in agreement with the findings of Xu et al (2009) where singing skills were found to be significantly worse for CI users than a NH group. Results from the current study indicate that although all three HI groups are worse than the NH group in terms of singing competency they do not differ significantly from each other.

Although significant differences between HI groups were not identified in singing competency, voice irregularity from laryngograph recordings indicatied that vocal production was worse for users of CIs. Singing voice irregularity was attained through examination of Fx and Qx cross-plots. IFx cross-plots showed that both the BCI and BMS groups had marked diplophonia in their spread of irregularity. This indicated that both implanted groups' singing voice quality was not as accurate in terms of pitch as the NH and BHA groups, even though IFx differences between HI groups were not found to be significant. IQx comparisons show the NH group to have smallest amount of irregularity in vocal fold contact of the four groups. However the

IQx value was only just significantly lower than the BCI and BHA groups. Qx cross-plots show that the BCI group had the greatest spread of irregularity and this group has been found to be significantly worse than the BMS group. No other significant differences between HI groups were observed. These voice irregularity results suggest that CI pitch representation does have a negative effect on vocal pitch production although this could also be attributed to group differences for example degree and type of hearing loss, and other factors such as unequal sample numbers between groups.

6.1.4 Music enjoyment and Appreciation for HI Children

It has been reported that HI adults report reduced musical appreciation and enjoyment when compared with NH groups (Gfeller et al. 2000a). However, when HI children are examined conflicting results are found (Stordahl 2002). Results from the current study examine theseaspects associated with music and therefore provide comparison of these subjective variables between paediatric NH and HI populations with different intervention devices (BCI, BHA and BMS). This comparison between different groups of HI children offers a distinct difference to what has been presented in current published literature and therefore has value both in research and clinical disciplines. Results from the current study confirm the findings of Stordahl (2002) because no significant differences were shown between any of the groups (BCI, BHA, BMS and NH) on the MSP emotional aspects domain. These results indicate that emotional reactions associated with music are not heavily influenced by limitations in pitch perception or production for HI children; this being regardless of intervention device they use. Despite this a medium positive correlation was found between the MSP emotional aspects domain score and PMMA tone raw score, suggesting that as pitch perception improves this will have a positive impact on emotional aspects.

6.1.5 Limitations of the research

Recruitment was challenging and only 57 participants were recruited to take part in the main study phase, which was then further split into four intervention-device groups. In order to minimise the effect that small numbers of participants would have, the data was collected using validated test measures where normative values were available.

The NH group was the same group who undertook the pilot study therefore would have repeated the tests in the main study phase. This could have given them advantage over the other groups in the main study phase. They also appeared to be a high performing NH group in comparison to the normative data, therefore it was considered important to make comparisons to normative data as well as to this group who completed the test battery in the same experimental conditions.

Within the study it was difficult to control for level of hearing loss in the different intervention groups. Hearing levels were significantly better for the BHA group in comparison to the BMS and BCI groups. This is expected based on the preferred method of intervention for children with severe-profound hearing loss being CIs and therefore finding hearing-aided participants with comparable levels of hearing loss who have not been implanted was challenging.

In addition, gaining an indication of hearing age and controlling for this across the groups was very difficult. A developmental equivalent (Renfrew word finding vocabulary test) was chosen; however, it was acknowledged that making a judgement based on a measure of spoken vocabulary may not be completely appropriate for indicating general developmental stage when hearing is an issue. However there is a lot of evidence to suggest that vocabulary age is a strong indicator of developmental stage (Bloom 1993; Hoff 2005) so it was considered to be a reasonable proxy that could be estimated very quickly within the test session.

Some of the other potential confounding variables were device manufacturer, configuration of device settings, duration of implant use, change in HI over time, prior music exposure and musical training. Controlling for these variables was difficult due to the small sample size and variability in the sample.

6.2 **Conclusions**

The main research questions addressed with the work carried out within this thesis were: do differences exist between different groups of HI children using different amplification devices for the hearing loss, and do these groups also differ from NH children in terms of general musical ability, pitch perception and singing ability. Based on these questions the primary aims of the work undertaken within this thesis were to establish if differences in pitch perception, production and general musical ability were displayed between different groups of HI children. The different groups were defined by the intervention devices the children use to manage their hearing loss (CIs, HAs or both). Additionally comparisons to NH children were made.

Results presented in Chapter 5 indicated that HI children do not perform as well as NH children in tasks associated with pitch perception or production. However, this difference was not observed between NH and HI children for rhythm perception tests or for emotional aspects associated with music such as enjoyment and appreciation.

Comparisons between HI groups showed that children with BCI have significantly worse pitch perception (discrimination) than both BHA and BMS groups. This provides an indication that CI children who have useable residual hearing may benefit from acoustic amplification for musical pitch perception. This finding presents interesting information because current NICE technical guidance recommends that suitable children with severe-profound HL should be offered BCI. When considering music, results from the current research indicate that this NICE recommendation may prevent some children (with bilateral conventional CIs) accessing the optimal auditory environment based on the processing limitations of their devices. Although a relationship was found between pitch perception and singing competency within the sample, significant differences in singing competency between HI groups was not found. However, singing voice irregularity measures indicated that CIs or level of HI could negatively impact on vocal pitch production. This was shown because CI users had a wider spread of successive vocal fold frequencies and vocal fold contact phases.

6.2.1 Future Directions

The research presented in this thesis gives valuable information about the differences observed between groups of HI children using different intervention devices in terms of musical pitch perception, production and general musical development in children. It would ,however, be advantageous to conduct similar assessments with a larger cohort of children with a greater age range and track them over time. This would not only provide robust results but also provide developmental profiles associated with each groupand each measure so that perceptual and production skills can be tracked. It would also be of interest to examine the effects of musical exposure, musical training, and intervention device settings on these outcome measures. Further studies in these areas would provide an evidence base which could inform clinical practice and enhance the understanding of limitations and expectations of different HI children using various management devices for music. They could also provide information on optimal device settings for music and what types of music exposure and training may be beneficial for the development of musical skills in HI children.

Voice analysis within the current research highlighted the potential impact of differing hearing impairments and the intervention devices that are used for hearing loss on voice production. This type of voice assessment would also be an important area to include in future studies as it could influence voice therapy. Voice therapy is considered a useful part of the habilitation process for children with CIs. Currently therapists (both speech and language and music) work with multi discipline teams to device individual voice therapy plans (including auditory training) in order to enhance voice production. Laryngograph assessment would provide a resource whereby quick objective assessments can be made without being intrusive. This assessment could be used in studies to assess voice therapy and track development over time.

Additional studies on voice production would also be an interesting area to explore further with HI children. Very few studies have been published to date which focus on the singing abilities of HI children and the factors which could affect development. Therefore further research examining singing with different groups of HI children of varied age groups would be of interest. It would also be informative to track singing development over time and examine the affect of specific training programs. It could then be established how these skills develop and how improvements can be made for these populations.

ABBREVIATIONS

ANOVA – Analysis of Variance

BCI – Bilateral Cochlear Implant

BHA – Bilateral Hearing Aid

BM – Basilar Membrane

BMS – Bimodal Stimulation

CFx – Cross Plots for Fx

CI – Cochlear Implant

CICS – Cochlear-Implanted Children's Support Group

CQx – Cross Plots for Qx

DL – Difference Limen

DLF – Frequency Difference Limen

EA – MSP Emotional Aspects Domain

EAS – Electro-Acoustic Stimulation

EEG – Electroencephalogram

EM – MSP Exposure to Music Domain

F0 – Fundamental Frequency

FC – Frequency Compression

FT – Frequency Transportation

Fx – Successive Vocal Fold Vibrations

HA – Hearing Aid

HI – Hearing Impaired/Hearing Impairment

HINT – Hearing In Noise Test

IDS – Infant Directed Speech

IHC – Inner Hair Cells

IoE – Institute of Education

IFx – Irregularity of Successive Vocal Fold Vibrational Frequencies

IQx – Irregularity of Vocal Fold Contact Phase

LSD – Least Significant Difference

MAIS – Meaningful Auditory Integration Scale

MD – MSP Melody and Dynamic Domain

MSP – Musical Stages Profile

MuSIC – Musical Sounds In Cochlear Implants

NDCS – National Deaf Children’s Society

NFC – Non-Linear Frequency Compression

NH – Normal Hearing

NICE – National Institute for Health and Care

NSP – National Singing Programme

NSS – Normalised Singing Score

OHC – Outer Hair Cells

PMMA – Primary Measures of Musical Audiation

Qx – Vocal Fold Contact Timing

R – MSP Rhythmical Changes Domain

SA – MSP Sound Awareness Domain

SEN – Special Educational Needs

UK – United Kingdom

ACKNOWLEDGEMENTS

I would like to thank my supervisors Dr Debi Vickers and Dr Merle Mahon for their constant support and guidance throughout PhD Study. I would also like to thank a number of others who have provided guidance on particular areas of the research project.

Firstly I would like to thank Dr Jo Saunders, Professor Graham Welch and Dr Evangelos Himonides for their help and guidance with the assessment of participants' singing abilities. This included advice on selecting appropriate test materials, training on delivery of test protocol and analysis of participants' singing recordings. I would also like to thank Professor Adrian Fourcin and Dr Evelyn Abberton for their advice and guidance on use and analysis of the Laryngograph recordings within the research study.

I am particularly grateful to all families who gave up their time to take part in the research project. I also would like to thank the charities (Children's Cochlear Implanted support group, the National Deaf Children's Society and the Ear Foundation), schools (Darrick Wood Primary School, Maple Primary School and Cowley Hill Primary School) and hospitals (Royal National Ear, Nose and Throat hospital, Bedford hospital, Great Ormond Street hospital, Reading hospital and St Albans & Watford hospital) in which they were recruited from. I particularly acknowledge Trisha Kemp of the Children's Cochlear Implanted support group who informed a large number of families about the research.

I would also like to thank Dr Josephine Marriage for reviewing early versions of the PhD thesis, and Dr Clara Kalu, Professor Tim Cole, Dr Angie Wade and Dr Rosie Lovett who all provided guidance on statistical analysis.

I also am grateful to Advanced Bionics and Phonak UK for providing financial support for the PhD study.

BIBLIOGRAPHY

Abdi, S., Khalessi, M., Khorsandi, M., & Gholami, B. (2001) Introducing music as a means of habilitation for children with cochlear implants. International Journal of Pediatric Otorhinolaryngology. 59 (2) 105-113

ANSI (1994) American National Standard Acoustical Terminology. American Standards Institute. New York

Anvari S, Trainor L, Woodside J, & Levy B (2002) Relations among musical skills, phonological processing, and early reading ability in preschool children. J. Experimental Child Psychology. 83, 111–130

Asp, F.,M ä ki-Torkko, E., Karltorp, E., Harder, H., Hergils, L., Eskilsson, G., & Stenfelt, S. (2012) Bilateral versus unilateral cochlear implants in children: Speech recognition, sound localization, and parental reports. International Journal of Audiology. 51(11), 817-832

Baruch, C., & Drake, C. (1997) Tempo discrimination in infants. Infant Behaviour & Development, 20 (4) 573-577

Bendor, D., & Wang, X., (2005) The neuronal representation of pitch in primate auditory cortex. Nature, 436 (7054) 1161-1165

Baskent, D. & Shannon, R. (2004) Interactions between cochlear implant electrode insertion depth and frequency-place mapping. J. Acoust. Soc. Am. 117 (3), 1405-1416

Baumann, U. & Nobbe, A. 2006. The cochlear implant electrode-pitch function. *Hearing Research,* 213, 34-42

Bentley A (1966) Musical ability in children and its measurement. London, England: Harrap.

Bibas, A., Xenellis, J., Michaels, L., Anagnostopoulou, S., Ferekidis, E., & Wright, A. (2008) Temporal bone study of development of the organ of Corti: correlation between auditory function and anatomical structure. Journal of Largngology and Otology. 122 (4) 336-342

Bland, J.M & Altman, D.G. (1996a).Measurement error. British Medical Journal (Clinical research edition), 313, 744.

Bloom, L. (1993) Language acquisition and the power of expression. In H. L. Roitblat, L. M. Herman & P. E. Nachtigall (Eds.), Language and communication: comparative perspectives. Hillsdale, NJ: Erlbaum

Boex, C., Baud, L., Cosendai, G., Sigrist, A., Kos, M. I. & Pelizzone, M. (2006). Acoustic to electric pitch comparisons in cochlear implant subjects with residual hearing. Journal of the Association for Research in Otolaryngology, 7, 110-124.

Bond, M., Mealing, S., Anderson, R., Elston, J., Weiner,G., Taylor, R., Hoyle, M., Liu, Z., Price, A., & Stein, K. (2009) The effectiveness and cost-effectiveness of cochlear implants for severe to profound deafness in children and adults: a systematic review and economic model. NIHR Health Technology Assessment programme: Executive Summaries.

Boyd, P. J. (2011). Potential Benefits From Deeply Inserted Cochlear Implant Electrodes. Ear and Hearing, 32, 411-427.

Brockmeier, S., Peterreins, M., Lorens, A., Vermeire, K., Helbig, S., Anderson, I., Skarzynski, H., Van de Heyning, P., Gstoettner, W., & Kiefer, J. (2010) Music Perception in Electric Acoustic Stimulation Users as Assessed by the Mu.S.I.C. Test. Cochlear Implants and Hearing Preservation. Adv Otorhinolaryngol. 67,70–80

Carlyon, R., Buus, S., & Florentone, M. (1990) Temporal integration of trains of tone pulses by normal and by cochlearly impaired listeners. Journal of the Acoustic Society of America. 87 (1) 260-268

Carlyon, R., Lynch, C. & Deeks, J. (2010). Effect of stimulus level and place of stimulation on temporal pitch perception by cochlear implant users. Journal of the Acoustical Society of America 127(5),2997-3008

Carral, V., Huotilainen, M., Ruusuvirta, T., Fellman, V., Naatanen, R., & Escera, C. (2005) A kind of auditory ‘primitive intelligence’ already present at birth. European Journal of Neuroscience. 21(11) 3201-3204

Chasin, M., & Russo, F. (2004) Hearing aids and music. Trends in Amplification. 8 (2) 35-47

Cheveigne, A. (2005) Pitch Perception Models. In:Plack et al, eds. Pitch. Neural Coding and Perception. Springer, pp 169-235

Ching, Y., Massie, R., Van. W., Rushbrooke, E., & Psarros, C. (2009) Bimodal fitting or bilateral implantation? Cochlear Implants International. 10 Suppl 1, 23-27

Ching, T., van Wanrooy, E., & Dillon, H. (2007) Binaural-Bimodal Fitting or Bilateral Implantation for Managing Severe to Profound Deafness: A Review. Trends Amplif 2007; 11; 161

Clark, E. V. (2009) First Language Acquisition (2nd edn). Cambridge: Cambridge University Press.

Cole, T. (1988) Fitting smoothed centile curves to reference data. Journal of the Royal Society, Series A, 151, 385-418

Cole, T & Green, P. (1992) Smoothing reference centile curves: the LMS method and penalized likelihood. Statistics in Medicine, 11, 1305-1319

Cooper, H. (1991) Practical Aspects of Audiology:Cochlear Implants. A Practical Guide. San Diego, Singular Publishing Group

Cooper, R & Aslin, R. (1990) Preference for infant directed speech in the first month after birth. Child Development, 61, 1584-1596

Costa-Giomi, E (1999) The effects of three years of piano instruction on children's cognitive development. Journal of Reasearch in Muisc Education, 47, 198-212

Costa-Giomi, E & Descombes, V. (1996) Pitch labels with single and multiple meanings: a study with French-speaking children. Journal of Research in Music Education, 44 (3), 204-214

Cronbach LJ (1951). Coefficient alpha and the internal structure of tests. Psychometrika 16 (3): 297–334

Cullington, H., & Zeng, F. (2011) Comparison of Bimodal and Bilateral Cochlea Implant Users on Speech Recognition with Competing Talker, Music Perception, Affective Prosody Discrimination, and Talker Identification. Ear and Hearing, 32 (1), 16-30

Data Protection Act (1998) Data Protection Action. [online] Available from: http://www.legislation.gov.uk/ukpga/1998/29/contents [Accessed 5 May 2013]

Davies. A. D. M., & Roberts, E. (1975). Poor pitch singing: A survey of its incidence in school children. Psychology of Music, 3 (2), 24-36.

DeCasper, A.J., Lecanuet, J.-P., Busnel, M.-C., Granier-Deferre, C., & Maugeais, R. (1994). Fetal reactions to recurrent maternal speech. Infant Behavior and Development, 17, 159-164

Dehaene-Lambertz,C & Pena (2001) Electrophysiological evidence for automatic phonetic processing in neonates. Cognitive Neuroscience and neuropsychology, 12(14) 3155-3158

Demany, L. Mckenzie, B., & Vurpillot, E. (1977) Rhythm perception in early infancy. Nature. 266 (5604), 718-719

Denora (2000). Music in everyday life. Cambridge, Cambridge University Press

Department of Education. 2013. 2014 National Curriculum. [online]. Available from http://www.education.gov.uk/schools/teachingandlearning/curriculum/nationalcurriculum2014 [Accessed 1 May 2013]

Dillon, H. (2001) Hearing Aids. United States of America. Boomerang Press

Dorman, M., Gifford, R., Spahr, A., & McKarns, S. (2008) The benefits of combined acoustic and electric stimulation for the recognition of speech, voice and melodies. Audiology & Neuro-Otology. 13(2), 105-112

Dorman, M. F., Spahr, T., Gifford, R., Loiselle, L., McKarns, S., Holden, T., Skinner, M. & Finley, C. (2007). An electric frequency-to-place map for a cochlear implant patient with hearing in the nonimplanted ear. Journal of the Association for Research in Otolaryngology, 8, 234-240

Eimas, P., Siquelan, E., Jusczyk, P., & Vigorito, J. (1971) Speech Perception in Infants. Science. 171 (3968) 303

Evans, E. (1975) The sharpening of frequency selectivity in the normal and abnormal cochlea. Audiology, 14, 419-442

Evans, E. & Harrison, R. (1976) Correlation between outer hair cell damage and deterioration of cochlear nerve tuning properties in the guinea pig. J.Physiol, 252, 43-44

Fernald (1985) Four-month-old infants prefer to listen to motherese. Infant Behaviour and Development, 8, 181-195

Fernald (1991) Prosody in Speech to Children:Prelinguistic and linguistic functions. Annals of Child Development, 8, 43-80

Fitzpatrick, E. M., Seguin, C., Schramm, D.,Chenier, J., & Armstrong, S. (2009). Users' experience of a cochlear implant combined with a hearing aid. International Journal of Audiology, 48(4), 172 - 182

Flynn, M., Dowell, R., & Clark, G. (1996) Speech perception of hearing aid versus cochlear implantees. Cochlear Implants 261-265

Fourcin, A. (2009) Aspects of Voice Irregularity Measurement in Connected Speech. Folia Phoniatr Logop, 61, 126-136

Fourcin, A., Abberton, E., Richardson, K., & Shaw, T. (2011) Aspects of Voice Measurement with young users of cochlear implants. Seminars in Hearing. 32(1), 42-52

Franks, J. (1982) Judgments of Hearing Aid Processed Music, Ear and Hearing. 3(1), 18–23

Galvin III, J., Fu, Q., & Nogaki, G (2007) Melodic contour identification by cochlear implant listeners. Ear and Hearing. 28 (3), 302-319

Galvin K.L., Mok M. & Dowell R.C . (2007) Perceptual benefit and functional outcomes for children using sequential bilateral cochlear implants .Ear Hear,28, 470– 482

Gantz, B., Turner, C., Gfeller, K., & Lowder (2005) Preservation of hearing in cochlear implant surgery:Advantages of combined electrical and acoustic speech processing. Laryngoscope. 115 (5), 796-802

Geers, A. (1997) Comparing implants with hearing aids in profoundly deaf children. Otolaryngology-Head and Neck Surgery, 117(3), 150-154

Geers, A., & Moog, J (1991) Evaluating the Benefits of Cochlear Implants in and Education Setting. American Journal of Otology, 12, 116-125

Gfeller, K., Christ, A., Knutson, J., Witt, S., Murray, K., & Tyler, R. (2000a) Musical Backgrounds, listening habits, and aesthetic enjoyment of adult cochlear implant recipients. Journal of the American Academy of Audiology. 11(7), 390-406

Gfeller, K., & Lansing, C. (1991) Melodic, rhythmic and timbral perception of adult cochlear implant users. Journal of Speech and Hearing Research. 34 (4), 916-920

Gfeller, K., Turner, C., Oleson, J., Zhang, X., Gantz, B., Froman, R., & Olszewski, C (2007) Accuracy of cochlear implant recipients on pitch perception, melody recognition, and speech reception in noise. Ear and Hearing. 28(3), 412-423

Gfeller, K., Woodworth, G., Robin, D., Witt, S., & Knutson, J. (1997) Perception of rhythmical and sequential pitch patterns by normally hearing adults and adult cochlear implant users. Ear and Hearing. 18(3), 252-260

Gfeller, K., Witt, S., Kim, K., & Knutson, J. (1998) The Iowa Music Perception and Appraisal Battery.

Gfeller, K., Witt, S.A., Spencer, L.J., Stordahl, J., & Tomblin, B. (1998). Musical involvement and enjoyment of children who use cochlear implants. Volta Review, 100, (4) 213-233

Gfeller, K., Olszewski, C., Turner, C., Gantz, B., & Oleson, J. (2006) Music perception with cochlear implants and residual hearing. Audiology & Neuro-Otology. 11 Suppl 1, 12-15

Gfeller, K., Mehr, M., & Witt, S. (2001) Aural Rehabilitation of Music Perception and Enjoyment of Adult Cochlear Implant Users. Journal of the Academy of Rehabilitative Audiology, 34, 27

Gfeller, K., Oleson, J., Knutson, J.F., Breheny, P., Driscoll, V. & Olszewski, C. (2008). Multivariate predictors of music perception and appraisal by adult cochlear implant users. Journal of the American Academy of Audiology, 19, 120-134.

Gfeller, K., Witt, S., Stordahl, J., Mehr, M., & Woodworth, G. (2000b) The effects of training on melody recognition and appraisal by adult cochlear implant recipients. Journal of the Academy of Rehabilitative Audiology, 33, 138

Goldstein, J (1973) An optimum processor theory for the central formation of the pitch of complex tones. Journal of the Acoustical Society of America, 54, 1496-1516

Golub, J., Won, J., Drennan, W., Worman , T., & Rubinstein, J. (2012) Spectral and temporal measures in hybrid cochlear implant users: on the mechanism of electroacoustic hearing benefits. Otology & Neurology, 33 (2), 147-153

Good, J., Aggleton, J., Kentridge, R., Barker, J., & Neave, N. (1997) Measuring musical musical aptitude in children:on the role of age, handedness, scholastic achievement, and socioeconomic status. Psychology of Music, 25(1), 57-69

Gordon, E.E. (1979). Manual for the Primary measures of music audiation. Chicago, IL.: G.I.A. Publications, Inc.

Gordon EE (1990) Predictive validity study of AMMA: A one-year longitudinal predictive validity study of the Advanced Measures of Music Audiation. Chicago, IL: GIA Publications.

Grannier-Deferre, C., Ribeiro, A., Jacquet, A., & Bassereau, S. (2011) Near-term foetuses process temporal features of speech. Developmental Science, 14(2), 336-352

Green, P.(1987) Penalized likelihood for general semi-parametric regression models, International Statistical review, 55, 245-259

Grieco-Calub T.M. & Litovsky R.Y. (2010) Sound localization skills in children who use bilateral cochlear implants and in children with normal acoustic hearing . Ear Hear , 31 , 645 – 656

Grieco-Calub T.M. , Litovsky R.Y. & Werner L.A. (2008) Using the observer based psychophysical procedure to assess localization acuity in toddlers who use bilateral cochlear implants . Otol Neurotol , 29 , 235 – 239

Gromko, J., & Poorman, A. (1998) The effect of music training on preschoolers' spatial-temporal task performance. Journal of Research in Music Education, 46, 173-181

Hallam, S., Cross, I., & Thaut, M. (2009) The Oxford Handbook of Music Psychology. Oxford. Oxford University Press

Hargreaves, D.J (2009) Musical Development. In In S.Hallum, I.Cross and M.Thaut eds. The Oxford Handbook of Music Psychology. Oxford. Oxford University Press, pp217-252

Harrison RV, Evans EF (1979) Cochlear fibre responses in guinea pigs with well defined cochlear lesions. Stand Audio1 [Suppl] 9, 83-92.

He, C., Hotson, L., & Trainor, L. (2007) Mismatch responses to pitch changes in early infancy. Journal of Cognitive Neuroscience, 19(5), 878-892

Hepper, P.(1992) Fetal psychology: an embryonic science. In J. Nijhuis ed. Fetal Behaviour. Oxford. Oxford University Press, pp 129-156

Hepper, P., & Shahidullah, B. (1994) Deevelopment of Fetal Hearing. Archives of Disease in Childhood, 71(2), F81-F87

Hoff, E (2005). Language Experience and Language Milestones During Early Childhood. In K. McCartney & D. Phillips (Eds). Blackwell Handbook of early childhood development: Blackwell Publishing, blackwell reference online

Hopkins, K., and Moore, B., (2007) Moderate cochlear hearing loss leads to a reduced ability to use temporal fine structure information J. Acoust. Soc. Am. 122(2), 1055-1068

Hurwitz, I., Wolff, P., Bortnick, B., & Kokas, K. (1975) Nonmusical effects of Kodaly music curriculum in primary grade children. Journal of Learning Disabilites, 8, 167-174

Jackson, C. & Furnham, A. (2000). Designing and analysing questionnaires and surveys: a manual for health professionals and administrators. London, UK. Whurr Publishers:

Kang, R., Nimmons, G., Drennan, W., Longnion, J., Ruffin, C., Nie, K., Won, J., Worman, T., Yueh, B., & Rubinstein, J. (2009) Development and validation of the University of Washington clinical assessment of music perception test. Ear and Hearing.30(4)411-418

Karma, K. (2007) Musical aptitude definition and measure validation: Ecological validity can endanger the construct validity of musical aptitude tests. Psychomusicology: Music, Mind and Brain 19, 79–90

Kisilevsky, B., Hains, S., Lee, K., Xie, X., Huang, H., Ye, H., Zhang, K., & Wang, Z. (2003) Effects of experience on fetal voice recognition. Psychological Science, 14(3), 220-224

Kong, Y.Y., Cruz, R., Jones, J.A., & Zeng, F.G. (2004) Music perception with temporal cues in acoustic and electric hearing. Ear Hear 25,173-185

Kong, Y., Stickney, G., & Zeng, F.(2005) Speech and melody recognition in binaurally combined acoustic and electric hearing. Journal of the Acoustic Society of America. 117(31), 1351-1361

Kuhl, P., Williams, K., Lacerda, F., Stevens, K., & Lindblom, B. (1992) Linguistic experience alters phonetic perception in infants by 6 months of age. Science. 255 (5044) 606-608

Kuk, F., & Baekgaard, L. (2009) Considerations in fitting hearing aids with extended bandwidths. Hearing Review, 16(11), 32-38

Lamont, A. (1998) Music, Education, and the development of pitch perception: the role of context, age and musical experience. Psychology of Music, 26, 7-25

Laryngograph (2013). Speech Studio [online]. Available from: http://www.laryngograph.com/pr_studio.htm [Accessed 3rd May 2013]

Leal, M., Shin, Y., Laborde, M., Calmels, M., Verges, S., Lugardon, S., Andrieu, S., Deguine, O., & Fraysse, B. (2003). Music perception in adult cochlear implant recipients. Acta Oto-Laryngologica.123 (7), 826-835

Lee, K., Van Hasselt, C., Chiu, S., & Cheung, D. (20020 Cantonese tone perception ability of cochlear implant children in comparison with normal hearing children. Internal Journal of Pediatric Otorhinolaryngogolgy, 63, 137-147

Leighton, G., & Lamont, A. (2006) Exploring children’s singing development:do experinces in early schooling help or hinder? Music Education Research, 8(3), 311-330

Leon, A., Davis, L., & Kraemer, H. (2011). The role and interpretation of Pilot Studies in Clinical research. J Psychiatr Res. 45(5):626-629

Licklider, J. (1956). Auditory frequency analysis. In: Information Theory. Academic Press, p253-268

Liberman, M., Dodds, L., & Learson, D.(1986) Structure-function correlation in noise-damaged ears:a light and electron-microscopic study. In: R Salvi et al eds. Basic and Applied Aspects of Noise-Induced Hearing Loss. York, Plenum, pp 163-176

Limb, C. & Rubinstein, J. (2012) Current Research on Music Perception in Cochlear Implant Users. Otolaryngologic Clinics of North America, 45, (1) 129-+

Looi, V. (2008) The effect of cochlear implantation on music perception. A review. Otolaryngology, 58, 169-190

Looi, V., McDermott, H., McKay, C., & Hickson, L. (2008) Music perception of cochlear implant users compared with that of hearing aid users. Ear and Hearing. 29(3), 421-434

Looi, V., & Radford, C. (2011) A comparison of the speech recognition and pitch ranking abilities of children using unilateral cochlear implant, bimodal stimulaton or bilateral hearing aids. International Journal of Pediatric Otorhinolaryngology, 75(4), 472-482

Looi, V. & She, J. (2010) Music perception of cochlear implant users: A questionnaire, and its implications for a music training program. International Journal of Audiology, 49, (2) 116-128

Ludwig van Beethoven (1934). BrainyQuote.com [online] Available from. http://www.brainyquote.com/quotes/quotes/l/ludwigvanb153104.html [Accessed August 23, 2012)

McCarney R, Warner J, Iliffe S, van Haselen R, Griffin M, & Fisher P (2007). The Hawthorne Effect: a randomised, controlled trial. BMC Med Res Methodol 7: 30

Macherey, O., Deeks, J., & Carlyon, R. (2011) Extending the Limits of Place and Temporal Pitch Perception in Cochlear Implant Users. JARO 12, 233–251

McDermott, H (2011) Benefits of combined acoustic and electric hearing for music and pitch perception. Seminars in Hearing. 32(1), 103-114

McDermott, H. (2004) Music perception with cochlear implants: A review. Trends in Amplification. 8(2), 49-82

Miller, R., Schiling, J., Franck, K., & Young, E. (1997) Effects of acoustic trauma on the representation of the vowel/./ in cat auditory nerve fibres. Journal of the Acoustic Society of America. 101, 3602-3616

Mitani, C., Nakata, T., Trehub, S.E., Kanda, Y., Kumagami, H., Takasaki, K., Miyamoto, I., & Takahashi, H. (2007). Music recognition, music listening, and word recognition by deaf children with cochlear implants. Ear and Hearing.28 (SUPPL.2)29S-33S

Mirza, S., Douglas, S.A., Lindsey, P., Hildreth, T., & Hawthorne, M. (2003) Appreciation of music in adult patients with cochlear implants: A patient questionnaire. Cochlear Implants International.4 (2) 85-95

Moore, B.(1995) Perceptual consequences of cochlear damage. Oxford. Oxford University Press

Moore, B. (2003) Coding of sounds in the auditory system and its relevance to signal processing and coding in cochlear implants. Otol. Neurotol. 24, 243–254

Moore, B., & Carlyon, R. (2005a) Pitch for Hearing-Impaired Listeners and Cochlear Implantees. In: A Fay & A. Popper eds. Pitch, Neural Coding and Perception. Springer, pp 234-277

Moore, B. (2008) An introduction to the Psychology of Hearing (5th edition). London. Academic Press

Moore, B., & Carlyon, R. (2005b) Perception of Pitch by People with Cochlear Hearing Loss and by Cochlear Implant Users. In: Plack et al eds. Pitch. Neural Coding and Perception. Springer, pp 234-277

Moore, B., & Peters, R. (1992) Pitch Discrimination and Phase sensitivity in young and elderly subjects and its relationship to frequency selectivity. Journal of the acoustical society of America. 91, 2881-2893

Moore, B. (1996) Perceptual consequences of cochlear hearing loss and their implications for the design of hearing. Ear and Hearing, 17(2), 133-161

Moore, B., Wojtczak, M., & Vickers, D (1996) Effect of loudness recruitment on the perception of amplitude modulation. Journal of Acoustical Society of America. 100 (1), 481-489.

Morrongiello, B., & Roes, C. (1990) Developmental changes in children's perception of musical sequences: effects of musical training. Developmental Psychology. 26, 814-820

Murbe, D., Pabst, F., Hofmann, G., & Sundberg, J. (2002) Significance of auditory and kinaesthetic feedback to singers' pitch control. Journal of voice. 16(1), 44-51

Nakata, T., Trehub, S.E., Mitani, C., & Kanda, Y. (2006) Pitch and timing in the songs of deaf children with cochlear implants. Music Percept. 24, 147–154

National Institute for Health and Care Excellence (NICE) (2009) Cochlear implants for children and adults with severe to profound deafness. NICE technology appraisal guidance 166. London: National Institute for Health and Care Excellence.

Nilsson, M., Soil, S., & Sullivan, J.(1993) Development of the Hearing In Noise Test for the measurement of speech reception thresholds in quiet and in noise. J acoustic society of Am. 95 (2) 1085-1099

Nittrouer, S., & Chapman, C. (2009) The effects of bilateral electric and bimodal electric-acoustic stimulation on language development. Trends in Amplification. 13(3), 190-205

Ohm, G. (1843) Uber die Definition des tones, nebst daran geknupfter Theorie der Sirene und ahnlicher tonbildender Vorrichtungen. Ann Phys Chem. 59, 513-565

Opinio 1998. [online] Available from: http://www.ucl.ac.uk/isd/staff/e-learning/tools/opinio [Accessed 1st July 2009]

Osberger, M., Robbins, A., Miyamoto, R., Beryy, S., Myres, W., Kessler, K., & Pope, M. (1991) Speech Perception Abilities of Children with Cochlear Implants, Tactile Aids, or Hearing Aids. American Journal of Otology. 12, 105-115

Patel, A. (2008) Music, Language and the Brain. Oxford. Oxford University Press

Peretz, I., Champod, A., & Hyde, K. (2003) Varieties of musical disorders: The Montreal Battery of Evaluation of Amusia. Annals of the New York Academy of the Sciences. 999, 58–75.

Plack, C (2005) The Sense of Hearing. New Jersey. Lawrence Erlbaum Associates

Plack, C., Oxenham, A., Fay, R., & Popper, A. (2005) Pitch, Neural Coding and Perception. New York, Springer Science.

Plantinga, J. & Trainor, L (2009) Melody recognition by two-month-old infants. Journal of the Acoustical Society of America. 125 (2), EL58-EL62

Porta, M. (2008) Dictionary of Epidemiology. 5. Oxford: Oxford University Press.

Rauscher, F. (2009) The impact of music instruction on other skills. In S.Hall, I. Cross & M. Thaut eds. The Oxford Handbook of Music Psychology. Oxford. Oxford University Press, pp244-252

Rauscher, F., Shaw, G., Levine, L., Wright, E., Dennis, W., & Newcomb, R. (1997) Music training causes long-term enhancement of preschool children's spatial-temporal reasoning abilities. Neurological Research, 19, 1-8

Rauscher, F., & Zupan, M. (2000) Classroom keyboard instruction improves kindergarten children's spatial-temporal performance: A field experiment. Early childhood Research Quarterly, 15, 215-228

Renfrew, C.E. (2010). The Renfrew Language Scales: Word finding vocabulary test. Revised edition: Speechmark

Richards, D., Frentzen, B., Gerhardt., McCann, M., & Abrams, R. (1992) Sound levels in the huan uterus. Obstetrics and Gynecology. 80, 186-190

Robbins, A., Renshaw, J., & Berry, S. (1991) Evaluating meaningful auditory integration in profoundly hearing impaired children. Am J Otol 12, 144-150

Robertson, D., & Manley, G. (1974) Manipulation of frequency anaylsis in the cochlear ganglion of the guinea pig. J. Comp.Physiol. 91, 363-375

Rocca, C. & Boyle, P. (2011) Muiscal potch perception and production in children with cochlear implants. International Journal of Pediatric Otorhinolaryngology. Conference:10th Europeon Symposium on Paediatric Cochlear Implantation. Athens, Greece. May

Ross, E., Thompson, R., & Yenkosky, J. (1997) Lateralization of Affective Prosody in Brain and the Collosal Integration of Hemispheric Language Functions. Brain and Language 56, 27 – 54.

Ruggero, M (1994) Cochlear delays and travelling waves: comments on ‘Experimental look at cochlear mechanics’. Audiology. 33, 131-142

Ruggero, M., & Rich, N. (1991) Furosemide alters organ of corti mechanisms: Evidence for feedback of outer hair celss upon basilar memebrane. J.Neuroscience. 11, 1057-1067

Rutkowski, J (1997) The nature of children's singing voices: Characteristics and Assessment. In The phenomenon of singing. Ed B.A. Roberts, 201-9. St John's, NF: Memorial University Press

Scattergood, L. & Limb, C. (2010). Music Perception in Children with Cochlear Implants. Perspectives on Hearing and Hearing Disorders in Childhood, 20, 32-37

Schellenberg, E. (2004) Music lessons enhance IQ. Psychological Science. 15, 511-514

Schouten, J. (1938) The perception of subjective tones. Proc Kon Akad Wetenschap. 41, 1086-1093

Schouten, J. (1940) The residue and mechanism of hearing. Proc Kon Ned Akad Wetenschap. 43, 991-999

Seashore, C., Lewis, D., Saetveit, J.G. (1960) A second revision of the manual of instructions and interpretations for the Seashore Measures of Musical Talents (1939 revision). New York, NY: The Psychological Corporation.

Sing up (2013). The sing up programme [online]. Available from: http://www.singup.org/ [Accessed 3rd May 2013]

Sloboda, J (2009) The role of music in everyday life. In S.Hallum, I.Cross and M.Thaut eds. The Oxford Handbook of Music Psychology. Oxford. Oxford University Press, pp 429-490

Smith, S., Gerhardt, K., Griffiths, S., Huang, X., & Abrams, R. (2003) Intelligibility of sentences recorded from the uterus of a pregnant ewe and from the fetal inner ear. Audiology and Neuro-Otology. 8, 347-353

Smith, Z., Delguette, B., & Oxenham, A. (2002) Chimaeric sounds reveal dichotomies in auditory perception. Nature. 416(6876), 87-90

Snik, A., Vermeulen, A., Brokx, J. & VanderBroek, P (1997) Long-term speech perception in children with cochlear implants compared with convential hearing aids. American Journal of Otology. 18(6), S129-S130

Somers, M. (1991) Speech-Perception Abilites in Children with Cochlear Implants or Hearing Aids. American Journal of Otology. 12, 174-178

Steffens, T., Lesinski-Schiedat, A., Strutz, J., Aschendorff, A., Klenzner, T., Rühl, S., Voss B.,Wesarg, T., Laszig, R., & Lenarz, T. (2008) The benefits of sequential bilateral cochlear implantation for hearing-impaired children . Acta Otolaryngol , 128 , 164–176

Steinberg, J. & Gardener, M. (1937) The dependence of hearing impairment on sound intensity. Journal of the Acoustic Society of America. 9, 11-23

Stordahl J (2002) Song recognition and appraisal: a comparison of children who use cochlear implants and normally hearing children. Journal of Music Therapy 39(1),2-19

Sundberg, J. (1987) The Science of the Singing Voice. Northern Illinios. University Press

Takeuchi, A. & Hulse, S (1993) Absolute Pitch. Psychological Bulletin. 113(2), 345-361

Terhardt, E. (1974) Pitch, consonance and harmony. Journal of the Acoustical Society of America. 55, 1061-1069

Trainor, L. & Trehub, S. (1994) Key membership and implied harmony in wertern tonal music: developmental perspectives. Perception and Psychophysics. 56, 125-132

Trainor, L. J., & Unrau, A. J. (2012). Development of pitch and music perception. In L. Werner, R. R. Fay & A. N. Popper (Eds.), Springer Handbook of Auditory research: Human Auditory Development. 223-254. New York. Springer

Trehub, S. (2003) The developmental origins of musicality. Nature Neuroscience. 6(7),669-673

Trehub, S., Cohen, A., Thorpe, L. & Morrongiello, B (1986) Development of the perception of musical relations:semitone and diatonic structure. Journal of Experimental Psychology:Human Perception and Performance. 12, 295-301

Trehub, S.E., Unyk A, Kamenetsky S, Hill D, Trainor, L., & Henderson J (1997) Mothers' and Fathers' singing to infants. Developmental Psychology, 33, 500-507

Trehub, S., Vongpaisal, T., & Nakatab, T. (2009) Music in the Lives of Deaf Children with Cochlear Implants. The Neurosciences and Music III—Disorders and Plasticity: Ann. N.Y. Acad. Sci. 1169, 534–542.

van Besouw, R.M., Grasmeder, M.L., Hamilton, M.E., & Baumann, S.E. (2011). Music activities and responses of young cochlear implant recipients. International Journal of Audiology, 50, (5) 340-348

Van Deun L. , van Wieringen A. & Wouters J (2010) Spatial speech perception benefits in young children with normal hearing and cochlear implants .Ear Hear , 31 , 702 – 713

Veekmans, K., Ressel, L., Mueller, J., Vischer, M., & Brockmeier, S. (2009) Comparison of music perception in bilateral and unilateral cochlear implant users and normal-hearing subjects. Audiology and Neurotology.14(5), 315-326

Vermiere, K., Nobbe, A., Schleich, P., Nopp, P., Voormolen, M. H. & van de Heyning, P. H. (2008). Neural tonotopy in cochlear implants: An evaluation in unilateral cochlear implant patients with unilateral deafness and tinnitus. Hearing Research, 245, 98-106.

Vickers, D., Dincer, H., Boyle, P., Kirkim, G., Olgun, L., Incesulu, A., Yucel, E., Onder, S., & Aygener, N. (2007) Development of Musical Behavior in Children with Cochlear Implants. Advanced Bionics Auditory Research Bulletin , 146-148.

Vongpaisal, T., Trehub, S.E., & Schellenberg, E.G. (2006). Song recognition by children and adolescents with cochlear implants. Journal of Speech, Language, and Hearing Research, 49, (5) -1103

Vongpaisal T., Trehub S.E., & Schellenberg E.G. (2009) Identification of TV tunes by children with cochlear implants. Music Perception, 27: 17–24.

Wan C, Rüber T, Hohmann A, & Schlaug G. (2010) The Therapeutic Effects of Singing in Neurological Disorders. Music Percept. 27(4): 287–295

Wang, S., & Huang, J. (2010) Musical note perception and musical sound vocal production in cochlear implant children. Proceedings of 20th International Congree on Acoustics, ICA. 23-27

Wang, S., Liu, B., Dong, R., Zhou, Y., Li, J., Qi, B., Chen, X., Han, D., & Zhang, L. (2012) Music and lexical tone perception in chinese adult cochlear implant users. Laryngoscope, 122, (6), 1353-1360

Welch, G (1985). Variability of practice and knowledge of results as factors in learning to sing in tune. Bulletin of the Council for Research in Music Education, 85, 238-247

Welch G.F (1998) Early childhood musical development. Research studies in Music Education 11:27-41

Welch, G. (2006), Singing and vocal development," In G. McPherson, ed. The Child as musician: a handbook of musical development, Oxford: Oxford University Press, pp. 311-329.

Welch, G., Himonides, E., Papageorgi, I., Saunders, J., Rinta, T., Stewart, C., Preti, C., Lani, M., Vraka, M., & Hill, J. (2009). The National Singing Programme for primary schools in England: an initial baseline study. Music Education Research, 11, (1) 1-22

Welch, G.F. (1996). The Singing Competencies of 5-Year-Old Developing Singers. Bulletin of the Council for Research in Music Education (127) 155-162

Welch, G.F., Sergeant, D.C., & White, P.J. (1997). Age, sex, and vocal task as factors in singing "in tune" during the first years of schooling. Bulletin of the Council for Research in Music Education (133) 153-160

Werker, J. & McLeod, P. (1989). Infant preference for both Male and Female infant-directed talk: a developmental study of attention and affective responsiveness. Canadian Journal of Psychology, 43, 230-246

Werner, L.A. & Vandenbos, G.R. (1993). Psychology Update - Developmental Psychoacoustics - What Infants and Children Hear. Hospital and Community Psychiatry, 44, (7) 624-626

Wightman, F. (1973). The pattern-transformation model of pitch. Journal of the Acoustical Society of America, 54, 407-416

Wilson, B. (2000) Cochlear implant technology In J. Niparko et al., eds. Cochlear Implants: Principles & Practices. New York: Lippincott, Williams & Wilkins, pp. 109-118.

Wilson, B., Sun, X., Schatzer, R., & Wolford, R. (2004). Representation of fine structure or fine frequency information with cochlear implants. International Congress Series, 1273, 3-6

Wilson, B.S. & Dorman, M.F. (2008a). Cochlear implants: A remarkable past and a brilliant future. Hearing Research, 242, (1-2) 3-21

Wilson, B.S. & Dorman, M.F. (2008b). Cochlear implants: Current designs and future possibilities. Journal of Rehabilitation Research and Development, 45, (5) 695-730

Wing H (1948) Tests of musical ability and appreciation: An investigation into the measurement, distribution, and development of musical capacity. London, England: Cambridge University Press.

Wolfe, J., Baker, S., Caraway, T., Kasulis, H., Mears, A., Smith, J., Swim, L., & Wood, M. (2007) One-year postactivation results for sequentially implanted bilateral cochlear implant users. Otol Neurotol , 28, 589–596

Woolf, N., Ryan, A., & Bone, R. (1981). Neural phase locking properties in the absence of cochlear outer hair cells. Hearing Research, 4, 335–346.

Xu, L., Zhou, N., Chen, X., Li, Y., Schultz, H., Zhao, X., & Hanb, D. (2009) Vocal singing by prelingually-deafened children with cochlear implants Hear Res. 255(1-2),129–134

Yuba, T., Itoh, T., & Kaga, K. (2009). Unique Technological Voice Method (The YUBA Method) Shows Clear Improvement in Patients with Cochlear Implants in Singing. Journal of Voice.23 (1), 119-124

Yucel, E., Vickers, D., Sennaroglu, G., Dincer, H., Budak, B., & Belgin, E. (2007) Effects of Pitch, Rhythm, and Melody Training on Speech and Music Development in Children with Cochlear Implants. Advanced Bionics Auditory Research Bulletin , 150-151.

Yucel, E., Sennaroglu, G., & Belgin, E. (2009). The family oriented musical training for children with cochlear implants: Speech and musical perception results of two year follow-up. International Journal of Pediatric Otorhinolaryngology.73 (7) 1043-1052

APPENDICES

Appendix 1: Musical Stages Profile Questionnaire

Musical Stages Profile

These questions have been developed to cover some of the key areas of musical development. It may be that your child does not yet do many of the activities listed. Please do not worry, the activities are intended to cover a wide age range and not all children will do all the different items.

Please try to answer the questions as carefully as possible and write any comments that could give us further information.

Thank you for taking the time to help

A. General Information

Today's Date: …../…../….. Subject Identifier: ....

Date of birth of child: …../…../….. ....Child's age: ....

Session Information
....

Child's gender: Male □ Female □

Your relationship to child:...

Does the child have any siblings: Yes □ No □

How many?..

Age and Gender of each child...

....

What is the family language spoken at home? ....

Does your child speak other languages? Yes □ No □

If so, please list the languages spoken ....

....

Child's Preference:

Male Voices ☐

Female Voices ☐

No Preference ☐

Does your child have any Hearing problems?
Yes ◻ No ◻

If yes, complete the next highlighted section. If not please skip highlighted section

Hearing problem: Right ear ◻ Left ear ◻ Both ears ◻

What was the hearing problem caused by?
(e.g. family history/infection/unknown)…………………………………………….

Hearing loss? Yes ◻ No ◻

If so:-
When was hearing loss acquired? (e.g. from birth/3 months/2 years)…………

Degree of hearing impairment: Mild ◻
Mild-Moderate ◻
Moderate ◻
Moderate-Severe ◻
Severe ◻
Severe-Profound ◻
Profound ◻

What has child's management been for hearing impairment?

Surgical procedure ◻

Hearing aid(s) ◻ If so - Unilateral ◻ Bilateral ◻

Cochlear implant(s) ◻ If so - Unilateral ◻ Bilateral ◻

Bimodal (hearing aid + implant) ◻

Age at implantation? .... Date of switch on…………………………

Mode of communication? Verbal ◻ Sign ◻ Gesture ◻

Other……………………………………….

In which of the following places does your child like to listen to music:

a. at home

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

b. in the car

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

c. at school / pre-school / nursery / playgroups

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Does your child participate in music lessons/music groups (in/or out of school):

Yes □ No □

If so please comment
....
....
....
....

Does your child play a musical instrument?

Yes □ No □

If yes, what do they play ....

Are there any other instruments your child likes to play?

....
....
....

What are your child's Favourite Songs or Nursery Rhymes?

....
....
....

B. Sound awareness and general reaction

1. **Does your child start moving or dancing when there is some music being played (radio etc …)?**

   - ☐ Never
   - ☐ Rarely
   - ☐ Occasionally
   - ☐ Frequently
   - ☐ Always

2. **Does your child start clapping when they hear a song or music being played?**

   - ☐ Never
   - ☐ Rarely
   - ☐ Occasionally
   - ☐ Frequently
   - ☐ Always

The following questions relate to musical listening, it may be that your child does not perform the activity and that can be perfectly normal. Please feel free to add comments after any of the questions to clarify your answer. If you answer "Never" to any of the questions please add a note to clarify whether the question is irrelevant or if "Never" is the appropriate answer. This is of particular relevance for questions about playing a musical instrument or singing.

C. Melody and dynamics changes

3. Does your child spontaneously understand changes in melody within musical tunes?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments ....
....
....
....

4. Does your child spontaneously try to sing a familiar melody (like nursery rhymes or lullabies he/she has heard)?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments ....
....
....
....

5. **When you listen to music or you hum the melody, does your child try to vocalise?**

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments ....
....
....
....

6. **If your child tries to sing can he/she follow the melody of the song?**

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments..
....
....
....

7. **Does your child spontaneously understand variations in loudness within musical tunes?**

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments..
....
....
....

8. **Can you recognise the songs that your child sings?**

☐ Never
☐ Rarely
☐ Occasionally
☐ Frequently
☐ Always

Comments..
....
....
....

9. **Does your child sometimes vocalise as though they are singing (i.e. with large changes in pitch)?**

☐ Never
☐ Rarely
☐ Occasionally
☐ Frequently
☐ Always

Comments..
....
....
....

10. **When listening to a song will your child start to sing words at the ends of the phrases?**

☐ Never
☐ Rarely
☐ Occasionally
☐ Frequently
☐ Always

Comments..
....
....
....

11. When singing a song will your child vary loudness appropriately?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments...
....
....
....

12. If your child plays an instrument can s/he monitor and control the loudness appropriately (in a group/ in response to the dynamic variations)? Any instrument at all: woodblock, tambourine, piano……

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments...
....
....
....

D. <u>Rhythmical changes</u>

13. Does your child ever spontaneously:

a. clap hands to music?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

b. drum a beat on something (drum, pot, …) to music?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments ....
....
....
....

14. When you listen to music with your child and you clap the beat with your hands, does your child clap along with you?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments..
....
....
....

15. If your child claps or bangs a beat to music, is it in time with the beat of the music?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments...
....
....
....

16. Does your child clap at different speeds in response to musical rhythm?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments...
....
....
....

17. If your child is following a beat by banging, clapping, marching…are they able to follow a change in a tempo?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments...
....
....
....

E. **Emotional aspects**

18. Does your child ever spontaneously ask you to sing or play music?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments...
....
....
....

19. Does your child like to listen to recorded music (e.g. on CD) or your singing when he/she is going to sleep?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments...
....
....
....

20. Does your child ever ask to listen to a particular CD or tape?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments...
....
....
....

21. Can your child say when a favourite song is being played?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments..
....
....
....

22. Does music change your child's mood?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments..
....
....
....

23. Does singing have a comforting effect on your child e.g. when distressed or going to sleep?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments..
....
....
....

24. Does your child show emotional reactions to different music?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments...
....
....
....

25. Does your child appear to enjoy music?

- ☐ Never
- ☐ Rarely
- ☐ Occasionally
- ☐ Frequently
- ☐ Always

Comments...
....
....
....

26. How important is music to your child?

- ☐ Not at all Important (Music of no interest, potentially even disliked)
- ☐ Slightly Important (Occasionally responds but very little interest)
- ☐ Moderately Important (Enjoyed but not essential, never requested)
- ☐ Very Important (Enjoys music and requests to listen or play music)
- ☐ Extremely Important (Crucial to everyday life)

Thank you for taking the time to complete this questionnaire.

INFORMATION FOR PARENTS/GUARDIANS ABOUT THE RESEARCH

Music Perception and Production in Hearing Impaired Children

Invitation

We would like to invite you and your child to take part in a study which forms part of some PhD research. Before you decide whether or not to take part, we would like you to understand why the research is being done and what it would involve for you. **One of our team is always available to go through the information sheet with you and answer any questions you have at any point.** Talk to others about the study if you wish.

(Part 1 tells you the purpose of this study and what will happen to you and your child if you take part. Part 2 gives you more detailed information about the conduct of the study).

Ask us if there is anything that is not clear.

PART 1

What is the purpose of the study?

The study will compare the musical abilities of children with different management options for their hearing impairment i.e. cochlear implants, hearing aids or combinations of both.

The results will be used to give information on how best to utilize signal processing options to build on music perception and enjoyment for hearing impaired children of this age. It may also have implications for future product development with respect to enhancing musical skills and enjoyment for hearing impaired individuals.

This study represents a collaboration between University College London and Audiology and Cochlear-implant centres in and outside of London.

Why have my child and I been invited?

You and your child have been invited because your child is cared for by [insert programme name here] and is aged between 5 and 7 years. Approximately 50 families will take part.

Do we have to take part?

No. It is up to you and your child to decide whether or not to join the study. We are available to describe the study to you and go through this information sheet with you before you make any decision to be involved. If you agree to take part, we will ask you to sign a consent form. You and your child are free to withdraw at any time, without giving a reason. This would not affect the standard of care you or your child receives from your Audiology or cochlear-implant centre.

What will happen to my child and me if we agree to take part?

We shall pass your contact details to Sian Edwards at the Ear Institute, University College London. She will arrange a time for you to visit the Ear Institute. The first visit takes place within a month of your child starting the study. The visit will take up to two hours. If your child is tired during a visit, we may ask you to come back on another day. This means there will be a minimum of one visit, and a maximum of two. We will try to arrange the visits at times that are convenient for you.

During each visit, we shall ask your child to take part in musical and singing tasks designed to assess their musical abilities, along with some tests of hearing and speech. We shall ask you to complete some questionnaires relating to your experience of your child's hearing impairment and about your child's musical development and enjoyment. The aim of the study is to compare musical outcomes for groups of children, *not* to compare individual children. Taking part in the study will not affect the medical care that your child receives.

Further details are given in Part 2 of this information sheet.

Expenses and payments

For each visit, we will pay you an inconvenience allowance; this is intended to cover the cost of travel to the Ear Institute, childcare costs for siblings and to thank you for taking part. If visit is to take place within your local Audiology department the inconvenience allowance will be revised to reflect less travel expenses.

What are the other possible disadvantages and risks of taking part?

There are no risks in taking part. Some children may find the assessments boring. We will take breaks during the assessments to minimise this. It is possible you might find some of the questionnaires difficult to answer (for example, some parents find it difficult to estimate the quality of life of their child). You would need to travel and to give up some of your time in order to help us. We would prefer you not to bring siblings to the assessments, so you would need to arrange alternative care for them.

What are the possible benefits of taking part?

The information that we obtain from you and your child will help us to compare the perception of musical attributes for the different management options available for children of this age. This information will help clinicians and parents to make decisions about how best to enhance these musical abilities for hearing-impaired children in the future. We will send you a report after each visit to describe the results of the assessments of your child.

What if there is a problem?

Any complaint about the way you have been dealt with during the study or any adverse effect on you or your child caused by the study will be addressed. Detailed information is given in Part 2.

Will my taking part in the study be kept confidential?

Yes. We will follow ethical and legal practice and all information about you will be handled in confidence. The details are included in Part 2.

This completes Part 1 of the Information Sheet.

If the information in Part 1 has interested you and you are considering taking part, please read the additional information in Part 2 before making any decision.

PART 2

What will happen to my child and me if we take part?

Why would we have to visit the Ear Institute?

We have special equipment for measuring children's listening and musical skills in the Ear Institute.

How would we travel to the Ear Institute?

The Ear Institute is close to Kings Cross and easy to reach by public transport. Parking in the local area is very limited. We will give you detailed instructions on how to find the Ear Institute.

What will happen at the Ear Institute?

We shall ask you to spend up to one and a half hours with us at each appointment. We will assess your child's musical abilities through pitch, rhythm and timbre discrimination tasks as well as a measurement of their singing voice. All tests have been selected to be appropriate for children of this age. We will have several breaks. We shall ask you to remain in the room with your child and to help by giving your child praise and encouragement.

Sometimes it is difficult to interpret a young child's responses during the assessment. We will make voice-recording of part of the session, so that we can refer back if necessary.

We will ask you about your child's musical abilities and behaviours, and about your child's health and well-being in questionnaire form.

Sometimes, children are tired during a visit. If this happens, we may ask you to come back to the Ear Institute to repeat some of the assessments. We will pay you an inconvenience allowance designed to cover travelling costs for each visit. If it would be more convenient, it may be possible for one of the research team to visit you and your child at home/audiology or cochlear implant department to complete the assessments.

How long will the study go on?

You and your child would be involved in the study for up to 12 months.

What will happen if I don't want to carry on with the study?

You may withdraw from the study at any time and without giving a reason. If you withdraw, we will need to use the research data that we have gathered from you and your child up to that point.

What if there is a problem?

If you have a concern about any aspect of this study, you should speak to Sian Edwards who will do her best to answer your questions (telephone 07779269757).

Every care will be taken in the course of this study. However, in the unlikely event that you are injured by taking part, compensation may be available.

In the event that something goes wrong and you are harmed and this is due to someone's negligence then you may have grounds for a legal action for compensation against University College London. If you suspect that the injury is the result of the Sponsor's (University College London) or the hospital's negligence then you may be able to claim compensation. After discussing with your research doctor, please make the claim in writing to Dr Debi Vickers who is the Chief Investigator for the research and is based at the Ear Institute, 332-336 Gray's Inn Road, London. WC1X 8EE.The Chief Investigator will then pass the claim to the Sponsor's Insurers, via the Sponsor's office. You may have to bear the costs of the legal action initially, and you should consult a lawyer about this.

Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated by members of staff or about any side effects (adverse events) you may have experienced due to your participation in the research, the normal National Health Service complaints mechanisms are available to you. Please ask your research doctor if you would like more information on this. Details can also be obtained from the Department of Health website: http://www.dh.gov.uk

Will our taking part in this study be kept confidential?

Any information which you and your child give to the research team, and all of the measurements that are collected from you and your child, will be confidential. Some parts of your child's medical records and the data collected for the study will be looked at by authorised persons from your child's hospital and from the research team. All will have a duty of confidentiality to you and your child and nothing that could reveal your identity or the identity of your child will be disclosed outside the research team without your permission.

We will send you a report after each visit to describe the results of the assessments of your child. If you wish, we will send a copy of these reports to your child's audiologist. This is voluntary.

The research team will comply with the terms of the UK Data Protection Act 1988. They will store the information and the measurements in anonymous computer files and in locked filing cabinets. They will store names and address separately from other data. No names will be used when the research is written up. Your results will be kept for 20 years and will then be destroyed.

Some study documents may also be looked at by authorised representatives from University College London (UCL) Research & Development Unit to check that the study is being carried out correctly. Professional standards of confidentiality will be followed by the authorised representatives. The handling, processing, storage and destruction of their data will be in accordance with the UK Data Protection Act 1998 and UCL's Data Protection policy.

What will happen to the results of the research study?

We shall report the results at medical and scientific meetings and in medical and scientific journals. We will send you a one-page summary of the results of the study. Neither your identity, nor that of your child, will be disclosed when we report the results of the study.

Who is organising and funding the research?

The research is organised by the Ear Institute, University College London. None of the researchers, nor their institution, will be paid for including you and your child in the study. The research is funded by sponsorship from Advanced Bionics and PhonaK UK.

Who has reviewed the study?

All research in the NHS is looked at by an independent group of people, called a Research Ethics Committee, to protect your interests.

What should we do next?

Please read the Consent Form that is attached to this Information Sheet. We will give you copies of these documents to take home. If you would like to take part, please complete the consent form and hand in or post to your Audiology/cochlear implant department or alternatively bring it with you to your next routine appointment.

If you would like more information, please get in touch with Sian Edwards at the Ear Institute. She can be reached by telephone at 07779269757, by e-mail at sian.edwards@ucl.ac.uk, or by letter at the address at the end of this information sheet.

Thank you for considering taking part in this study. If you choose to take part, you will be given this information sheet and a copy of your signed consent form to keep

UCL EAR INSTITUTE

Patient identification number for this study: __________

CONSENT FORM FOR PARENTS/GUARDIANS

Title of Project: Music Perception and Production in Hearing Impaired Children

Please initial box

1. I confirm that I have read and understood the information sheet dated 18/01/2011 (version 1.1) for the above study. I have had the opportunity to consider the information and to ask questions. I have had these questions answered satisfactorily. ☐

2. I understand that the participation of my child and me in the study is voluntary and that we are free to withdraw at any time without giving a reason, without our medical care or legal rights being affected. ☐

3. I understand that information from relevant sections of my child's medical notes, including our contact details, will be sent to individuals at the Ear Institute. I give permission for these individuals to have access to my child's records and to the data generated by the research. ☐

4. I agree that researchers at the Ear Institute may make a voice-recording while my child takes part in tests. This recording will not be seen by anyone other than the researchers involved in the study, unless I give my agreement in writing after visiting the Ear Institute. The recording will be destroyed as soon as possible. ☐

5. I agree that the anonymous findings from the research can used in publications and reports as detailed in the information sheet. I understand that the identity of me and my child will not be revealed. ☐

6. I understand that study documents *may* be looked at by responsible representatives from the Research Governance Sponsor of this study (UCL/UCLH R&D Unit) to ensure that the study is being conducted properly. I give permission for these individuals to have access the necessary information. ☐

7. I agree that my child may take part in the study. ☐

8. I agree to take part in the study, myself. ☐

9. I would like my child's audiologist to be sent a report describing my child's results. YES/NO (this is optional - please delete as appropriate) ☐

   Name of audiologist___________________________

   Name of hospital/clinic_________________________

____
Name of child

________________________________	_______________	_________________________
Name of parent/guardian	Date	Signature
________________________________	_______________	_________________________
Name of person taking consent	Date	Signature

When completed: 1 for parent; 1 for Ear Institute file; 1 (original) to be kept in medical notes.

UCL EAR INSTITUTE

POSTAL INFORMATION SHEET FOR PARENTS/GUARDIANS ABOUT THE RESEARCH

Music Perception and Production in Hearing Impaired Children

Invitation

We would like to invite you and your child to take part in a study which forms part of some PhD research. Before you decide whether or not to take part, we would like you to understand why the research is being done and what it would involve for you. **Please read this information sheet carefully.** Talk to others about the study if you wish.

(Part 1 tells you the purpose of this study and what will happen to you and your child if you take part. Part 2 gives you more detailed information about the conduct of the study).

Please contact Sian Edwards if there is anything that is not clear. Contact details for Sian are at the end of this information sheet.

PART 1

What is the purpose of the study?

The study will compare the musical abilities of children with different management options for their hearing impairment i.e. cochlear implants, hearing aids or combinations of both.

The results will be used to give information on how best to utilize signal processing options to build on music perception and enjoyment for hearing impaired children of this age. It may also have implications for future product development with respect to enhancing musical skills and enjoyment for hearing impaired individuals. This study represents a collaboration between University College London and Audiology and Cochlear-implant centres and charities in and outside of London.

Why have my child and I been invited?

You and your child have been invited because your child is aged between 5 and 8 years and suffers with hearing impairment. Approximately 50 families will take part.

Do we have to take part?

No. It is up to you and your child to decide whether or not to join the study. We will describe the study and go through this information sheet with you before you make any decision to be involved. If you agree to take part, we will ask you to sign a consent form. You and your child are free to withdraw at any time, without giving a reason. This would not affect the standard of care you or your child receives from your audiology or cochlear-implant centre.

What will happen to my child and me if we agree to take part?

We shall pass your contact details to Sian Edwards at the Ear Institute, University College London. She will arrange a time for you to visit the Ear Institute. The visit takes up to one and a half hours. If your child is tired during a visit, we may ask you to come back on another day. This means there will be a minimum of one visit, and a maximum of two. We will try to arrange the visits at times that are convenient for you.

During the visit, we shall ask your child to take part in musical and singing tasks designed to assess their musical abilities, along with some tests of hearing and speech. We shall ask you to complete some questionnaires relating to your experience of your child's hearing impairment and about your child's musical development and enjoyment. The aim of the study is to compare musical outcomes for groups of children, *not* to compare individual children. Taking part in the study will not affect the medical care that your child receives.

Further details are given in Part 2 of this information sheet.

Expenses and payments

For each visit, we will pay you an inconvenience allowance (£30); this is intended to contribute the cost of travel to the Ear Institute, childcare costs for siblings and to thank you for taking part. If visit is to take place within your home/alternative location the inconvenience allowance will be revised to reflect less travel expenses.

What are the other possible disadvantages and risks of taking part?

There are no risks in taking part. Some children may find the assessments boring. We will take breaks during the assessments to minimise this. It is possible you might find some of the questionnaires difficult to answer (for example, some parents find it difficult to estimate the quality of life of their child). You would need to travel and to give up some of your time in order to help us. We would prefer you not to bring siblings to the assessments, so you would need to arrange alternative care for them.

What are the possible benefits of taking part?

The information that we obtain from you and your child will help us to compare the perception of musical attributes for the different management options available for children of this age. This information will help clinicians and parents to make decisions about how best to enhance these musical abilities for hearing-impaired children in the future. We will send you a report after each visit to describe the results of the assessments of your child.

What if there is a problem?

Any complaint about the way you have been dealt with during the study or any adverse effect on you or your child caused by the study will be addressed. Detailed information is given in Part 2.

Will my taking part in the study be kept confidential?

Yes. We will follow ethical and legal practice and all information about you will be handled in confidence. The details are included in Part 2.

This completes Part 1 of the Information Sheet.

If the information in Part 1 has interested you and you are considering taking part, please read the additional information in Part 2 before making any decision.

PART 2

What will happen to my child and me if we take part?

Why would we have to visit the Ear Institute?

We have special equipment for measuring children’s listening and musical skills in the Ear Institute, however this equipment can be portable so alternative locations can be arranged

How would we travel to the Ear Institute?

The Ear Institute is close to Kings Cross and easy to reach by public transport. Parking in the local area is very limited. We will give you detailed instructions on how to find the Ear Institute.

What will happen at the Ear Institute?

We shall ask you to spend up 1 ½ hours with us at each appointment. We will assess your child’s musical abilities through pitch and rhythm discrimination tasks as well as a measurement of their singing voice. All tests have been selected to be appropriate for children of this age. We will have several breaks.

Sometimes it is difficult to interpret a young child's responses during the assessment. We will make voice-recording of part of the session, so that we can refer back if necessary.

We will ask you about your child's musical abilities and behaviours, and about your child's health and well-being in questionnaire form.

Sometimes, children are tired during a visit. If this happens, we may ask you to come back to the Ear Institute to repeat some of the assessments. We will pay you an inconvenience allowance designed to cover travelling costs for each visit. If it would be more convenient, it may be possible for one of the research team to visit you and your child at home/audiology or cochlear implant department to complete the assessments.

How long will the study go on?
You and your child would be involved in the study for up to 12 months.

What will happen if I don't want to carry on with the study?

You may withdraw from the study at any time and without giving a reason. If you withdraw, we will need to use the research data that we have gathered from you and your child up to that point.

What if there is a problem?

If you have a concern about any aspect of this study, you should speak to Sian Edwards who will do her best to answer your questions (telephone 07779269757).

Every care will be taken in the course of this study. However, in the unlikely event that you are injured by taking part, compensation may be available.

In the event that something goes wrong and you are harmed and this is due to someone's negligence then you may have grounds for a legal action for compensation against University College London. If you suspect that the injury is the result of the Sponsor's (University College London) or the hospital's negligence then you may be able to claim compensation. After discussing with your research doctor, please make the claim in writing to Dr Debi Vickers who is the Chief Investigator for the research and is based at the Ear Institute, 332-336 Gray's Inn Road, London. WC1X 8EE.The Chief Investigator will then pass the claim to the Sponsor's Insurers, via the Sponsor's office. You may have to bear the costs of the legal action initially, and you should consult a lawyer about this.

Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated by members of staff or about any side effects (adverse events) you may have experienced due to your participation in the research, the normal National Health Service complaints mechanisms are available to you. Please ask your research doctor if you would like more information on this. Details can also be obtained from the Department of Health website: http://www.dh.gov.uk

Will our taking part in this study be kept confidential?

Any information which you and your child give to the research team, and all of the measurements that are collected from you and your child, will be confidential. Some parts of your child's medical records and the data collected for the study will be looked at by authorised persons from your child's hospital and from the research team. All will have a duty of confidentiality to you and your child and nothing that could reveal your identity or the identity of your child will be disclosed outside the research team without your permission.

We will send you a report after each visit to describe the results of the assessments of your child. If you wish, we will send a copy of these reports to your child's audiologist. This is voluntary.

The research team will comply with the terms of the UK Data Protection Act 1988. They will store the information and the measurements in anonymous computer files and in locked filing cabinets. They will store names and address separately from other data. No names will be used when the research is written up. Your results will be kept for 20 years and will then be destroyed.

Some study documents may also be looked at by authorised representatives from University College London (UCL) Research & Development Unit to check that the study is being carried out correctly. Professional standards of confidentiality will be followed by the authorised representatives. The handling, processing, storage and destruction of their data will be in accordance with the UK Data Protection Act 1998 and UCL's Data Protection policy.

What will happen to the results of the research study?

We shall report the results at medical and scientific meetings and in medical and scientific journals. We will send you a one-page summary of the results of the study. Neither your identity, nor that of your child, will be disclosed when we report the results of the study.

Who is organising and funding the research?

The research is organised by the Ear Institute, University College London. None of the researchers, nor their institution, will be paid for including you and your child in the study. The research is funded by sponsorship from Advanced Bionics and PhonaK UK.

Who has reviewed the study?

All research in the NHS is looked at by an independent group of people, called a Research Ethics Committee, to protect your interests.

What should we do next?

If you would like to take part, please complete the tear-off slip at the end of this form and post/email it to Sian Edwards. Sian will contact your child's hospital or clinic to obtain some information form your child's medical records. Sian will then contact you to arrange a convenient time for you to visit the Ear Institute.

If you would like more information, please get in touch with Sian Edwards at the Ear Institute. She can be reached by telephone at 07779269757, by e-mail at sian.edwards@ucl.ac.uk, or by letter at the address at the end of this information sheet.

Thank you for considering taking part in this study.

- -

detach slip here

Music Perception and Production in Hearing Impaired Children

I am interested in taking part in this study. I give consent for the research team to access my child's medical records and to contact me.

Name of child:______________________________DOB:__________________

Ethnicity:_________________

Name of parent/guardian:____________________________

Signature of parent/guardian: _________________________ Date: _______

Address: ____

____

Telephone number: ______________________________Email

Address:_________________________________

Name of the hospital or clinic that looks after your child's hearing aids or cochlear

implants:____

Please detach this slip and return it to: Sian Edwards, UCL Ear Institute, 332-336 Gray's Inn Road, London, WC1X 8EE or email to sian.edwards@ucl.ac.uk

CHILDREN'S INFORMATION SHEET

Dear (participants name here),

My name is Sian. I would like to invite you to help me with my research.

"How do children hear and sing music?"

I want to know more about the way you hear and understand music –
as well as the way you sing

<u>What will happen?</u>

You will be invited to your hospital Audiology department my University…

I will carry out some music tasks with you.

For some of the games you will have to listen

For some you will have to sing

And others you will play games on a computer!

It won’t take too long!
And we will take lots of breaks so that you do not get tired.

You can ask me any questions.

You can always talk to me about it…

What happens when the research study finishes?

If you or parents/carers want

You will receive a letter telling you what the study found.

Thanks for reading!
Would you like to take part? (can be answered verbally)
Yes □ No □

Appendix 6: NSP Child Singing Assessment form

National Singing Programme: Child singing assessment framework (as at May 2008)