Characterizing Perception of Prosody in Children with Hearing Loss

By

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To parents who don’t let hearing loss stop them from helping their children achieve their desired outcomes in life

To my parents, Ajit & Anuradha whose perseverance to help my sister be an independent, confident adult who has hearing loss, is an inspiration

and

To my sister Manasi, who doesn’t let her hearing loss hold her back

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CHAPTER I

INTRODUCTION

The ability to understand and convey one's thoughts and emotions through spoken language is important for successful communication. The prosody of spoken language, including the intonation, rhythm, and stress present in speech, is important for language acquisition, language comprehension, and communication (Mehler et al., 1988; Nazzi, Bertoncini, & Mehler, 1998; Pierrehumbert, 2003; Wells, Peppé, & Goulandris, 2004). In typically developing children, this process of language acquisition and development is shaped by the perceptual and cognitive abilities of the child, as well as the quality and quantity of linguistic input received in the early years of life (Kuhl, 2004; Maurer & Werker, 2014). Thus, presumably, any alteration or disruption in sensory input or the quality and quantity of input could have a negative impact on natural development of spoken language.

Childhood hearing loss can limit a child's auditory access to the prosodic and phonemic features of speech that are necessary for language development. Delayed or degraded access to the speech spectrum can disrupt development of speech perception, language, and academics. In fact, children with hearing loss who have limited auditory access to the speech spectrum demonstrate deficits in speech perception and production (Davidson, Geers, Blamey, Tobey, & Brenner, 2011; Eisenberg, 2007), language development (Moeller, Tomblin, Yoshinaga-Itano, Connor, & Jerger, 2007; Spencer, Barker, & Tomblin, 2003), and social competence (Antia, 2011; Moeller, 2007; Most, Shina-August, & Meilijson, 2010). Restoring auditory access to the speech spectrum through hearing aids and cochlear implants has proven to be an effective intervention to minimize the negative impact of hearing loss and facilitate language development (e.g., Niparko et al., 2010; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000; Yoshinaga-Itano, Baca, & Sedey, 2010). Given that perception of prosodic features of language is shaped by a child's auditory experience of the language (Bijeljac-Babic, Serres, Höhle, & Nazzi, 2012; Gervain & Werker, 2013), it is of interest to explore the impact of childhood hearing loss on perception of prosodic features, particularly, stress, intonation, and rhythm. It is also of interest to examine how current hearing technology, hearing aids and cochlear implants, might minimize the negative impact of childhood hearing loss and facilitate perception of prosody, so that children with hearing loss perform comparably or "catch up" to their hearing peers.

The benefit of hearing technology and other interventions has often been examined in the context of improvement in speech perception, which is fundamental to language acquisition and comprehension. Most studies of speech perception have focused on phonemic features, and only a few have focused on prosodic features. Studies to date have demonstrated that, perception of stress and intonation in spoken language is deficient in children with hearing loss compared to children with normal hearing (Chin, Bergeson, & Phan, 2012; Lenden & Flipsen, 2007; Most & Peled, 2007; O'Halpin, 2010). It has been observed that individuals who use hearing aids might demonstrate better perception of stress and intonation than individuals who use cochlear implants (Most, Harel, Shpak, & Luntz, 2011; Most & Peled, 2007). These deficits have been attributed in part to the current limitations of access to prosodic features through cochlear implant technology (Limb & Roy, 2014; Most et al., 2011). Perception of rhythm by children with hearing impairments has been examined in the context of music, and on average is considered to be comparable to individuals with normal hearing (Drennan & Rubinstein, 2008; McDermott, 2004, Shirvani, Jafari, Matasaddi, Jalaie, Mohagheghi, & Tale, 2016).

The present study focused on perception of prosody in children with hearing loss by comparing perception of stress, intonation, and speech rhythm in school-age children with hearing loss and children with normal hearing. Potential differences in perception of prosody within the children with hearing loss who used different hearing technology – bilateral cochlear implants, or one cochlear implant and one hearing aid, hereafter referred to as “bimodal technology” - were also examined. In this chapter prosodic features and their role in early language acquisition and development are discussed, followed by a closer examination of perception and production of stress, intonation and rhythm in children with and without hearing loss, and the contribution of hearing technology to perception of prosody.

Prosody

A continuous speech stream of natural utterances in any language can be analyzed on the basis of its segmental and suprasegmental features. Segmental features are those related to the relatively distinct units of sound, vowels and consonants, whereas suprasegmental features tend to span across sound units. Suprasegmental features are frequently referred to as the prosody of a language, including characteristics such as intonation, stress, and rhythm (Nooteboom, 1997). Suprasegmental features can convey attributes of the talker’s gender, affect, intent (e.g., interrogative, declarative), as well as certain semantic features, such as distinctions between nouns and verbs (e.g., “rebel” vs. “rebel”) or compound words and phrases (e.g., “greenhouse” vs. “green house”; Nooteboom, Brokx, & De Rooij, 1976).

The prosody of an utterance is conveyed by variations in fundamental frequency, amplitude, and duration, and is reflected in the stress, rhythm, intonation, and tone of the utterance (Fletcher, 2010; Lehiste, 1970). The fundamental frequency is determined by the rate of vibration of the vocal cords, and is unique to each individual. The fundamental frequency of a speaker is perceived as pitch, with men having low-pitched voices, and females having higher-pitched voices. Generally, fundamental frequency has a range of 80-200 Hz, with average around 120 Hz in adult males, range of 180-400 Hz, with an average of 200 Hz in females, and range of 200-325 Hz, with an average of 270 Hz in children (Nooteboom, 1997; Perry, Ohde, & Ashmead, 2001; Sorenson, 1989). The amplitude is a measurement of sound energy, and is perceived as the volume or loudness of an utterance. The duration of a word is mostly set by the length of the syllable, perceived as being long or short. Variation in one feature is often accompanied by change in other features (Fletcher, 2010; Lehiste, 1970); for example, rise in fundamental frequency at the end of a question is accompanied by lengthening of the final syllable. This study examined the perception of stress, intonation, and rhythm in children with and without hearing loss.

Stress is reflected primarily by the change in duration and amplitude, along with fundamental frequency at the word-level (Fry, 1955; Pierrehumbert, 2003). In English, most words are trochaic, meaning that the stress is on the initial syllable. Stress can help indicate a change in meaning at the word level, e.g., <u>re</u>bel (noun) instead of re<u>bel</u> (verb; Fry, 1955); or at the phrase level, e.g., “greenhouse” or “green house” (Vogel & Raimy, 2002). Stress or emphasis on a particular word can also indicate the importance of a key word, and mark phrasal boundaries. The ***rhythm*** of a phrase, sentence or language is determined by the variations in duration and amplitude as well as fundamental frequency (Fletcher, 2010). Stress on certain words that can mark boundaries, which are preceded or followed by silences, influences perception of speech rhythm (e.g., “The boy (pause) is pouring juice (pause) in the glass,” and “The boy is pouring (pause) juice in the glass”.) In fact languages can be classified into rhythmic classes: stress-timed languages, e.g., English; syllable-timed languages, e.g., French; and mora-timed languages, e.g., Japanese (Nespor, Shukla, & Mehler, 2011). ***Intonation*** of an utterance is determined primarily by the variations in fundamental frequency, along with variations in duration, and amplitude (Fletcher, 2010). Examples include a rising fundamental frequency of a question compared to a falling fundamental frequency of a declarative statement, or an increase in amplitude to reflect anger or excitement. While the intonation of an utterance is related to variations in fundamental frequency, amplitude, and duration across the utterance, changes in fundamental frequency at the syllable level, perceived as variations in pitch, influence the tone of the utterance. In tonal languages such as Mandarin, changes in tone can reflect a change in meaning of the word. To Mandarin speakers, depending on the rise and fall of tone, “ma” can mean “mother”, “horse”, “hemp” or “scold”.

Adequate access to variations in fundamental frequency, amplitude and duration is important for perception of stress, rhythm, and intonation. Sensitivity to variations in fundamental frequency facilitates perception of intonation and stress, and limited sensitivity to variation in fundamental frequency might contribute to deficits in perception of intonation and stress (Chatterjee & Peng, 2008; Most et al., 2011). Individuals who have low-frequency hearing loss have demonstrated atypical pitch perception (Turner, Burns, & Nelson, 1983). Cochlear implant users who have limited sensitivity to fundamental frequency due to limitations of their cochlear implant technology also demonstrate deficits in perception of stress and intonation (O’Halpin, 2010; Torppa et al., 2014). However, researchers have discovered that when sensitivity to variations in fundamental frequency is limited, individuals with hearing loss might rely on cues of amplitude and duration for perception of intonation and stress (Chatterjee & Peng, 2008; Meister, Landwehr, Pyschny, Walger, & Wedel, 2009; O’Halpin, 2010). The reliance on alternative cues for perception and potential deficits in perception is discussed later in this chapter.

Role of Prosody in Language Acquisition

Perception of prosodic features plays an important role in language acquisition in infancy as well as language and literacy development in childhood. In infancy, perception of prosody facilitates attunement to the ambient language(s) and segmentation of a continuous speech stream, which are two important pre-cursors to spoken language development. In childhood, perception of prosody is important for language comprehension (Gordon, Shivers, et al., 2015), learning to read (Holliman et al., 2016), and interpreting the intent and affect of the talker. In fact, in the long term, deficits in perception of prosody can have a negative impact on language, literacy, and social competence (Gordon, Jacobs, Schuele, & McAuley, 2015; Goswami, Gerson, & Astruc, 2009; Holt, Yuen, & Demuth, 2016; Paul, Augustyn, Klin, & Volkmar, 2005).

In the first year of life, infants attend to various features of their ambient language and demonstrate a developmental pattern for discriminating between two languages based on the prosodic and phonemic features of the languages (for review see Maurer & Werker, 2014). By the end of the first year, infants are attuned to many of the prosodic and phonemic features of their ambient language, and are more likely to ignore objective variations in phonemic features and develop categorical perception of phonemic features that are meaningful in the ambient language, (e.g., Japanese infants' reduced sensitivity to the distinction between /r/ and /l/ which is not relevant in Japanese; Kuhl, 2004). Individual differences in this early developing attunement to phonemic features of ambient language, as measured by speech perception, predict vocabulary acquisition at two years of age (Tsao, Liu, & Kuhl, 2004), and reading outcomes at five years (Cardillo, 2010; Kuhl, 2010)

In the context of prosodic perception, infants progress from identifying and discriminating on the basis of broad features, such as rhythm of continuous speech, to discriminating on the basis of finer features, such as amplitude variations at the syllable level (Nazzi & Ramus, 2003; Soderstrom, Seidl, Nelson, & Jusczyk, 2003). In studies of infants who were habituated to speech from one language, and then exposed to a different language, infants changed their sucking behavior, indicating that they identified the difference in the rhythm of the two languages. Newborns discriminated between languages from different rhythm classes – English vs. Italian (Mehler et al., 1988); English vs. Japanese (Nazzi et al., 1998); Dutch vs. Japanese (Ramus, 2002). In a similar study, four-month-old infants discriminated between speech from native and non-native languages that were from the same rhythm class - Spanish vs. Basque (Molnar, Gervain, & Carreiras, 2014). Six-month-old infants perceived the subtler variations in prosodic features of duration and stress, and discriminated between continuous speech that had natural clausal boundaries from speech that had modified clausal boundaries (Soderstrom et al., 2003). In recent studies, bilingual infants perceived stress distinctions in both of their ambient languages, whereas monolingual infants only perceived stress distinction in their ambient language, indicating that auditory experience of ambient language(s) shapes perception of language-specific prosodic features (Bijeljac-Babic et al., 2012; Gervain & Werker, 2013). By nine months infants being to rely on phonemic and prosodic features and demonstrate attunement to the phonotactic probabilities that are essential for early word learning (Jusczyk, Luce, & Charles-Luce, 1994; Mattys, Jusczyk, Luce, & Morgan, 1999; Saffran, Newport, & Aslin, 1996). Together, these studies indicate that infants attune to the prosodic and phonemic features of their ambient language(s) within the first year and this attunement to native language is shaped by their perceptual experiences.

A large body of literature on normal hearing infants' ability to perceive prosodic features of an utterance reveals the importance of this fundamental skill in the process of language acquisition (Jungheim, Miller, Kühn, & Ptok, 2014; Nazzi et al., 1998; Nazzi & Ramus, 2003; Soderstrom et al., 2003). How children learn single words and grammatical rules of their ambient language from listening to continuous speech streams has been of great interest to researchers of child language acquisition. The phenomenon of "prosodic bootstrapping" posits that infants perceive and identify patterns in prosody, especially the rhythm of their native language, and use it as a template to segment the speech stream into phrases and clauses (Golinkoff & Alioto, 1995; Nazzi & Ramus, 2003; Soderstrom et al., 2003; Wanner & Gleitman, 1982). In other words, prosodic perception in the pre-lingual stage serves as a precursor for word segmentation in continuous speech, and subsequent development of vocabulary and grammar. In a recent study, infants with hearing loss who had less than six months of auditory input through their cochlear implants, demonstrated stress perception similar to younger infants, suggesting that while delayed, infants with hearing loss demonstrated the same milestones as hearing infants (Segal, Houston, & Kishon-Rabin, 2016). These studies suggest that infants with hearing loss might follow the same pre-linguistic milestones that facilitate language acquisition, as children with normal hearing.

An important characteristic of a typically developing infant's auditory experience is exposure to "motherese" or infant-directed speech. Prosodic features of infant-directed speech are distinct from adult-directed speech. Fernald & Simon (1984) reported that infant-directed speech is characterized by differences in duration (longer pauses and shorter utterances), and fundamental frequency modulation (higher pitch and extended intonation contours; Fernald & Simon, 1984). Infants demonstrate a preference for infant-directed speech presumably because it is acoustically salient and engaging (Cooper, Abraham, Berman, & Staska, 1997; Fernald & Kuhl, 1987; Fernald & Simon, 1984).

In a study involving mothers of children with congenital hearing loss who received cochlear implants, researchers discovered that these mothers modified their infant-directed speech to match their child's auditory and linguistic abilities (Bergeson, Miller, & McCune, 2006; Kondaurova & Bergeson, 2011; Kondaurova, Bergeson, & Xu, 2013). The characteristics of the infant-directed speech used by these mothers were similar to those of mothers whose babies had the same amount of auditory experience. How infants with hearing loss perceive the prosodic features of this infant-directed speech, and whether perception differs from infants with normal hearing has not yet been studied. However, repetitions of utterances during infant-directed speech were positively correlated with later vocabulary acquisition (Houston et al., 2012). During early intervention, clinicians and educators often use the strategy of "acoustic highlighting" to modify the prosodic features of an utterance, and to increase the salience of auditory input (Cole & Flexer, 2007; Easterbrooks, Lederberg, & Connor, 2010). Anecdotal data indicate that the strategy of "acoustic highlighting" can lead to better perception and production of speech.

Taken together, this body of research indicates that adequate perception of stress, intonation and rhythm is important for early language development. Additionally, prosodic sensitivity of preschoolers and school-age children, determined by evaluating perception of stress, intonation, and rhythm is associated with language and literacy outcomes in children with typical and atypical language development. In other words, deficits in perception of stress, intonation, and rhythm can negatively impact language, literacy, and social interactions. For children who experience congenital hearing loss, perception of prosody in the context of early language acquisition could be disrupted due to minimal or degraded access to sound. Additionally, limitations of hearing technology and other audiological factors might influence perception of specific prosodic features and thereby create deficits in perception of stress, intonation and rhythm.

Perception and Production of Stress

Variations in duration and amplitude, along with the fundamental frequency of an utterance are manifested as stress in spoken language. At the word level, stress is perceived as an emphasis on a syllable. In English, a stress-timed language, most words have word initial or strong-weak or trochaic stress (e.g., baseball), and only a few words have weak-strong or iambic stress (e.g., guitar). Perceiving and producing the stress patterns of syllables correctly has implications for comprehending and conveying meaning (e.g., content and content). At the phrase-level, stress is an important marker for determining clausal and phrasal boundaries (e.g., “greenhouse” vs. “green house”). Additionally, perceiving whether a certain word is emphasized has important implications for comprehending the emotion and the intent of an utterance. More recently perception of stress has been associated with proficiency on grammatical tasks (Wells et al., 2004), whereas deficits in perception of stress observed in children with dyslexia (Goswami et al., 2013) and children with autism spectrum disorder are hypothesized to contribute to the deficits in their language and literacy outcomes (Paul et al., 2005; Rapin, Trudeau-Fisette, Bellavance-Courtemanche, & Ménard, 2015).

Typically developing children can imitate and produce compound words with appropriate stress in early childhood (Clark, Gelman, & Lane, 1985), however perception of phrase-level stress doesn't fully develop until adolescence (Vogel & Raimy, 2002). Vogel and Raimy (2002) conducted a study examining school-age children's ability to discriminate between compound words and phrases (e.g., "greenhouse" vs. "green house"). They observed that older children demonstrated greater accuracy than younger children when discriminating between utterances that were phonemically congruent and only differed by the placement of stress. On average, 11-year-old children demonstrated adult-like accuracy (73%) when discriminating between compound words and phrases, while 5-, 7-, and 9-year-old children had lower accuracy of 54%, 58% and 61%, respectively. The younger children also demonstrated greater accuracy when identifying compound words (e.g., greenhouse) compared to phrases (e.g., green house). This bias towards compound words was attributed to the children's familiarity with compound words, and diminished, as children matured. Vogel and Raimy speculated that this bias is a result of children's lexical knowledge or familiarity with the vocabulary, leading to greater importance given to the phonemic features than the prosodic features (Vogel & Raimy, 2002). In other words, if the prosodic features of an utterance match a word or concept in the child's lexicon, the utterance is perceived based on its phonemic features, and prosodic features are not taken into account. A recent study supports this hypothesis by demonstrating that children are sensitive to phrasal stress (as evidenced by ERPs; McCauley, Hestvik, & Vogel, 2013), but are biased towards identifying the utterances as compound words (Vogel, Hestvik, & Pincus, 2013). This bias towards compound words was not observed when children were presented with novel or unknown compound words (e.g., wetscrew, redcup). In fact, children were more likely to interpret unfamiliar compound words at the surface level and identify it as a phrase, i.e., adjective + noun (e.g., wet screw, red cup; Vogel & Raimy, 2002). In summary, in children with normal hearing, response bias towards compound words diminishes, and perception of phrase-level stress becomes adult-like by adolescence.

O'Halpin (2010) examined perception of stress at the phrase-level in 5-16 year old English-speaking school-age children with hearing loss and those with normal hearing (O'Halpin, 2010). Similar to Vogel and Raimy's study, children were asked to discriminate between compound words (e.g., greenhouse) and phrases (e.g., green house). On this task, children with hearing loss who used cochlear implants were less accurate than children with normal hearing, but there was large variability (range of 47%-96%) in the accuracy of perception of stress at the phrase-level between the two groups. As in previous studies, older children with normal hearing demonstrated greater accuracy than younger children. Children with hearing loss also demonstrated greater accuracy as they matured, but did not demonstrate the same high accuracy as the children with normal hearing. Additionally, children with hearing loss were more likely to identify utterances as phrases, similar to a response pattern observed in typically developing children when the compound words were unfamiliar or novel (Vogel & Raimy, 2002). However, no additional conclusions can be drawn, as the children's familiarity with the vocabulary or overall linguistic proficiency was not reported.

Other studies have examined word- and phrase-level stress in children with hearing loss who speak Hebrew (Most & Peled, 2007) and Finnish (Torppa et al., 2014). Torppa and colleagues (2014) examined perception of stress at the phrase-level by comparing Finnish-speaking unilateral cochlear implant users and normally-hearing children's ability to discriminate between compound words and phrases (e.g., bluebell and blue bell in Finnish). All children were evaluated twice – initial study visit followed by a study visit after 14-17 months. Children who used cochlear implants were categorized as those who participated in music-related activity and those who did not between the two study visits. Cochlear implant users who were exposed to music performed similarly to children with normal hearing, but cochlear implant users who were not exposed to music demonstrated deficits in perception of stress, suggesting that intervention that increased a child's sensitivity to variations in prosody might contribute to perception of stress (Torppa et al., 2014). Most and Peled (2007) compared perception of word-level stress between children who differed by severity of hearing loss (severe or profound) and hearing technology used (hearing aids or cochlear implants). Children were asked to discriminate between words that differed by stress – initial stress or final stress. Compared to children with severe and profound hearing loss who used hearing aids, children with profound hearing loss who used cochlear implants demonstrated less accuracy when perceiving word-level stress, indicating that difference in perception of stress might be associated with access available through hearing technology (Most & Peled, 2007). However, none of the participants had a perfect score, and comparisons were not made with normal-hearing individuals in this study.

Perception of stress at the sentence level has been studied in several studies using a task where participants are presented with short sentences and asked to identify the word that was emphasized or was "most important". For example, "The BOY is painting the boat" and "The boy is painting the BOAT". Children who used cochlear implants performed similarly compared to children who had hearing loss and used hearing aids (Most & Peled, 2007), but were less accurate compared to children with normal hearing (O'Halpin, 2010; Torppa et al., 2014).

In addition to studies of the perception of stress, studies of its production have also been reported. Children with cochlear implants have demonstrated deficits in production of stress. In a non-word repetition task, 8-9 year old English-speaking cochlear implant users imitated the correct number of syllables 64% of the time and the correct pattern of primary stress 61% (Carter, Dillon, & Pisoni, 2002). Maintaining prosodic properties for words with the least number of syllables and initial syllable stress was easiest for these cochlear implant users. Lenden & Flipsen (2007) analyzed production of stress in six, 3-6 year old English-speaking children through conversational samples obtained over a period of three months. Adult listeners judged children's production of stress in spontaneous speech to be deficient, but phrasing, rate, loudness, and pitch were not deficient (Lenden & Flipsen, 2007).

Perception of word-, phrase-, and sentence-level stress has also been examined in pre- and post-lingually deafened adults who used cochlear implants or bimodal hearing technology. Similar to children, English-speaking adults demonstrated deficits in their ability to discriminate between compound words and phrases (Kalathottukaren, Purdy, & Ballard, 2015). Deficits were also observed in perception of word-level stress in Hebrew-speaking adults who used bimodal technology (Most et al., 2011). In perception of sentence-level stress, German-speaking adult cochlear implant users demonstrated lower accuracy than adults who had normal hearing (Meister et al., 2009), and Hebrew-speaking adult cochlear implant users demonstrated lower accuracy when they used unilateral cochlear implant only compared to when they used bimodal technology (Most et al., 2011). The findings from these studies suggest that even in adults who have had more exposure to speech than children, perception of stress is deficient. Adults who used a hearing aid in addition to a cochlear implant demonstrated greater sensitivity to stress, suggesting that auditory access available through hearing technology might contribute to perception of stress.

In summary, studies to date have demonstrated that perception of stress at the word-, phrase-, and sentence-level, is deficient in children and adults with hearing loss. It is possible that individuals who use hearing aids have better auditory access that allows greater sensitivity to stress. Additionally, perception of stress improves with maturity in children with normal hearing and children with hearing loss. In the present study, using a paradigm used in previous research (O'Halpin, 2010; Vogel & Raimy, 2002), the construct of stress was investigated at the phrase level, by asking participants to discriminate between compound words and phrases (e.g. "greenhouse" and "green house") through picture identification. The participants' ability to detect word boundaries based on stress might provide a starting point into investigating how children who have hearing loss might be different than children who have normal hearing in terms of phrasal discrimination.

Perception and Production of Intonation

The intonation of an utterance is determined primarily by the variation in fundamental frequency, and associated variations in duration and amplitude. Perceiving and producing the intonation of an utterance accurately is important for successful social interactions. Intonation signals the affect of the speaker – happiness, sadness, anger, etc., as well as the intent of the speaker – interrogative, declarative, exclamatory or even sarcasm. In typically developing children, perception of intonation, as evidenced by the ability to imitate utterances with rising and falling contours is still developing in pre-school age children (Loeb & Allen, 1993; Snow, 1998). Perceiving intonation to interpret the affect and intent of the speaker continues to develop into the childhood and even adolescence (Wells et al., 2004). In children on the autism spectrum, perception and production is deficient and can negatively affect social interactions (Frota, Butler, & Vigário, 2014). Additionally, there is a positive relationship between perception of intonation and proficiency on grammatical tasks (Wells et al., 2004). In children who have dyslexia, deficits in auditory processing of amplitude and frequency variation have been associated with poor phonological awareness (Goswami, Gerson, & Astruc, 2009) and subsequent reading deficits.

In children with hearing loss, several studies have explored perception and production of intonation to understand or convey the intent or the affect of the talker (Chin et al., 2012; Most & Peled, 2007; Nakata, Trehub, & Kanda, 2012; Peng, Tomblin, & Turner, 2008). Given the central role of fundamental frequency in conveying the intonation of the utterance and limited spectral resolution of cochlear implant technology (Limb & Roy, 2014; Zeng, 2004), studies have focused on examining perception of intonation in individuals who use cochlear implants. Peng, Tomblin, and Turner (2008) compared 26, 7-20 year old English-speaking cochlear implant users to 17 age-matched individuals with normal hearing, on their ability to identify the intent of an utterance based on its intonation. All hearing-impaired children wore at least one cochlear implant, which they had received before six years of age, and used for 5 – 23 years. It is unknown if any of the children used a hearing aid during this task. Most children had some exposure to sign language. In this task, ten sets of utterances that were phonemically congruent but prosodically incongruent (e.g. “The cat is in the kitchen.” and “The cat is in the kitchen?”), were presented by six talkers (three male, three female). Children heard one utterance per trial and identified whether it was a statement or question, i.e., if the sentence was “telling something” or “asking something”. The average accuracy of identification for the cochlear implant users was 70%, which was above chance, but significantly lower than the normal hearing group who demonstrated near perfect accuracy (97%). There was variability in the response accuracy of children with cochlear implants ranging from 50% accuracy to near perfect accuracy. This indicated that some children who used cochlear implants demonstrated greater sensitivity to intonation of utterances but others did not. Perception of intonation was significantly related to chronological age and duration of device experience or “hearing age”. It is important to note that in this study half of the children did not receive cochlear implant(s) until after 3.5 years of age and might have missed out on certain sensitive periods of auditory learning (Sharma, Dorman, & Spahr, 2002; Sharma, Gilley, Dorman, & Baldwin, 2007). Additionally, it is unknown if any of the children had progressive hearing loss and had auditory access through hearing aids prior to receiving cochlear implants.

In another study of 8-15 year old Hebrew-speaking children with hearing loss, researchers compared perception of intonation in children with severe and profound hearing loss who used hearing aids to children with profound hearing loss who used cochlear implants (Most & Peled, 2007). The intonation subtest from the Hebrew Speech Patterns Contrast (HeSPAC; Kishon-Rabin, Eran & Boothroyd, 1990) that comprised 24 sets of utterances that were phonemically congruent but prosodically incongruent (e.g., “*cham po.*” and “*cham po?*”) was administered. Children heard one utterance per trial and identified it as a statement or a question. Children with profound hearing loss who used cochlear implants demonstrated lower accuracy when identifying an utterance as a statement or question, compared to children with severe and profound hearing loss who used hearing aids, indicating that difference in perception of intonation might be associated with access available through hearing technology (Most & Peled, 2007). Additionally, children in all three groups had greater accuracy on the statement trials than the question trials. In other words, children with hearing loss, irrespective of the hearing technology used, were more likely to misidentify a question as a statement. There were no significant correlation between the cochlear implant users’ response accuracy and age at implantation or duration of device experience. However, the researchers note that most of the implant users received their cochlear implants “late”, i.e. after 6 years of age, and this might have impacted their proficiency in auditory only perception of intonation.

In addition to deficits in perception of intonation to convey intent, children who use cochlear implants have demonstrated deficits in production of intonation. Peng, Turner, and Tomblin (2008) also examined the production of intonation in 26 cochlear implant users and 17 children with normal hearing. The experimenter elicited statements and questions through a role-playing game. Adult listeners judged the intent of the child’s elicited utterance as being declarative or interrogative. The average accuracy for production of sentences as statements or questions for the cochlear implant users was above chance (73%), but lower than the normal hearing group (97%). In another study of 15, 6-10 year old children who used cochlear implants and received them before 3.5 years of age, the production of intonation was judged to be deficient compared to their normal hearing peers. Even after taking into account the duration of device experience cochlear implant users continued to lag behind their hearing peers (Chin et al., 2012). In a more recent study, compared to adolescents with normal hearing, adolescent cochlear implant users demonstrated deficits in their production of intonation, and general understanding of how prosody conveys intent (Holt et al., 2016). These studies indicate that compared to children with normal hearing, children who use cochlear implants are deficient in their production of intonation to covey intent.

Adults who used cochlear implants demonstrated similar deficits in identification of utterances as statements or questions, when compared to both adults who used bimodal technology (Most et al., 2011), and adults with normal hearing (Kalathottukaren et al., 2015; Meister et al., 2009). Meister and colleagues (2009) further explored the contribution of sensitivity to variation in fundamental frequency to perception of intonation by using synthetic stimuli, where fundamental frequency contours of the last syllable in the sentence were modified while maintaining the duration and amplitude. Cochlear implant users continued to demonstrate deficits in discriminating between statement and questions, indicating that they made limited use of the fundamental frequency cue when determining intonation of an utterance (Meister et al., 2009). In a similar study by Chatterjee and Peng (2008), English-speaking adult cochlear implant users were presented with sentences and bisyllabic words (e.g. popcorn) with modified fundamental frequency, and asked to identify the utterance as being a statement or a question. Cochlear implant users were more accurate at identifying stimuli with lower-initial fundamental frequency, than higher initial-fundamental frequency, indicating that they primarily relied on temporal cues of speech (Chatterjee & Peng, 2008).

In addition to the intent of the speaker, intonation of an utterance also indicates the affect of the speaker. Researchers have observed deficits in perception (Cullington & Zeng, 2011; Kalathottukaren et al., 2015; Nakata et al., 2012) and production (Chin et al., 2012; Nakata et al., 2012) of affect in cochlear implant users. Nakata, Trehub & Kanda (2012) observed that 5-13 year old Japanese-speaking cochlear implant users performed worse than their hearing peers on affect recognition of semantically neutral Japanese sentences, with the most difficulty in recognizing angry sentences. Imitation of sentences indicating disappointment and surprise was worse in cochlear implant users than the normal hearing group. In general, the cochlear implant users performed like chronologically younger normal hearing children, indicating that duration of auditory experience might play a role (Nakata et al., 2012). English-speaking children who used cochlear implants, who were asked to produce happy and sad utterances, were less accurate than their hearing peers (Chin et al., 2012). In post-lingually deafened adults, bilateral cochlear implant users demonstrated poorer performance in affect recognition compared to adults who used bimodal technology, and adults who had normal hearing, but the differences were not statistically significant (Cullington & Zeng, 2011), largely because of high inter-individual variability in the bimodal and bilateral group.

In summary, perception and production of intonation, which is used to convey intent and affect, is deficient in children and adults who use cochlear implants. While factors such as age at implantation and hearing age might contribute to perception of intonation, studies to date have attributed the deficits in perception of intonation to the limited spectral resolution available through cochlear implants. It is interesting to note that in adults, in spite of substantial auditory experience, and presumably "normal" prosodic perception prior to onset of hearing loss, the auditory signal provided through cochlear implants was not sufficient to restore perception of intonation, suggesting that the limitations of the technology play a role in perception of prosody. In this study, the construct of intonation as it conveys intent, will be investigated in children who use bilateral cochlear implants and bimodal hearing technology, using a statement-question identification task similar to the one used by Peng, Tomblin, and Turner (2008). The results of this task will provide insight into the participants' ability to perceive the intent of the talker based on the intonation of the utterance and when phonemic or semantic cues, such as wh- questions are limited.

Perception and Production of Rhythm

Rhythm is a construct most commonly associated with music, and refers to the periodic repetitions within the music. In the context of continuous speech in spoken language, the rhythm of an utterance is influenced by the words that are stressed or emphasized, and the phrases or chunks of words that are separated by pauses (Fletcher, 2010; Hausen, Torppa, Salmela, Vainio,

& Särkämö, 2013). Often variations in duration and amplitude of utterances are perceived as variations in rhythm. Perceiving the rhythm of a continuous speech stream or language, and identifying it as familiar/ unfamiliar, or native/ non-native is an early developing skill observed in infants (Nazzi et al., 1998; Nazzi, Jusczyk, & Johnson, 2000; Nazzi & Ramus, 2003; Ramus, 2002) as well as non-human primates (Tincoff et al., 2005). Newborns can discriminate between languages that belong to different rhythm classes (stress-timed, syllable-timed, mora-timed) when the continuous speech stimuli are low-pass filtered at 400Hz, indicating that prosodic cues provide adequate information to allow for discrimination based on speech rhythm (Nazzi, 1998). By the end of the first year, infants discriminate between native and non-native language(s), within and outside rhythm classes, such as English and French, on the basis of prosodic and phonemic features (for review see Kuhl, 2004; Maurer & Werker, 2014).

Awareness and sensitivity to speech rhythm continues to influence language and literacy development. In typically developing 6-year-old children, proficiency in rhythm perception, as evidenced by their ability to compare utterances and identify whether they matched on the basis of speech rhythm was linked to morpho-syntactic skills (Gordon, Shivers, et al., 2015). It has been proposed that rhythmic sensitivity is correlated with language and reading outcomes in typically developing children as well in children who have deficits in reading (Gordon, Jacobs, et al., 2015; Goswami et al., 2009; Wood & Terrell, 1998). Given that rhythm perception is an early emerging skill, and important for language acquisition and development, it is interesting to consider it in the context of children who have congenital hearing loss and might not have adequate auditory experience and/or auditory access through hearing technology, to develop age-appropriate perception of rhythm.

Currently, little is known about hearing impaired children’s perception of speech rhythm in the context of early language acquisition and later language development. In one study which compared infants who were exposed to American Sign Language (ASL) and those who were not, infants who had exposure to sign language discriminated between “hand shapes” that were meaningful in ASL and those that were meaningless in ASL, suggesting that even children who are learning a visual language develop attunement to their ambient language (Baker, Golinkoff, & Petitto, 2006; Palmer, Fais, Golinkoff, & Werker, 2012).

Perception and production of rhythm in children and adults who have hearing loss has been examined mostly in the context of music perception in cochlear implant users. When asked to sing familiar songs from memory, 5-10 year old, Japanese-speaking children who used cochlear implants were equally accurate in maintaining the rhythm of the song as compared to children who had normal hearing (Nakata, Trehub, Mitani, & Kanda, 2006). In a more recent study, children with cochlear implants demonstrated that they could find and move in accordance to music when the primary cue was a rhythm presented on the drum (Phillips-Silver, 2014).

On a rhythm-matching task, post-lingually deafened adult cochlear implant users performed similarly to adults who had similar degrees of hearing loss and used hearing aids (Looi, McDermott, McKay, & Hickson, 2008). A review of the literature indicates that adequate perception of duration and amplitude is accessible through current hearing technology and facilitates perception of musical rhythm in individuals who have hearing loss at a level similar to their normally-hearing peers (Drennan & Rubinstein, 2008; Limb, 2006; Limb & Roy, 2014; Limb & Rubinstein, 2012; McDermott, 2004).

Perception of speech rhythm has not yet been investigated in children with hearing loss. In this study, the ability of children with and without hearing loss to detect and match a low-pass filtered utterance to one of two unfiltered utterances based on their rhythm was examined. Additionally, their ability to discriminate between their native language – English, and non-native language – French, which are in different rhythm classes, was also examined. This is a first step towards examining the impact of childhood hearing loss on the ability to perceive underlying rhythm in non-musical utterances. Findings from the present study could inform future studies examining rhythm-based language discrimination in infants and young children who have hearing loss, as well as studies examining factors affecting language and literacy outcomes in children with hearing loss.

Hearing Technology and Perception of Prosody

As noted earlier, the prosody of an utterance is determined by variations in fundamental frequency, duration and amplitude. Access to temporal features of speech to identify variation in duration and amplitude, and spectral features of speech to identify variations in fundamental frequency, is necessary to detect and identify auditory cues of prosody (Rosen, 1992). The literature reviewed thus far demonstrates deficits in perception of prosodic features in children with hearing loss. Given the variability in perception of prosodic features observed in this population, it is important to examine the contribution of audiological factors, such as age at amplification, duration of auditory experience, and access to the auditory spectrum via hearing technology.

Advances in hearing technology, especially cochlear implant technology, have allowed children with profound hearing loss to develop spoken language (Niparko et al., 2010; Svirsky et al., 2000). Cochlear implants can provide adequate access to the speech spectrum and facilitate speech perception and spoken language development, but continue to have some limitations

(Limb & Roy, 2014; Zeng, 2004). While current cochlear implants provide adequate access and sensitivity to variations in duration and amplitude, due to limitations in spectral and temporal resolution, they do not provide adequate access to variations in fundamental frequencies (Chatterjee & Peng, 2008; Limb, 2006; Meister et al., 2009). Many pre- and post-lingually deafened cochlear implant users have limited sensitivity to variation in fundamental frequencies and demonstrate deficits in perception of pitch (Limb & Roy, 2014; Looi et al., 2008; McDermott, 2004), and research to improve access and reduce this deficit is ongoing (Crew, Galvin, & Fu, 2012; Fu, Hsu, & Horng, 2004; Green, Faulkner, Rosen, & Macherey, 2005; Han et al., 2009; Lan, Nie, Gao, & Zeng, 2004; Limb & Rubinstein, 2012). One intervention that could improve perception of pitch is electric and acoustic stimulation, i.e. using a hearing aid in addition to a cochlear implant in the same ear, or bimodal technology, i.e., using a unilateral cochlear implant with hearing aid in the contralateral ear (Gifford et al., 2015; Gifford, Dorman, McKarns, & Spahr, 2007; McDermott, 2011; Sheffield, Simha, Jahn, & Gifford, 2016).

Cochlear implants provide electrical stimulation to the auditory nerve by converting wideband acoustic stimuli to narrowband channels. Hearing aids amplify the auditory input providing acoustic hearing without substantially changing its temporal and spectral features. When cochlear implant users have access to an acoustic signal through hearing aids, their perception of speech, prosody, and music improves (Cullington & Zeng, 2011; Gfeller, Olszewski, Turner, Gantz, & Oleson, 2006; Gifford, Dorman, McKarns, & Spahr, 2007; Most, Harel, Shpak, & Luntz, 2011). It has been hypothesized that acoustic access to low-frequency information contributes to perception of variations in fundamental frequency and pitch. Individuals who have low-frequency hearing loss demonstrated atypical pitch perception (Turner et al., 1983), suggesting that access to low-frequency information is important to perception of pitch. Gfeller et al. (2006) observed that individuals who had access to low-frequency acoustic hearing through a hearing aid in addition to their cochlear implants, had better perception of pitch and melody compared to individuals who used cochlear implants only (Gfeller et al., 2006). Children with profound hearing loss who used hearing aids demonstrated greater accuracy in perception of stress and intonation than children who used cochlear implants (Most & Peled, 2007). In a study of adult bimodal technology users, Most, Harel, Shpak, and Luntz (2011), observed better perception of stress and intonation when individuals used bimodal technology compared to the unilateral cochlear implant only. Moreover, aided and unaided thresholds of the contralateral ear at 250 Hz and 500 Hz, in these bimodal users were significantly correlated with accuracy on tasks of stress and intonation, indicating that access to low-frequencies might be an important contributor to prosody perception (Most et al., 2011). However, Cullington and Zeng (2011) observed that even though adult bimodal technology users were objectively more accurate than bilateral cochlear implant users, the difference in response accuracy was not statistically significant, suggesting that some bilateral implant users were comparable to bimodal technology users in their perception of pitch (Cullington & Zeng, 2011).

This study further explored the contribution of hearing technology to perception of prosody in school-age children with hearing loss who used bilateral cochlear implants, and children with hearing loss who used bimodal technology. These groups of children tend to have fairly similar early development with respect to the severity and duration of unaided hearing loss. Therefore, differences in prosodic ability between these groups might be attributed largely to their differential access to prosodic information via the hearing devices they used. Additionally, given that early amplification and longer duration of auditory experience have been linked with better outcomes for children with hearing loss (e.g., Ching et al., 2008; Niparko et al., 2010;

Yoshinaga-Itano, 2003) the contribution of age at implantation and duration of auditory experience or “hearing age” to perception of prosody was also examined.

Research Questions and Hypotheses

The purpose of this study was to characterize perception of prosody, especially stress, intonation, and rhythm in children with and without hearing loss, and explore the contribution of hearing technology. The first research aim was to characterize perception of stress, intonation, and rhythm in spoken language. For this purpose, the research questions were:

1. Are there differences between children with hearing loss and children with normal hearing in their perception of stress, intonation, and rhythm?
2. Are there differences between children with hearing loss, who differ by hearing technology used – bilateral cochlear implants vs. bimodal technology in their perception of stress, intonation, and rhythm?

The second research aim was to examine how attuned children are to the underlying prosodic features of their native language. For this purpose, the research question was: Are there differences between children who have hearing loss and children who have normal hearing in their ability to identify the language of an utterance based on phonemic and prosodic features?

For the first research aim, it was hypothesized that similar to prior research, children with hearing loss would demonstrate deficits in perception of stress and intonation, which rely on perceiving the subtle variations in duration, intensity, and fundamental frequency, but not in perception of rhythm, which primarily relies on perceiving variations in duration. It was expected that children with cochlear implants would demonstrate greater deficits in perception of stress and intonation compared to children who used bimodal technology. For the second research aim, it was hypothesized that children with normal hearing would outperform children with hearing loss in identifying the language of the utterance when minimal phonemic cues were available, indicating that children with hearing loss, bilateral implant users as well as bimodal technology users, were not as attuned to the prosodic features of their native language as their hearing peers. It is expected that characterizing and comparing perception of prosody in children who differed by their hearing status and the hearing technology used, could lead to better understanding of potential differences and factors that might contribute to these differences, which could be important for developing interventions for children with hearing loss.

CHAPTER II

METHODS

Participants

Thirty children between 8 and 16 years of age were recruited. Children were recruited into three groups based on their hearing status and the hearing technology they used. Ten children (*M* = 11 years, 5 months, range = 8 to 16 years; 2 males, 8 females) who had pre-lingual hearing loss and used bilateral cochlear implants were in the "bilateral" group. Ten children (*M* = 12 years, 4 months, range = 9 to 15 years; 4 males, 6 females) who had pre-lingual hearing loss and used bimodal technology, i.e., unilateral cochlear implant, and hearing aid in contralateral ear, were in the "bimodal" group. Ten children (*M* = 11 years, 2 months, range = 8 to 16 years; 3 males, 7 females) who had normal hearing were in the "normal hearing" group. Participants scored within the average or above average range on the Test of Non-Verbal Intelligence - 4 (M = 103, range = 87 to 128; TONI-4). On the TONI-4, participants in the bilateral group had mean score of 103, range = 87-128; participants in the bimodal group had mean score of 101, range = 87-114; and participants in the normal hearing group had mean score of 105, range = 91-117. By parental report, all participants spoke English as the primary language at home. Five participants (one from bilateral, two from bimodal, and two from normal hearing group) had some exposure to a second spoken language, primarily through second language instruction at school, but none were fluent in the second language. Five participants (two from bilateral, and three from normal hearing group) had some exposure to American Sign Language (ASL) and two participants from the bimodal group reported being fluent in ASL. See Table 2.1 for participant characteristics.

Table 2.1. Characteristics of participants in the bilateral, bimodal, and normal hearing groups

Group	ID	Age (months)	Gender	Race	Non verbal IQ
BILATERAL	CI 1	99	Female	White	106
	CI 2	101	Female	African American	107
	CI 3	103	Female	White	96
	CI 4	109	Female	White	104
	CI 5	121	Female	White	103
	CI 6	140	Male	White	110
	CI 7	163	Female	White	128
	CI 8	163	Male	White	100
	CI 9	173	Female	White	91
	CI 10	193	Female	White	87
BIMODAL	BT 1	109	Female	African American	87
	BT 2	114	Female	White	104
	BT 3	124	Female	Biracial	101
	BT 4	130	Male	White	107
	BT 5	143	Female	White	104
	BT 6	163	Female	African American	93
	BT 7	168	Male	White	95
	BT 8	169	Male	White	114
	BT 9	172	Female	Asian	95
	BT 10	188	Male	White	106
NORMAL HEARING	NH 1	101	Male	Biracial	117
	NH 2	101	Female	White	101
	NH 3	106	Female	Biracial	114
	NH 4	112	Female	White	115
	NH 5	130	Female	White	109
	NH 6	136	Female	White	94
	NH 7	137	Female	White	97
	NH 8	153	Male	Biracial	102
	NH 9	171	Female	White	114
	NH 10	196	Male	White	91

Non verbal IQ assessed using TONI-4 = Test of Non-Verbal Intelligence-4 (M = 100, SD = 10)

As shown in Table 2.2, for participants in the bilateral group, average age at diagnosis of hearing loss was 13 months, range of 1 to 31 months, and average hearing age, specifically duration of low-frequency access through hearing technology, was 9 years, 4 months, range of 5 to 14 years. In this group low-frequency pure tone threshold average (i.e., average of thresholds at 250, 500, and 100 Hz of the “better” ear) while wearing cochlear implants was 24 dB, range of 12 dBHL to 28 dBHL. One participant had thresholds below 20 dBHL, which could be indicative of a limited dynamic range, and thereby reduced access to the speech spectrum. For participants in the bimodal group, average age at diagnosis of hearing loss was 14 months, range of 1 to 44 months, and average hearing age, was 10 years, 10 months, range of 5 to 14 years. In this group, low-frequency pure tone threshold average while wearing the unilateral cochlear implant was 27 dBHL, range of 23 dBHL to 35 dBHL, and unaided low-frequency pure tone threshold average for the contralateral ear was 72 dBHL, range of 57 dBHL to 83 dBHL, and all participants’ hearing aids met DSL targets at 250 and 500 Hz. Pre-operative unaided thresholds for the ear that was implanted first were compared between the bilateral group and the bimodal group. However only data from nine of the bilateral group participants and six of the bimodal group participants were available. Two-tailed t-test conducted to compare pre-operative unaided thresholds indicated that the two groups were significantly different ($p > .05$) when low-frequency pure tone average thresholds were compared but not when pure tone average thresholds were compared. Unaided thresholds for the ear that was implanted second for the bilateral implant users, and the ear on which bimodal participants used a hearing aid were also compared. Data for all participants in both groups were available, and indicated significant differences ($p > .05$) between low-frequency pure tone average thresholds and pure tone average thresholds of the two groups. This indicates that participants were significantly different from an audiological perspective and the bimodal group had better underlying auditory functioning in the hearing aid ear. Participant recruitment and study participation followed procedures approved by the Institutional Review Board at Vanderbilt University. Participants who completed the study received a $30 gift card to a department store.

Test Setting

All data were collected in a single two-hour study visit at the Vanderbilt Bill Wilkerson Center. Eligibility and experimental measures were conducted in a 13 ft. x 12 ft. sound treated room, where the background sound level was less than 28 dBA. For the prosody related experimental measures participants sat 3 ft. from a Bose loudspeaker and computer screen (Samsung, 20-inch flat-panel screen). Tasks were programmed and presented through E-Prime software (E-Prime Professional 2.0.10.353). The experimenter sat next to participants and recorded responses. All auditory stimuli were routed through a GSI 61 clinical audiometer and presented at 60 dBA +/- 0.5 dB.

Table 2.2. Audiological characteristics of participants in the bilateral group

Group	ID	Age	H. Age	Age at Diag	Age at Amp	Low-Freq. PTA (dB)		Hearing Device	Strategy
						Right	Left		
BILATERAL	CI 1	99	84	15	15	20	23	Cochlear	ACE
	CI 2	101	68	31	33	22	22	Cochlear	ACE
	CI 3	103	76	24	27	23	28	Cochlear	ACE
	CI 4	109	108	1	1	28	30	Cochlear	ACE
	CI 5	121	106	11	15	32	23	AB	Hi Res 90K
	CI 6	140	114	15	26	25	33	Cochlear	ACE
	CI 7	163	149	10	14	25	27	Cochlear	ACE
	CI 8	163	149	1	14	28	45	AB	Hi Res Optima P
	CI 9	173	171	1	2	28	30	Cochlear	ACE
	CI 10	193	165	19	28	12	18	Cochlear	ACE

H.Age = hearing age, i.e., duration of how long the child has had access to sound, Age at Diag = age at diagnosis, Age at Amp = age at amplification, Hearing Device = manufacturer of hearing technology used, AB = Advanced Bionics

Table 2.3. Audiological characteristics of participants in the bimodal group

Group	ID	Age	H. Age	Age at Diag	Age at Amp	Low-Freq. PTA (dB)		Hearing Device	Strategy
						CI	HA		
BIMODAL	BT 1	109	62	44	47	27	62	Rt. – Phonak Lt. – Cochlear	ACE
	BT 2	114	89	25	25	28	57	Rt. – Phonak Lt. – Cochlear	ACE
	BT 3	124	102	21	22	23	83	Rt. – Cochlear Lt. - Phonak	ACE
	BT 4	130	125	2	5	28	78	Rt. – Phonak Lt. – Cochlear	ACE
	BT 5	143	119	18	24	28	80	Rt. – Cochlear Lt. – Phonak	ACE
	BT 6	163	135	26	28	23	75	Rt. – Cochlear Lt. – Phonak	ACE
	BT 7	168	164	2	4	28	77	Rt. – Phonak Lt. – AB	HiRes 90K
	BT 8	169	167	2	2	23	60	Rt. – Phonak Lt. – Med-El	NA
	BT 9	172	171	0	1	35	83	Rt. – Phonak Lt. – AB	HiRes Optima P
	BT 10	188	164	3	24	25	65	Rt. – Phonak Lt. – AB	HiRes Optima P w/ Fidelity 120

H.Age = hearing age, i.e., duration of how long the child has had access to sound, Age at Diag = age at diagnosis, Age at Amp = age at amplification, CI = cochlear implant, HA = hearing aid, Hearing Device = manufacturer of hearing technology used, AB = Advanced Bionics

Eligibility Measures

The following measures were administered to determine eligibility for this study. The study recruitment was advertised via flyers in clinic, social media, and direct contact with parents. Prior to the visit, parents of potential participants completed a short questionnaire (see Appendix A) through an online survey procedure (REDCap) or by phone. Information related to their child's hearing status, language(s) spoken at home, and any additional diagnosis was collected. For children who were reported to have hearing loss, information about age at diagnosis and hearing technology was also collected. The principal investigator reviewed parents' responses and the child's medical records to document hearing status, severity of hearing loss, duration of auditory experience through hearing technology, and benefit from hearing technology as indicated by aided thresholds, unaided thresholds, and speech perception scores. For the bimodal group participants, hearing aid benefit at 250Hz and 500Hz was verified by ensuring hearing aid programming met DSL 5.0 child standards at these frequencies. Out of all the potential participants, two children with hearing loss, who did not use bilateral hearing technology, or did not receive adequate benefit from their hearing aid in the low frequencies were excluded. Additionally, four children (one who used bimodal technology and three who had normal hearing) who were reported to be bilingual, as well as two children (one who used bimodal technology and one who had normal hearing) who had an additional diagnosis of visual impairment, cognitive deficits, or developmental disabilities were excluded from this study. A total of 30 children met the eligibility criteria for this study and participated.

During the study visit, eligibility measures for hearing, vision, and cognitive function were administered. Hearing screenings (i.e., detection of pure tones of 20 dB HL at 500 – 4000 Hz) were administered to the participants form the normal hearing group. The Phonak Ling 6 test (Scollie & Glista, 2012) was administered to the participants in the bilateral and bimodal groups while wearing their hearing technology in both ears. Detection thresholds for each of the six Ling sounds were documented. Additionally, for participants in the bimodal group, unaided thresholds for the hearing aid ear were obtained and hearing aid programming was verified by an audiology student trained in these procedures. Vision screening was conducted for all participants using the Tumbling E chart, which is a measure of visual acuity approved by the American Academy of Ophthalmology (American Academy of Ophthalmology, 2012). Children who had normal or corrected-to-normal vision passed this screening. Finally, the Test of Non-Verbal Intelligence-4 was administered. Participants who passed the hearing and vision screening, and scored in the average or above average range on the TONI-4 were included in the study. Any evaluations of word-level speech perception or sentence recognition skills on the day of the study visit were not administered due to time constraints of the study visit.

Experimental Measures

Five experimental measures were administered:

1. Digit span subtest from Wechsler's Intelligence Scale for Children - IV
2. Perceiving Stress: Word-Phrase Identification Task
3. Perceiving Intonation: Statement-Question Identification Task
4. Prosody Matching Task
5. Native Language Identification Task

The Digit Span subtest from the *Wechsler's Intelligence Scale for Children-IV* (WISC-IV; Wechsler, 2003) was administered to evaluate short-term memory and working memory. WISC-IV is a standardized cognitive assessment that is normed on children between 6 to 16 years of age. The digit span subtest, which includes backward and forward digit span tasks, was administered to all participants.

The *Perceiving Stress: Word-Phrase Identification task* was based on tasks implemented by Vogel & Raimy (2002) and O'Halpin (2010) in previous studies (O'Halpin, 2010; Vogel & Raimy, 2002). This task evaluated the listener's ability to discriminate between subtle markers of stress, based on variations in duration, amplitude, and fundamental frequency at the phrase level. Participants were asked to discriminate between pairs of compound words and phrases (e.g., "greenhouse" and "green house"). On the computer screen, participants viewed two images depicting a pair of compound word and phrase, placed side by side, with the numbers "1" and "2" underneath the left and right picture respectively (Figure 2.1). Participants were asked to listen and follow an auditory only direction (e.g., "Show me the greenhouse." or "Show me the green house.") and respond by identifying the picture corresponding to the utterance as “1” or “2”. Two male talkers and two female talkers recorded utterances for this task. Six pairs of tokens (blackboard – black board, bluebell – blue bell, bluejay – blue J, greenhouse – green house, hotdog – hot dog, White House – white house) were presented four times for a total of 24 trials (Figure 2.2). Each token was presented once by a male and once by a female talker in constrained random order. The order constraint ensured that the same token spoken by two different talkers (e.g. “greenhouse” and “greenhouse”), or two versions of the tokens (e.g., “greenhouse” and “green house”) were not presented in consecutive trials. See Appendix B for additional details regarding stimulus preparation and presentation.

Figure 2.1. Word-phrase identification task trial example

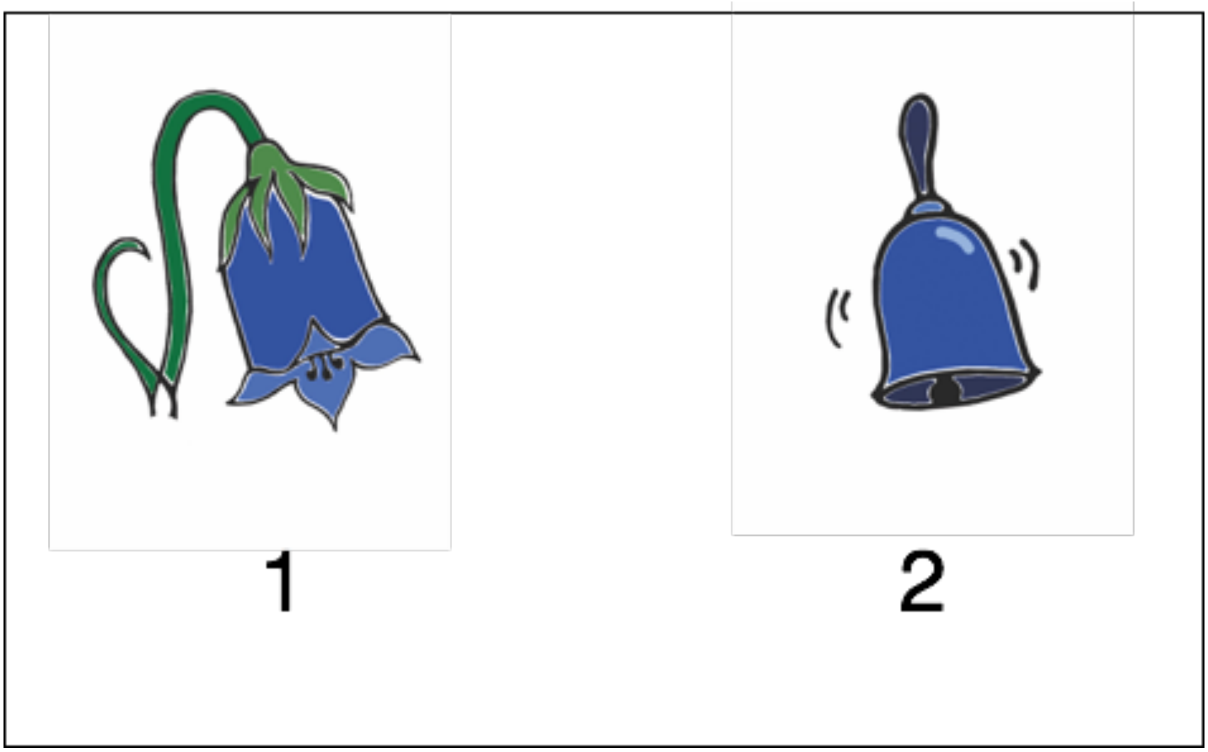
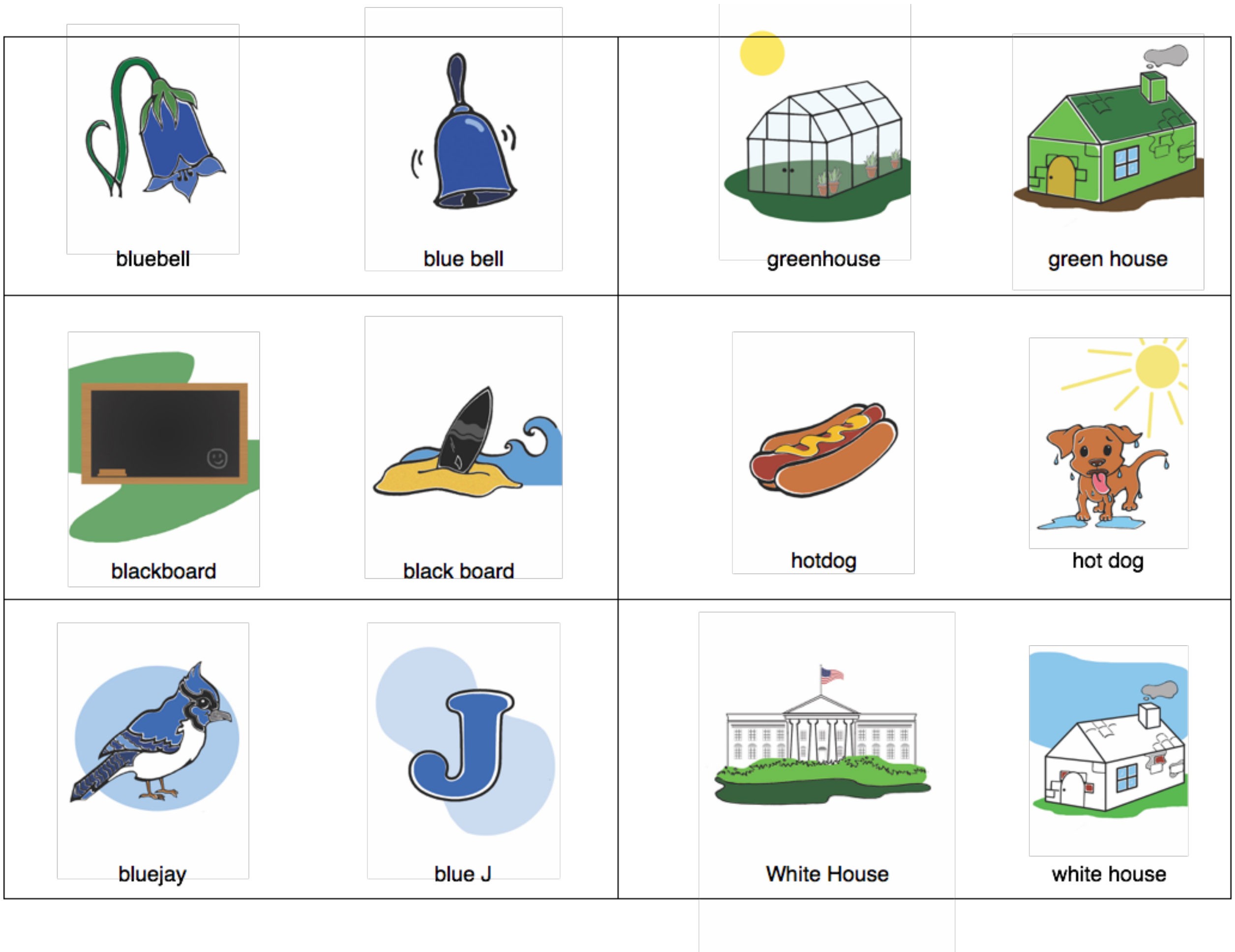


Figure 2.2. Stimuli used in the word-phrase identification task.



The *Perceiving Intonation: Statement-Question Identification task* was similar to the intonation perception task administered by Peng, Tomblin and Turner (2008). This task evaluated the listener's ability to identify the variations in intonation of the final word of an utterance to determine the intent of the talker. Participants were asked to identify the utterance as "statement", i.e. telling something, or "question", i.e., asking something, when presented with phonemically congruent but prosodically incongruent sentences (e.g., "The cat is in the kitchen." "The cat is in the kitchen?"). The four talkers from the previous task recorded stimuli for this task. Ten unique statements and their corresponding questions were presented in a constrained random order, once by a male talker and once by a female talker for a total of 40 trials. The order constraint ensured that an item (e.g., either of the circus sentences) did not occur on consecutive trials. Participants in the bimodal group completed this task twice – once while wearing bimodal technology, and once while wearing cochlear implant only. They completed 40 trials in each listening condition. The conditions were counterbalanced across participants. See Appendix C for additional details regarding stimulus preparation and presentation.

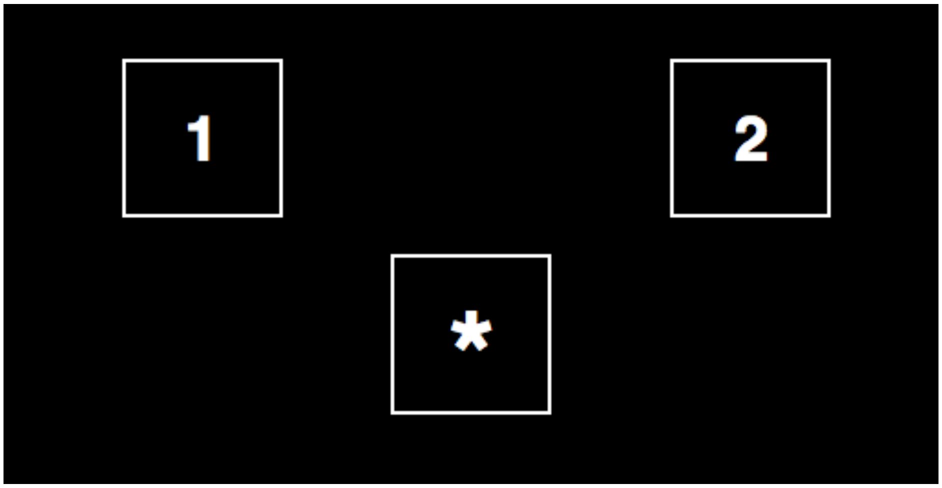
The *Prosody Matching task* was based on the rhythm matching task administered by Wood and Terrell (1988), and evaluated the listener's ability to match utterances based on their underlying prosody, i.e. differences in fundamental frequency, duration, and amplitude. Participants were asked to match one low-pass filtered utterance to one of two unfiltered utterances. Participants saw a dark screen. The utterances were presented along with a visual. During the 1st presentation, participants saw the number "1" in the top left area and heard the first unfiltered utterance. During the 2nd presentation, participants saw the number "2" in the top right area and heard the second unfiltered utterance. During the 3rd presentation, participants saw a picture of a star in middle and heard the low-pass filtered utterance, which matched one of the two previously presented utterances (see Figure 2.3).

Participants responded by indicating whether the low-pass filtered utterance matched unfiltered utterance "1" or "2". The unfiltered utterances consisted of one statement (e.g., "The boy is pouring juice in the glass.") and one of three foils:

a) Question (e.g., "The boy is pouring juice in the glass?"),
b) Short statement (e.g., "The boy is pouring juice."),
c) Alternative pausing (e.g., "The boy is pouring [pause] juice in the glass.").

The low-pass filtered utterances were filtered at 400 Hz, and equalized to unfiltered utterances based on “Perceived Loudness” in Adobe Audition. Two male talkers and two female talkers recorded stimuli for this task. Each unfiltered statement was presented twice along with one of the three foils, once by a male talker and once by a female talker, for a total of 48 trials. Talker gender, correct response position (1 or 2), correct response type (statement or foil), and type of foil (question, short statement, or alternative pausing) were equiprobable. See Appendix D for additional details regarding stimulus preparation and presentation.

Figure 2.3. Prosody matching task trial example



The *Language Identification task* evaluated the ability to identify the language of the utterance based on its phonemic and prosodic features. Participants were presented with short sentences in English or in French and were asked to identify whether or not the utterance was in English. Two female talkers who were proficient in English and French recorded stimuli for this task. Four blocks of 12 trials each were presented, for a total of 48 trials. Each trial consisted of six sentences in English and their French counterparts. The second and fourth block of stimuli consisted of sentences that were low-pass filtered at 700 Hz and equalized to the unfiltered utterances based on “Perceived Loudness” in Adobe Audition. (Adults with normal hearing piloted this task with utterances low-pass filtered at 400 Hz. They performed at chance level and reported that they could not hear any differences between the two languages. The task was re-administered with utterances low-pass filtered at 700 Hz and adults demonstrated improved accuracy but were not at ceiling.) See Appendix E for additional details regarding stimulus preparation and presentation.

Presentation sequence of the prosody-related tasks was determined by using a Latin Squares design to prevent first and second order effects.

CHAPTER III

RESULTS

This study characterized perception of prosody in children with normal hearing and children with hearing loss. The aims were to: (1) compare perception of prosody in children with and without hearing loss; (2) compare performance of children who use bilateral cochlear implants and children who use bimodal hearing technology (unilateral cochlear implant, with hearing aid in the contralateral ear); and (3) investigate the contribution of low-frequency access to perception of certain aspects of prosody. Results from the digit span subtest are provided followed by results from the four primary tasks. For repeated measures findings, sphericity violations were handled by using the Huynh-Feldt adjustment of degrees of freedom. Effect sizes are reported as partial eta-squared. Additionally, responses were converted to hit rates and false alarm rates to obtain *d*', a relatively bias-free sensitivity measure, and *c*, a measure of response bias. Hit rates and false alarm rates of 1 or 0 were converted based on the number of trials in each task per the guidelines in Macmillan & Creelman (2004).

Wechsler's Intelligence Scale for Children – IV Digit Span Subtest

The digit span subtest from WISC-IV was administered as a measure of short-term memory and verbal working memory. In this task, participants heard a series of numbers and were asked to repeat them in the same order in the digit span forward subtest, and in the reverse order in the digit span backward subtest. A composite scaled score for the digit span subtest was calculated based on the scores from the digit span backward and forward subtests. A score between 8 and 12 is considered to be in the average range on this subtest. As shown in Table 3.1, mean performance was within average range on the digit span subtest for the bilateral (*M* = 9.8, *SD* = 3.2), and bimodal group (*M* = 8.9, *SD* = 2.6), and above average for the normal hearing group (*M* = 13.3, *SE* = 2.4). On the digit span forward and backward subtests mean performance was also within the average range for the bilateral and bimodal group, but above average for the normal hearing group (see Table 3.1). The relationship between digit span scores and accuracy of prosody-related tasks was examined and is reported later in this chapter.

Table 3.1. Participants' performance on the Wechsler's Intelligence Scale for Children-IV, Digit Span subtest by group

Bilateral Group				**Bimodal Group**				**Normal Hearing Group**			
ID	**Digit Span**	**DSF**	**DSB**	**ID**	**Digit Span**	**DSF**	**DSB**	**ID**	**Digit Span**	**DSF**	**DSB**
CI1	14	15	10	BT1	7	7	7	NH1	14	15	10
CI2	10	9	10	BT2	8	10	7	NH2	18	15	18
CI3	7	9	6	BT3	7	6	9	NH3	14	16	10
CI4	13	13	13	BT4	11	11	12	NH4	12	10	14
CI5	10	9	12	BT5	10	9	11	NH5	13	14	10
CI6	10	12	8	BT6	11	15	7	NH6	13	13	11
CI7	11	10	13	BT7	10	10	11	NH7	14	13	13
CI8	12	14	11	BT8	11	13	7	NH8	9	10	8
CI9	8	4	12	BT9	11	13	7	NH9	15	16	14
CI10	3	2	8	BT10	3	4	5	NH10	11	13	8
Mean	**9.8**	**9.7**	**10.3**	**Mean**	**8.9**	**9.8**	**8.3**	**Mean**	**13.3**	**13.5**	**11.6**
SD	**3.2**	**4.2**	**2.4**	**SD**	**2.6**	**3.4**	**2.3**	**SD**	**2.4**	**2.2**	**3.1**
SE	**1.0**	**1.3**	**0.7**	**SE**	**0.8**	**1.1**	**0.7**	**SE**	**0.8**	**0.7**	**1.0**

DSF = Digit Span Forward, DSB = Digit Span Backward

Perceiving Stress: Word-Phrase Identification Task

In this task participants heard a short directive (e.g., "Show me the greenhouse") and identified one of two pictures (e.g., "greenhouse" and "green house") that matched the directive in terms of specifying a compound word or phrase. The primary cue for this distinction is stress:

greenhouse vs. green house. Raw numbers of correct responses were converted to percentage correct values, d' values, c values, and rationalized arcsine units (RAU; Studebaker, McDaniel, & Sherbecoe, 1995) for each participant (Table 3.2). To compute d' and c values, hits were defined as correct responses on compound word trials, and false alarms were incorrect responses on phrase trials (defining hits and false alarms conversely would lead to the same d' values). Hit rates of 1.0 were converted to .958, and false alarm rates of 0 to .042.

Differences in sensitivity to the compound word-phrase distinction across the three groups – bilateral, bimodal, and normal hearing - were examined by conducting between groups analysis of variance (ANOVA) with d' values as the dependent variable ($d' = z_{\text{hit}} - z_{\text{false alarm}}$). There was not a significant effect of Group, $F(2, 27) = 1.174$, $p < .324$, $\eta^2_P = .080$ (Figure 3.1). Planned linear contrasts between the means of the normal hearing group and the combined means of the hearing impaired groups, and between the means of the two hearing impaired groups, were not significant.

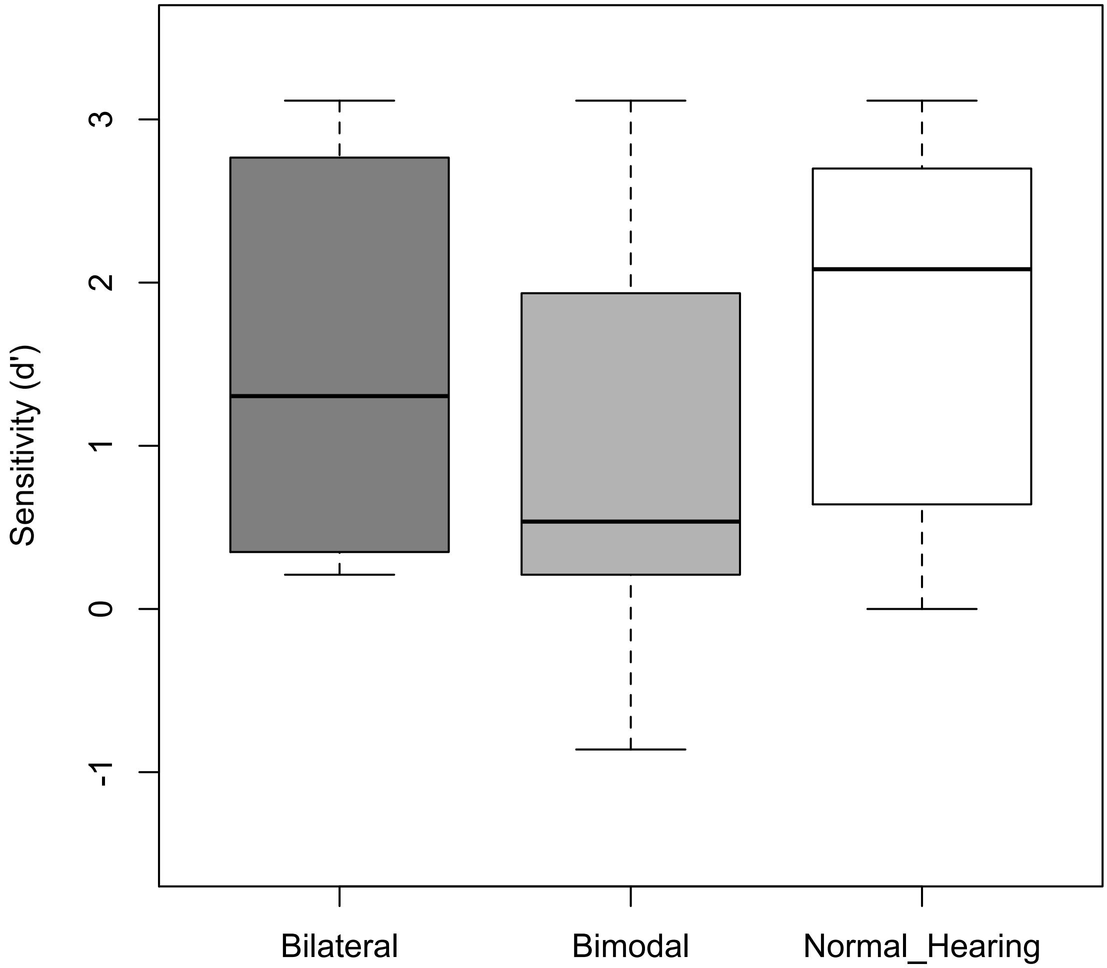
Although the groups did not differ in their sensitivity to the word-phrase distinction, each group showed evidence of sensitivity. The 95% confidence intervals on the group means of d' were on the positive side of zero (chance) for the bilateral group, $M = 1.479$, CI [0.630, 2.329], the bimodal group, $M = 0.955$, CI [0.037, 1.873], and the normal hearing group, $M = 1.775$, CI [0.944, 2.606]. These analyses indicate that participants in all three groups were sensitive to the distinction between compound word and phrases, and that the hearing-impaired participants performed similarly to normal hearing participants.

Table 3.2. Participants' performance on Word-Phrase Identification task by group

Group	ID	Total Accuracy (%)	Compound Word Accuracy (%)	Phrase Accuracy (%)	Total RAU	Compound Word RAU	Phrase RAU	Hit Rate	False Alarm Rate	*d'*	*c*
BILATERAL	CI1	54.2	58.3	50.0	53.725	57.200	50.000	0.583	0.500	0.210	-0.105
	CI2	58.3	58.3	58.3	57.474	57.200	57.200	0.583	0.417	0.421	0.000
	CI3	54.2	58.3	50.0	53.725	57.200	50.000	0.583	0.500	0.210	-0.105
	CI4	91.7	91.7	91.7	93.234	91.208	91.208	0.917	0.083	2.766	0.000
	CI5	66.7	83.3	50.0	65.152	80.981	50.000	0.833	0.500	0.967	-0.484
	CI6	87.5	91.7	83.3	87.436	91.208	80.981	0.917	0.167	2.350	-0.208
	CI7	79.2	75.0	83.3	77.660	72.386	80.981	0.750	0.167	1.642	0.146
	CI8	95.8	100.0	91.7	100.316	109.939	91.208	0.958	0.083	3.115	-0.174
	CI9	91.7	91.7	91.7	93.234	91.208	91.208	0.917	0.083	2.766	0.000
	CI10	54.2	100.0	8.3	53.725	109.939	8.792	0.958	0.917	0.349	-1.557
	Mean	**73.3**	**80.8**	**65.8**	**73.568**	**81.847**	**65.158**	**0.800**	**0.342**	**1.480**	**-0.249**
	SD	**17.6**	**17.1**	**27.3**	**18.883**	**20.423**	**26.804**	**0.162**	**0.273**	**1.186**	**0.490**
	SE	**5.6**	**5.4**	**8.6**	**5.971**	**6.458**	**8.476**	**0.051**	**0.086**	**0.375**	**0.155**
BIMODAL	BT1	54.2	58.3	50.0	53.725	57.200	50.000	0.583	0.500	0.210	-0.105
	BT2	66.7	66.7	66.7	65.152	64.585	64.585	0.667	0.333	0.861	0.000
	BT3	91.7	91.7	91.7	93.234	91.208	91.208	0.917	0.083	2.766	0.000
	BT4	54.2	58.3	50.0	53.725	57.200	50.000	0.583	0.500	0.210	-0.105
	BT5	83.3	83.3	83.3	82.328	80.981	80.981	0.833	0.167	1.935	0.000
	BT6	54.2	50.0	58.3	53.725	50.000	57.200	0.500	0.417	0.210	0.105
	BT7	70.8	75.0	66.7	69.144	72.386	64.585	0.750	0.333	1.105	-0.122
	BT8	50.0	100.0	0.0	50.000	109.939	-9.939	0.958	0.958	0.000	-1.732
	BT9	33.3	33.3	33.3	34.848	35.415	35.415	0.333	0.667	-0.861	0.000
	BT10	95.8	91.7	100.0	100.316	91.208	109.939	0.917	0.042	3.115	0.174
	Mean	**65.4**	**70.8**	**60.0**	**65.620**	**71.012**	**59.397**	**0.704**	**0.400**	**0.955**	**-0.178**
	SD	**20.0**	**21.2**	**29.3**	**20.746**	**22.519**	**32.745**	**0.206**	**0.278**	**1.283**	**0.554**
	SE	**6.3**	**6.7**	**9.3**	**6.560**	**7.121**	**10.355**	**0.065**	**0.088**	**0.406**	**0.175**
NORMAL HEARING	NH1	54.2	66.7	41.7	53.725	64.585	42.800	0.667	0.583	0.220	-0.321
	NH2	87.5	100.0	75.0	87.436	109.939	72.386	0.958	0.250	2.406	-0.529
	NH3	95.8	100.0	91.7	100.316	109.939	91.208	0.958	0.083	3.115	-0.174
	NH4	79.2	91.7	66.7	77.660	91.208	64.585	0.917	0.333	1.814	-0.476
	NH5	62.5	58.3	66.7	61.273	57.200	64.585	0.583	0.333	0.641	0.110
	NH6	50.0	100.0	0.0	50.000	109.939	-9.939	0.958	0.958	0.000	-1.732
	NH7	95.8	91.7	100.0	100.316	91.208	109.939	0.917	0.042	3.115	0.174
	NH8	87.5	83.3	91.7	87.436	80.981	91.208	0.833	0.083	2.350	0.208
	NH9	91.7	100.0	83.3	93.234	109.939	80.981	0.958	0.167	2.699	-0.382
	NH10	75.0	83.3	66.7	73.294	80.981	64.585	0.833	0.333	1.398	-0.268
	Mean	**77.9**	**87.5**	**68.3**	**78.469**	**90.592**	**67.234**	**0.858**	**0.317**	**1.776**	**-0.339**
	SD	**17.0**	**14.8**	**29.3**	**18.497**	**19.647**	**32.935**	**0.134**	**0.278**	**1.163**	**0.557**
	SE	**5.4**	**4.7**	**9.3**	**5.849**	**6.213**	**10.415**	**0.042**	**0.088**	**0.368**	**0.176**

Total trials = 24, Compound word trials = 12, Phrase trials = 12, RAU = rationalized arcsin unit, *d'* = d prime, *c* = criterion location

Figure 3.1. Sensitivity on the Word-Phrase Identification task, by group. Thick lines in boxes indicate group medians. Top and bottom lines of boxes indicate 75th and 25th percentile, respectively. *d*' values of 0, 1, 2, and 3 correspond approximately to percentages correct of 50% (chance), 69%, 84%, and 93%, respectively.



Although the group-based confidence intervals all fell above zero, Figure 3.2 shows that for some individual participants in each study group *d*' scores were below 1 (corresponding to about 69% correct), indicating fairly poor performance at distinguishing words from phrases. There was substantial variability across children within each study group. Thus, even in the group of children with normal hearing, distinguishing between compound words and phrases appeared to be difficult. This suggests that accuracy on the word-phrase identification task might have been influenced by factors other than perception of prosody, such as maturity and domain general cognitive skills.

To assess whether the groups differed in their bias to choose the compound word or phrase responses, the signal detection bias measure *c* was computed ($c = -0.5[z_{\text{hit}} + z_{\text{false alarm}}]$). A single factor between groups ANOVA with *c* as the dependent variable did not demonstrate a significant effect of Group, $F(2, 27) = 0.225$, $p < .800$, $\eta^2_P = .016$. Planned linear contrasts between the means of the normal hearing group and the combined means of the hearing impaired groups, and between the means of the two hearing impaired groups were not significant. The 95% confidence intervals on *c* overlapped zero for the bilateral group, *M* = -0.249, CI [-0.599, 0.102], the bimodal group, *M* = -0.178, CI [-0.573, 0.217], and the normal hearing group, *M* = -0.338, CI [-.736, 0.060]. One sample t-test comparing mean *c* values of the three groups combined, was on the negative side of zero, $t_{(29)} = 2.69$, $p < .012$, 95% CI [-0.450, -0.061], indicating a trend toward greater accuracy for identifying compound words compared to phrases. This trend aligns with prior research (Vogel & Raimy, 2002) and was further explored.

Figure 3.2. Receiver operating characteristic curves for Word-Phrase Identification task, by group. Each panel depicts the hit rates and false alarm rates of individual participants in a group. The solid diagonal indicates a *d*' score of 0, and subsequent curved lines indicate *d*' scores of 1, 2, and 3. The *d*' scores with zero bias (along the dashed lines) for values of 1, 2, and 3 correspond approximately to percentages correct of 69%, 84%, and 93%, respectively. The dashed line corresponds to no bias (*c* = 0), where the hit rate and false alarm rate are complementary. The letters A-J represent the 10 participants in each group, ordered from youngest (A) to oldest (J).

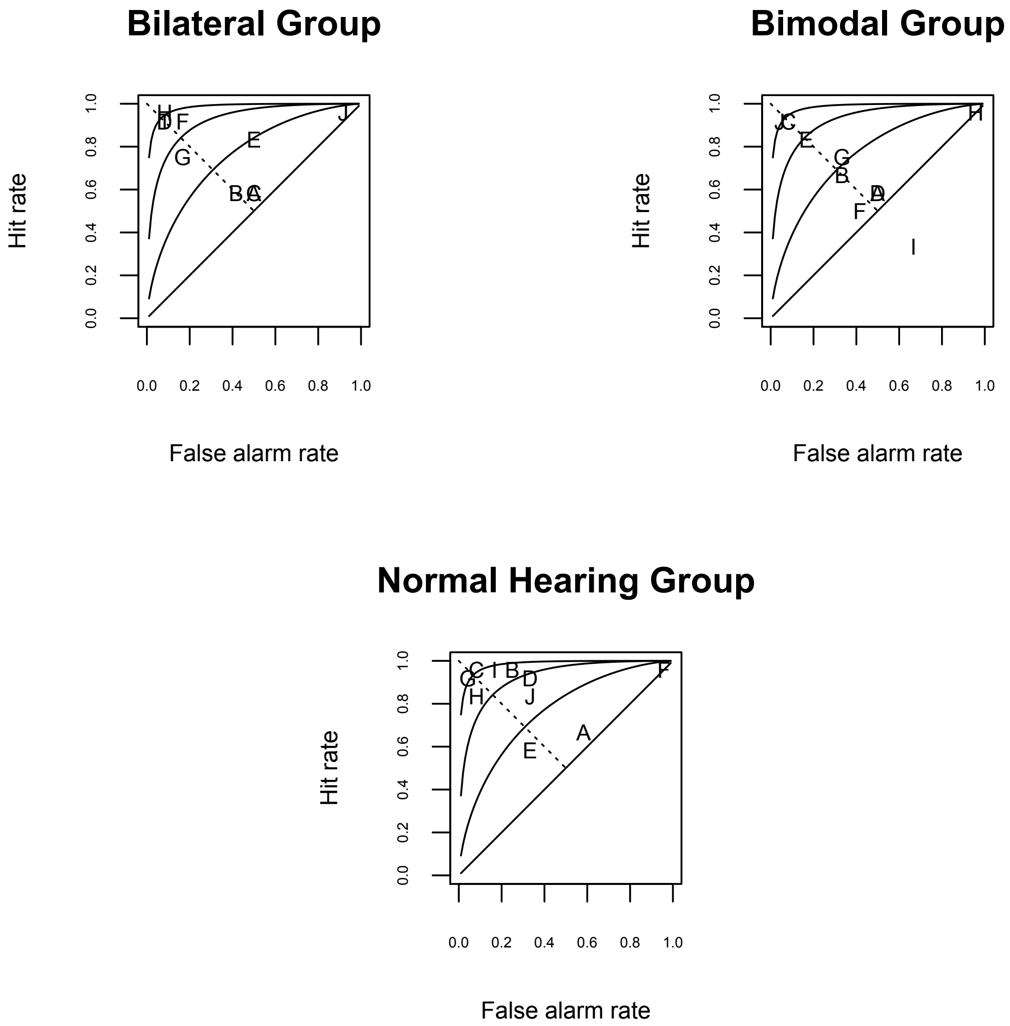
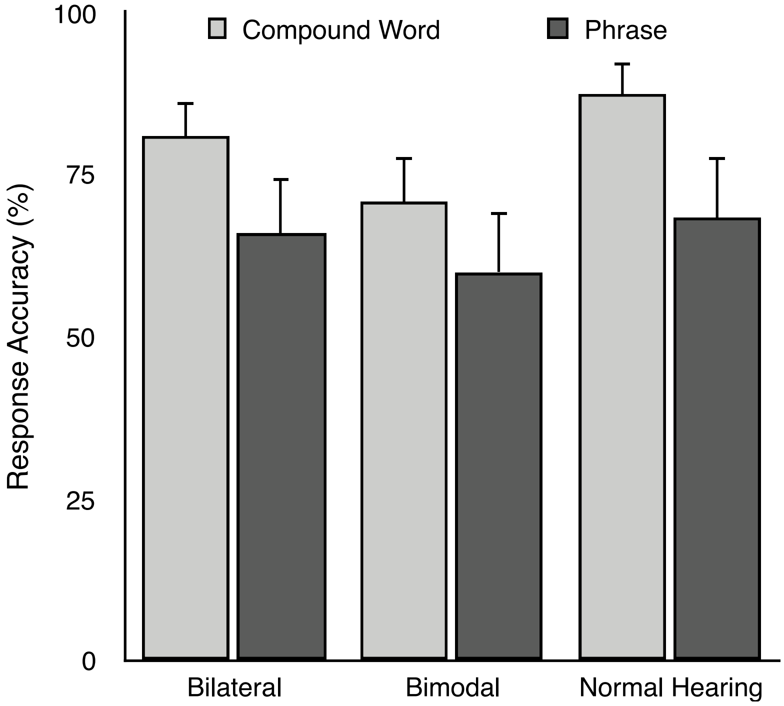


Figure 3.3 shows mean percentage correct for each group on the word and phrase items. To examine this statistically, an analysis of variance was conducted with RAU values for response accuracy as the dependent variable, Group (Bilateral, Bimodal, Normal Hearing) as a between-subjects factor, and Stimulus Type (Compound word, Phrase) as a within-subjects factor. There was a significant main effect for Stimulus Type, $F(1, 27) = 6.653$, $p < .016$, $\eta^2_P = .106$, with greater accuracy for identifying compound words ($M = 79.7\%$, $SE = 3.4\%$) than phrases ($M = 64.7\%$, $SE = 5.1\%$). There was no significant main effect for Group $F(2, 27) = 1.312$, $p < .286$, $\eta^2_P = .096$, or for the interaction $F(2, 27) = 0.259$, $p < .773$, $\eta^2_P = .019$. The same pattern of effects was observed in an analysis of variance with percentage correct as the dependent variable.

Figure 3.3. Mean response accuracy on the Word-Phrase Identification task by study group and stimulus type. Vertical bars indicate standard error.



As shown in Figures 3.3, averaged across the three groups, participants demonstrated greater accuracy at identifying compound words than phrases. The mean values for *c* (Table 3.2), which were significantly different from zero when averaged across groups, and were on the negative side of zero for the bilateral ($M = -0.249$), bimodal ($M = -0.178$), and normal hearing group ($M = -0.338$), along with the ROC curves (Figure 3.2), confirm this trend towards greater accuracy for compound words than for phrases. The preference for compound words over phrases has been attributed to the child's chronological age and linguistic proficiency and will be addressed in the next chapter.

Given the variability across individuals in performance on this task (Figure 3.2), correlational analyses were conducted to explore the relationship between sensitivity to the word-phrase distinction (d' values) and participant characteristics such as chronological age, non-verbal intelligence, and digit span, as well as audiological characteristics (Table 3.3). Correlations were analyzed across the entire sample, as well as separately within each of the groups, and for the two hearing impaired groups combined. There was a significant, positive relationship between d' values and digit span backward scores ($r = .370$, $p < .044$), across all participants, suggesting that better digit span scores were correlated with greater sensitivity. However, as shown in Figure 3.4, participants who used bimodal technology demonstrated a significant, negative correlation between d' values and performance on the digit span forward task ($r = -.802$, $p < .005$), indicating that greater sensitivity was correlated with lower accuracy on the digit span task. However, participants in the bilateral ($r = .334$, $p < .346$), and normal hearing groups ($r = .180$, $p < .618$), demonstrated weak, positive relationships, indicating that greater sensitivity was correlated with greater accuracy on the digit span task. A similar pattern was observed for correlations between digit span backward scores and d' values for each of the groups. This contradictory finding should be further investigated in a future study with a larger sample size. Age at diagnosis and age at amplification were significantly correlated with *d'* values for the participants in the bilateral group, but not the bimodal. Additionally, detection thresholds for "ee" on the Ling Six Sound Test, which served as a proxy for low-frequency access were significantly correlated with *d'* values. These findings indicate that auditory input received early in life, and access to low-frequency information might have a positive impact on sensitivity to the word-phrase distinction. Further examination of the impact of audiological factors on perception of prosody is provided at the end of this chapter.

Table 3.3. Correlation between *d'* values and participant characteristics on the Word-Phrase Identification task

Variable	All Groups (*n* = 30)	Normal Hearing (*n* = 10)	Bilateral (*n* = 10)	Bimodal (*n* = 10)	Hearing Impaired (*n* = 20)
Chronological Age	.096	.057	.364	.037	.160
Non-verbal IQ	.177	.074	.083	.248	.176
Digit Span	.091	.180	.334	**-.734**	-.128
Digit Span Forward	-.047	.086	.224	**-.802**	-.254
Digit Span Backward	**.370**	.327	.521	.004	.316
Audiological Factors					
Age at Diagnosis			**-.833**	.027	-.310
Age at Amplification			**-.655**	.292	-.093
Hearing Age			.526	-.088	.166
Ling Six Sounds					
ah			-.007	-.555	-.287
ee			-.465	-.532	**-.528**
oo			-.339	-.444	-.433
ss			.015	-.077	-.110
sh			-.140	.124	-.109
mm			.328	**-.653**	-.231

Hearing age = the duration of access to low-frequency auditory information through technology. The *r* values shown in bold are significant at $p < .05$.

Figure 3.4. Correlation between *d'* values and digit span forward scores on the Word-Phrase Identification task, by each study group. Solid lines in the figure show linear regression functions for each group. The *r* values shown in bold are significant at $p < .05$.

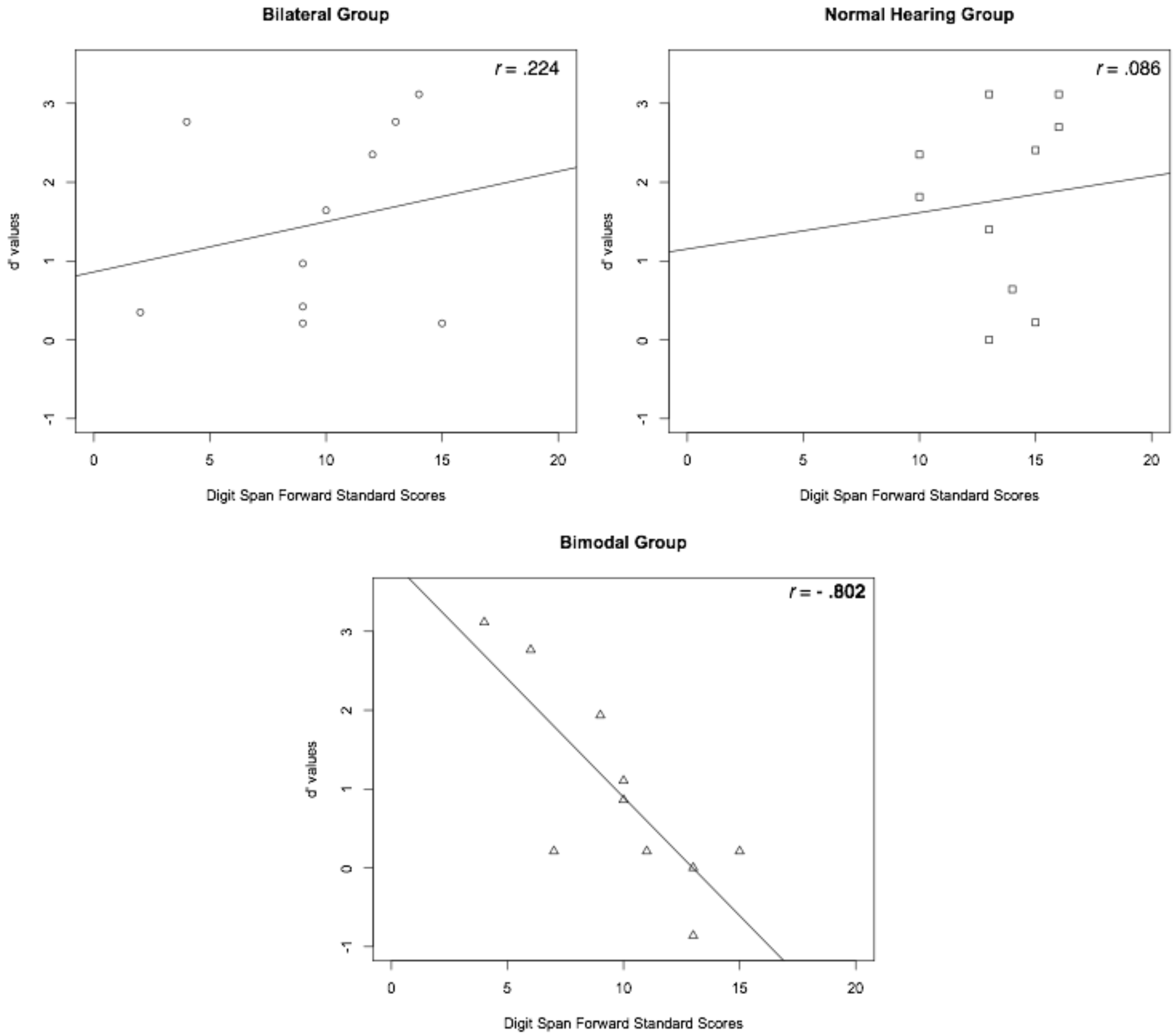
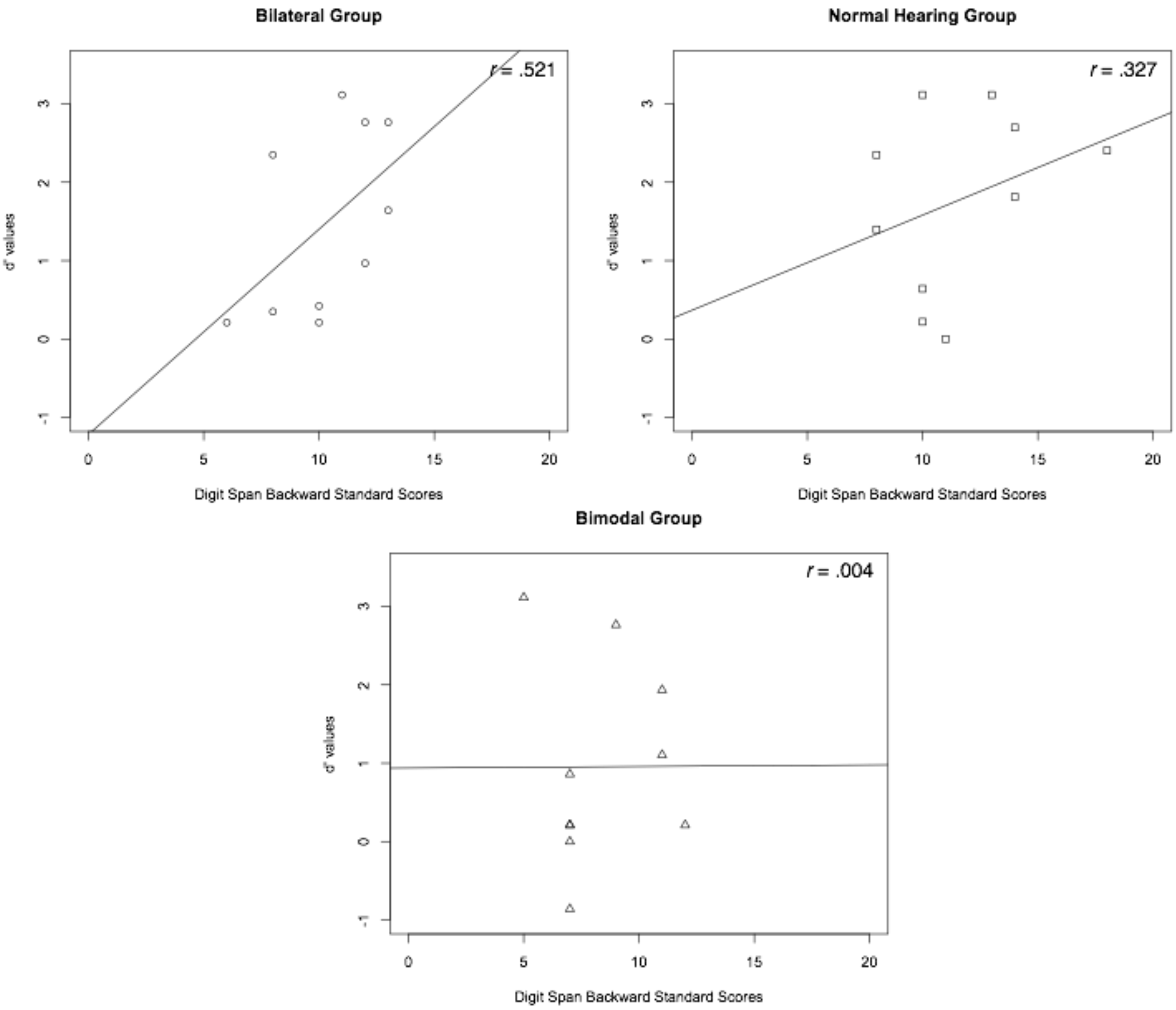


Figure 3.5. Correlation between *d'* values and digit span backward scores on the Word-Phrase Identification task, by each study group. Solid lines in the figure show linear regression functions for each group.



In summary, on the compound word-phrase identification task, children with and without hearing loss performed similarly, indicating no differences based on hearing status, or hearing technology used. A majority of the children in each study group were sensitive to the word-phrase distinction, indicated by *d'* scores of approximately 1 or more. Overall, they were more accurate in identifying compound words (e.g., “greenhouse”) than phrases (e.g., “green house”).

Individual differences in performance on this task show some associations with cognitive factors (digit span) and audiological factors, although the modest sample size suggests caution at interpretation.

Perceiving Intonation: Statement-Question Identification Task

In this task participants heard a short utterance (e.g., “They all went to circus,” or “They all went to the circus?”) and identified the utterance as a “statement” or “question”. This distinction is based mainly on the presence or absence of rising intonation at the end of the utterance. Participants in the bimodal group performed this task in two conditions, “bimodal” (cochlear implant in one ear and hearing aid in the other) and “unilateral” (cochlear implant only). Raw numbers of correct responses were converted to percentage correct values, d' values, c values, and rationalized arcsine units (RAU) for each participant, and were used for statistical analyses (Table 3.4 and Table 3.5). To compute d' and c values, hits were defined as correct responses on statement trials, and false alarms were incorrect responses on question trials. Hit rates of 1 were converted to .975, and false alarm rates of 0 were converted to .025.

Differences in sensitivity to the statement-question distinction across the three groups were examined with a single factor, between subjects ANOVA with d' values as the dependent variable. The effect of Group was not significant, $F(2,27) = 1.904$, $p < .168$, $\eta^2_P = .124$ (Figure 3.6). Planned linear contrasts between the means of the normal hearing group and the combined means of the hearing impaired groups, or between the means of the two hearing impaired groups were also not significant.

Table 3.4. Participants' performance on Statement-Question Identification task by group

	ID	Total Accuracy (%)	Statement Accuracy (%)	Question Accuracy (%)	Total RAU	Statement RAU	Foil RAU	Hit Rate	False Alarm Rate	*d'*	*c*
BILATERAL	CI1	70.0	75.0	65.0	68.638	73.103	63.483	0.750	0.350	1.060	-0.145
	CI2	65.0	95.0	35.0	63.809	98.196	36.517	0.950	0.650	1.260	-1.015
	CI3	77.5	85.0	70.0	76.334	83.998	68.188	0.850	0.300	1.561	-0.256
	CI4	90.0	100.0	80.0	91.659	112.776	78.322	0.975	0.200	2.802	-0.559
	CI5	97.5	100.0	95.0	105.363	112.776	98.196	0.975	0.050	3.605	-0.158
	CI6	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	CI7	92.5	100.0	85.0	95.508	112.776	83.998	0.975	0.150	2.996	-0.462
	CI8	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	CI9	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	CI10	87.5	95.0	80.0	88.178	98.196	78.322	0.950	0.200	2.486	-0.402
	Mean	**88.0**	**95.0**	**81.0**	**93.662**	**103.015**	**84.536**	**0.935**	**0.198**	**2.753**	**-0.300**
	SD	**13.0**	**8.5**	**20.5**	**19.581**	**14.432**	**25.106**	**0.076**	**0.198**	**1.129**	**0.322**
	SE	**4.1**	**2.7**	**6.5**	**6.192**	**4.564**	**7.939**	**0.024**	**0.063**	**0.357**	**0.102**
BIMODAL	BT1	57.5	50.0	65.0	56.828	50.000	63.483	0.500	0.350	0.385	0.193
	BT2	97.5	100.0	95.0	105.363	112.776	98.196	0.975	0.050	3.605	-0.158
	BT3	90.0	95.0	85.0	91.659	98.196	83.998	0.950	0.150	2.681	-0.304
	BT4	75.0	75.0	75.0	73.692	73.103	73.103	0.750	0.250	1.349	0.000
	BT5	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	BT6	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	BT7	95.0	100.0	90.0	99.921	112.776	90.407	0.975	0.100	3.242	-0.339
	BT8	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	BT9	82.5	85.0	80.0	81.942	83.998	78.322	0.850	0.200	1.878	-0.097
	BT10	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	Mean	**89.8**	**90.5**	**89.0**	**97.225**	**98.196**	**93.861**	**0.890**	**0.120**	**2.882**	**-0.071**
	SD	**14.2**	**16.6**	**12.4**	**20.792**	**22.185**	**18.721**	**0.156**	**0.115**	**1.273**	**0.160**
	SE	**4.5**	**5.2**	**3.9**	**6.575**	**7.016**	**5.920**	**0.049**	**0.036**	**0.403**	**0.050**
NORMAL HEARING	NH1	97.5	100.0	95.0	105.363	112.776	98.196	0.975	0.050	3.605	-0.158
	NH2	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	NH3	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	NH4	97.5	100.0	95.0	105.363	112.776	98.196	0.975	0.050	3.605	-0.158
	NH5	87.5	80.0	95.0	88.178	78.322	98.196	0.800	0.050	2.486	0.402
	NH6	92.5	95.0	90.0	95.508	98.196	90.407	0.950	0.100	2.926	-0.182
	NH7	97.5	95.0	100.0	105.363	98.196	112.776	0.950	0.025	3.605	0.158
	NH8	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	NH9	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	NH10	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	Mean	**97.3**	**97.0**	**97.5**	**107.834**	**106.415**	**106.166**	**0.953**	**0.040**	**3.583**	**0.006**
	SD	**4.2**	**6.3**	**3.5**	**9.815**	**11.583**	**8.826**	**0.055**	**0.024**	**0.495**	**0.173**
	SE	**1.3**	**2.0**	**1.1**	**3.104**	**3.663**	**2.791**	**0.017**	**0.008**	**0.156**	**0.055**

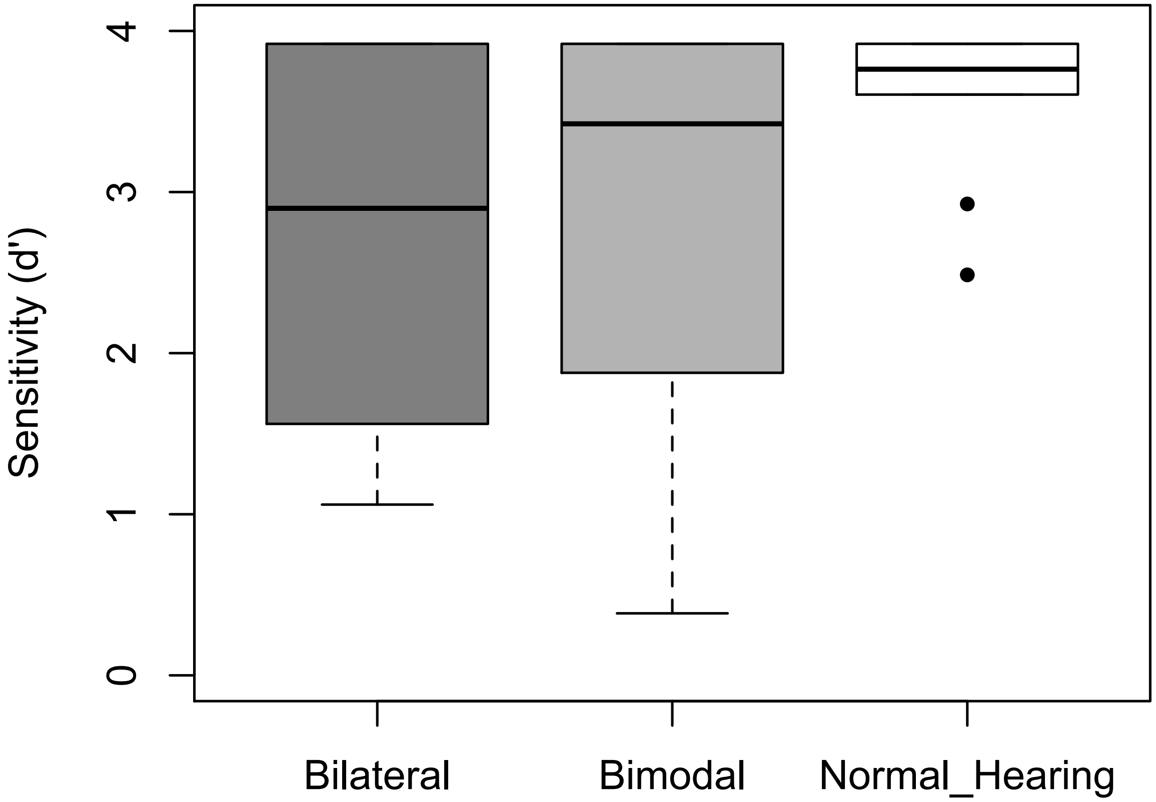
Total trials = 40, Statement trials = 20, Question trials = 20, RAU = rationalized arcsine unit, *d'* = d prime, *c* = criterion location

Table 3.5. Bimodal group participants' performance on Statement-Question Identification task in unilateral and bimodal condition

Con	**ID**	**Total Accuracy (%)**	**Statement Accuracy (%)**	**Question Accuracy (%)**	**Total RAU**	**Statement RAU**	**Foil RAU**	**Hit Rate**	**False Alarm Rate**	***d'***	***c***
UNILATERAL	BT1	42.5	35.0	50.0	43.172	36.517	50.000	0.350	0.500	-0.385	0.193
	BT2	92.5	90.0	95.0	95.508	90.407	98.196	0.900	0.050	2.926	0.182
	BT3	90.0	90.0	90.0	91.659	90.407	90.407	0.900	0.100	2.563	0.000
	BT4	85.0	95.0	75.0	84.961	98.196	73.103	0.950	0.250	2.319	-0.485
	BT5	87.5	100.0	75.0	88.178	112.776	73.103	0.975	0.250	2.634	-0.643
	BT6	87.5	90.0	85.0	88.178	90.407	83.998	0.900	0.150	2.318	-0.123
	BT7	97.5	100.0	95.0	105.363	112.776	98.196	0.975	0.050	3.605	-0.158
	BT8	80.0	80.0	80.0	79.076	78.322	78.322	0.800	0.200	1.683	0.000
	BT9	72.5	80.0	65.0	71.131	78.322	63.483	0.800	0.350	1.227	-0.228
	BT10	97.5	100.0	95.0	105.363	112.776	98.196	0.975	0.050	3.605	-0.158
	Mean	**83.3**	**86.0**	**80.5**	**85.259**	**90.091**	**80.700**	**0.853**	**0.195**	**2.250**	**-0.142**
	SD	16.2	19.4	14.8	18.198	22.991	16.274	0.188	0.148	1.188	0.265
	SE	5.1	6.1	4.7	5.755	7.270	5.146	0.060	0.047	0.376	0.084
BIMODAL	BT1	57.5	50.0	65.0	56.828	50.000	63.483	0.500	0.350	0.385	0.193
	BT2	97.5	100.0	95.0	105.363	112.776	98.196	0.975	0.050	3.605	-0.158
	BT3	90.0	95.0	85.0	91.659	98.196	83.998	0.950	0.150	2.681	-0.304
	BT4	75.0	75.0	75.0	73.692	73.103	73.103	0.750	0.250	1.349	0.000
	BT5	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	BT6	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	BT7	95.0	100.0	90.0	99.921	112.776	90.407	0.975	0.100	3.242	-0.339
	BT8	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	BT9	82.5	85.0	80.0	81.942	83.998	78.322	0.850	0.200	1.878	-0.097
	BT10	100.0	100.0	100.0	115.712	112.776	112.776	0.975	0.025	3.920	0.000
	Mean	**89.8**	**90.5**	**89.0**	**97.225**	**98.196**	**93.861**	**0.890**	**0.120**	**2.882**	**-0.071**
	SD	**14.2**	**16.6**	**12.4**	**20.792**	**22.185**	**18.721**	**0.156**	**0.115**	**1.273**	**0.160**
	SE	**4.5**	**5.2**	**3.9**	**6.575**	**7.016**	**5.920**	**0.049**	**0.036**	**0.403**	**0.050**

Total trials = 40, Statement trials = 20, Question trials = 20, RAU = rationalized arcsine unit, *d'* = d prime, *c* = criterion location

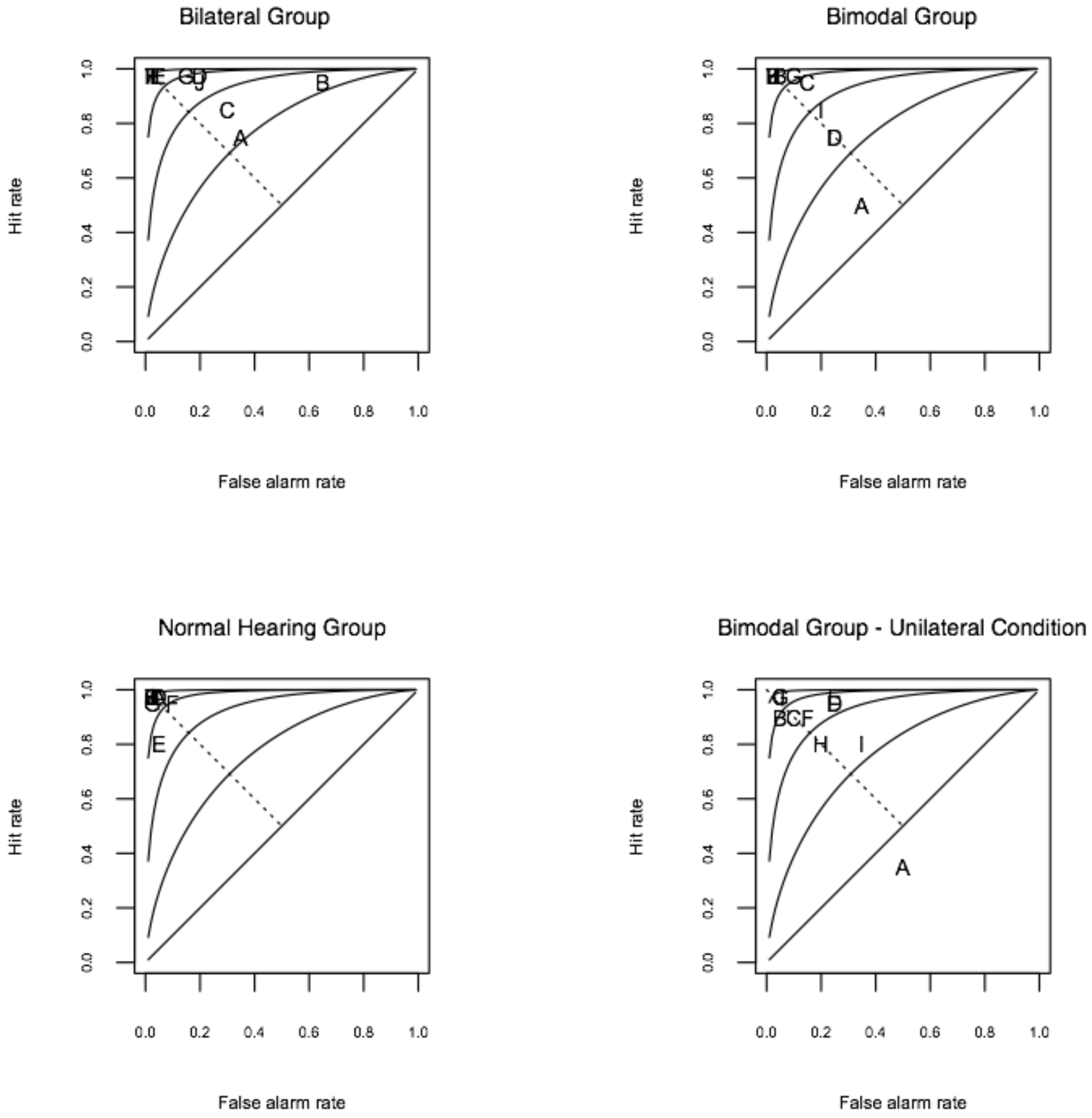
Figure 3.6. Participant's sensitivity on the Statement-Question Identification task, by group. The thick line in the box indicates the median performance. The top and bottom lines of the box indicate 75th and 25th percentile, respectively. *d*' value of 3.92 corresponds to 100% accuracy on this task, and *d*' values 0, 1, 2, and 3 correspond approximately to percentages correct of 50%, 69%, 84%, and 93%, respectively.



A comparison of means for each group demonstrated sensitivity to the statement-question distinction, with 95% confidence intervals being on the positive side of zero for the bilateral group, $M = 2.753$, CI [1.946, 3.560], the bimodal group, $M = 2.882$, CI [1.971, 3.793], and the normal hearing group $M = 3.583$, CI [3.229, 3.937]. Figure 3.7 shows hit rates, false alarms, and *d*' values for each participant. As this figure shows, only one child, in the bimodal group, had a *d*' value less than 1. Thus, the number of children who did quite well on this task was higher than on the Word-Phrase Identification task (see Figure 3.2). These findings indicate that participants in all the groups demonstrated sensitivity to the statement-question distinction, and their performance was comparable across groups.

Differences in response bias toward statements or questions across the three groups were examined by conducting an ANOVA with c values as the dependent variable. There was a significant effect of Group $F(2,27) = 4.784$, $p < .017$, $\eta^2_P = .262$ (Figure 3.8). Planned linear contrasts demonstrated significant differences between the normal hearing group and the combined hearing impaired groups $F(1,27) = 4.609$, $p < .041$, as well as between the means of the two hearing impaired groups $F(1,27) = 4.953$, $p < .035$. This indicates that response bias differed based on hearing status of the participants as well as the hearing technology used. A comparison of means for each group revealed greater tendency to identify an utterance as a “statement”, in the bilateral group $M = -0.300$, CI [-0.530, -0.070], but not in the bimodal group, $M = -0.071$, CI [-0.185, 0.044], or the normal hearing group $M = 0.006$, CI [-0.118, 0.130].

Figure 3.7. Receiver operating characteristic curves for Statement-Question Identification task, by group. Each panel depicts the hit rates and false alarm rates of individual participants in each group, and the bimodal group in the unilateral listening condition. The diagonal indicates a *d*' score of 0, and each subsequent curved line indicates *d*' score of 1, 2, 3, and 4 respectively. *d*' scores with zero bias (along the dashed lines) for values of 1, 2, and 3 correspond approximately to percentages correct of 69%, 84%, and 93%, respectively. *d*' score of 3.920 corresponds to 100% accuracy. The letters A-J represent the 10 participants in each group, ordered from youngest (A) to oldest (J).



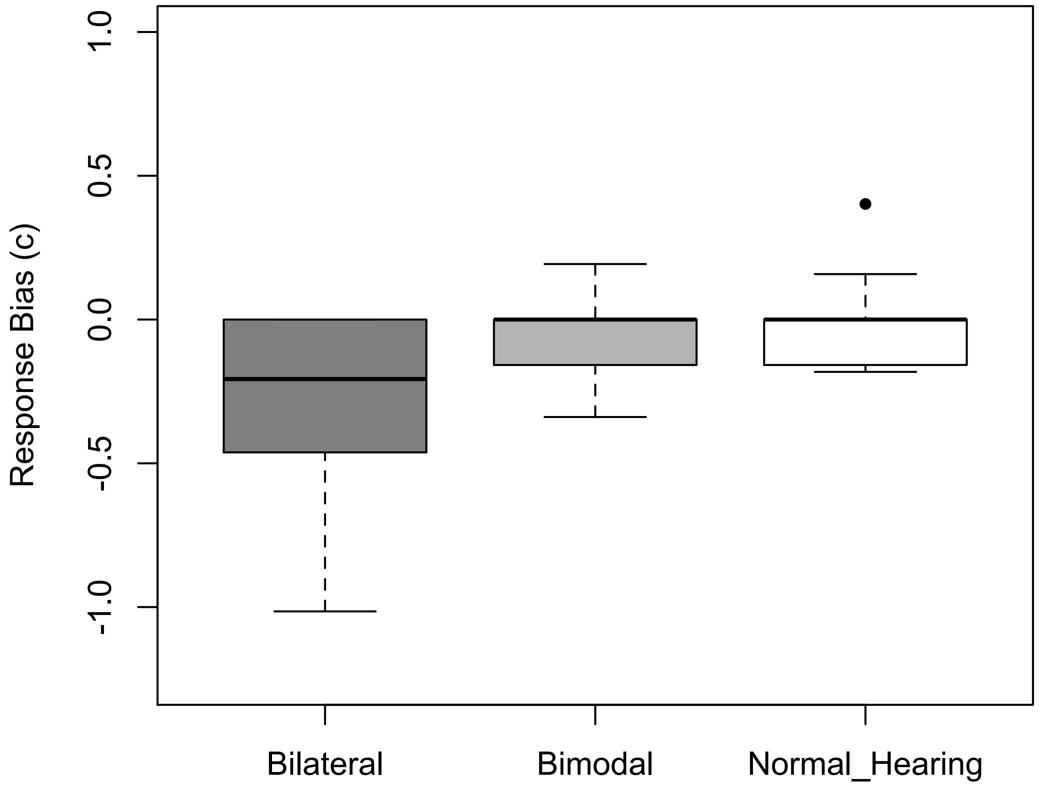
Bilateral Group

Bimodal Group

Normal Hearing Group

Bimodal Group - Unilateral Condition

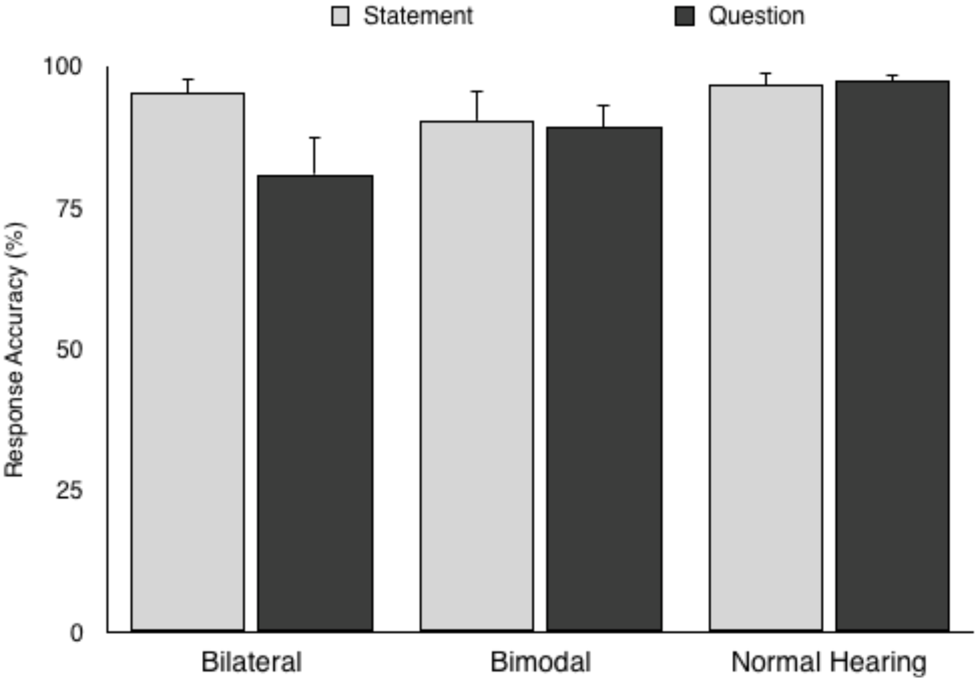
Figure 3.8. Participants' response bias on the Statement-Question Identification Task, by group. The thick line in the box indicates the median performance. The top and bottom lines of the box indicate 75th and 25th percentile, respectively. A negative *c* value indicates a tendency towards misidentifying questions as statements, and a positive value indicates a tendency towards misidentifying statements as questions.



Differences in response accuracy were further explored by conducting a mixed model ANOVA, with RAU values for response accuracy as the dependent variable, Group (bilateral, bimodal, normal hearing) as a between-subjects factor, and Stimulus Type (statement, question) as a within-subjects factor. See Figure 3.9. The main effect of Group was not significant, $F(2,27) = 1.675$, $p < .206$, $\eta^2_P = .398$, indicating that participants' performance was comparable across the three groups. There was a significant main effect of Stimulus Type, $F(1,27) = 8.885$, $p < .006$, $\eta^2_P = .248$, with participants demonstrating greater accuracy when identifying statements

(*M* = 94.2%, *SE* = 2.1%) than questions (*M* = 89.2%, *SE* = 2.8%). The interaction between Group and Stimulus Type, *F*(1,27) = 4.586, $p < .019$, $\eta^2_P = .254$ was significant. Together with analyses of sensitivity measure *d'*, and response bias measure *c*, these findings indicate that even though response accuracy and sensitivity was comparable across groups, participants in the bilateral group were more likely to identify utterances as statements, than the participants in the bimodal and normal hearing groups.

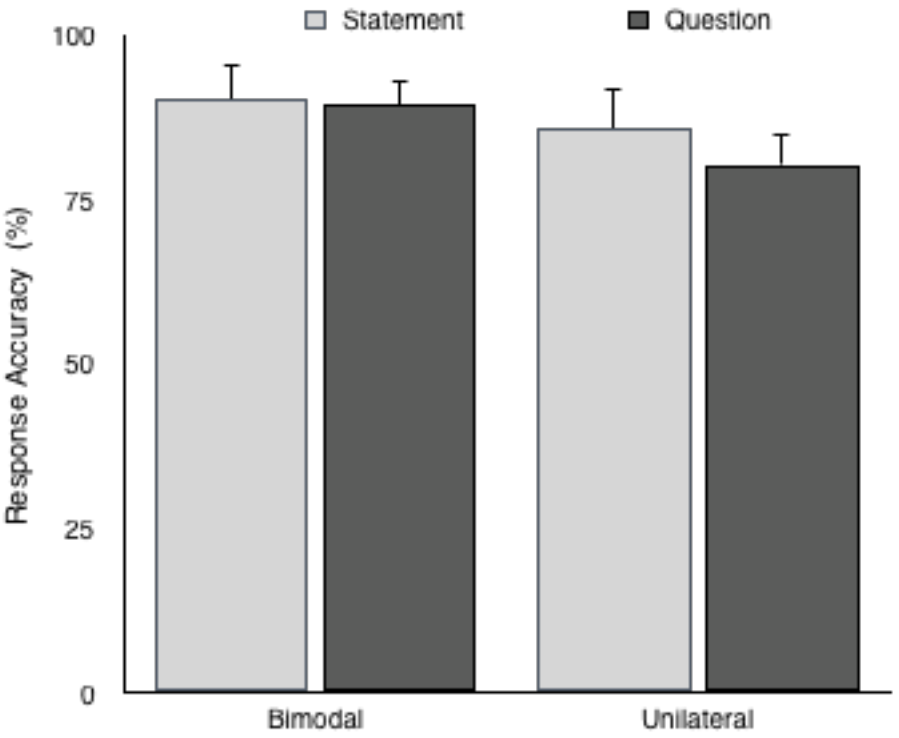
Figure 3.9. Mean response accuracy on the Statement-Question Identification task by group and stimulus type. Vertical bars indicate standard error.



In this task, to explore the contribution of acoustic hearing available through hearing aids, participants in the bimodal group completed the task in two conditions – bimodal (cochlear implant and hearing aid in opposite ears) and unilateral (cochlear implant in one ear). See Table 3.5 and Figure 3.7, panels on right. An analysis of variance with *d'* as the dependent variable did not demonstrate an effect of condition, $F(1, 9) = 4.565$, $p < .061$, $\eta^2_P = .068$. A comparison of means demonstrated that participants were sensitive to the statement-question distinction in both listening conditions, with 95% confidence intervals being on the positive side of zero in the bimodal condition, $M = 2.882$, CI [1.971, 3.793], and unilateral CI condition, $M = 2.250$, CI [1.400, 3.099]. An analysis of variance with c as the dependent variable was not significant, $F(1,9) = 0.514$, $p < .492$, $\eta^2_P = .029$, and 95% confidence intervals around the mean c values overlapped zero in the bimodal condition, $M = -0.071$, CI [-0.185, 0.044], and unilateral condition, $M = -0.142$, CI [-0.332, 0.048]. These findings indicate that in both conditions, participants were sensitive to the statement-question distinction, and their sensitivity was comparable in both conditions. There was no systematic response bias in either condition.

An analysis of variance with RAU values of response accuracy as the dependent variable, and Condition (bimodal, unilateral) and Stimulus Type (statement, question) as the within-subject factors was conducted. See Figure 3.10. There was a significant main effect of Stimulus type, $F(1,9) = 5.840$, $p < .039$, $\eta^2_P = .394$, with greater accuracy for statements ($M = 88.3\%$, $SE = 4\%$) than questions ($M = 84.8\%$, $SE = 3.1\%$). The main effect of Condition approached significance $F(1,9) = 5.084$, $p < .051$, $\eta^2_P = .382$, demonstrating that participants had greater accuracy in the bimodal condition than the unilateral condition, but the difference was not significant. The interaction between Condition and Stimulus Type was not significant $F(1,9) = 0.755$, $p < .408$, $\eta^2_P = .077$. These findings, along with the d' results, suggest that for bimodal users, performance was comparable in the two conditions that presumably differed by the acoustic hearing available through hearing aids. The previously observed trend of somewhat greater accuracy for statements than questions was also observed within the two conditions.

Figure 3.10. Bimodal group participants' mean response accuracy in the Bimodal and Unilateral Listening Conditions by stimulus type. Vertical bars indicate standard error.



Correlational analyses were conducted to explore the relationship between sensitivity to statement-question distinction (*d*' values) and participant characteristics as well as audiological characteristics of the participants in the two hearing-impaired groups (Table 3.6). There was a significant, positive relationship between chronological age and sensitivity to the statement-question distinction (r = .382) across the three groups. There was a significant, positive correlation between hearing age and *d*' values, indicating that longer duration of auditory experience was associated with greater sensitivity to the statement-question distinction for the children with hearing loss. Additional discussion of the impact of audiological factors on perception of prosody is provided at the end of this chapter.

Table 3.6. Correlations between *d'* values and participant characteristics on the Statement-Question Identification task

Variable	**All Groups (*n* = 30)**	**Normal Hearing (*n* = 10)**	**Bilateral (*n* = 10)**	**Bimodal (*n* = 10)**	**Hearing Impaired (*n* = 20)**
Chronological Age	**.382**	.150	.601	.513	**.551**
Non-verbal IQ	.211	.050	-.014	.493	.195
Digit Span	.181	.065	-.029	-.036	-.040
Digit Span Forward	.178	.059	-.103	.122	.006
Digit Span Backward	.194	.157	.378	-.172	.058
Audiological Factors					
Age at Diagnosis			**-.712**	-.280	-.435
Age at Amplification			-.445	-.176	-.278
Hearing Age			**.684**	.447	**.559**
Ling Six Sounds					
ah			-.262	.070	-.090
ee			-.519	-.489	-.472
oo			-.242	-.444	-.338
ss			-.070	-.452	-.234
sh			.103	.044	.089
mm			.220	-.581	-.217

Hearing age = the duration of access to low-frequency auditory information through technology. The *r* values shown in bold are significant at $p < .05$.

In summary, on the statement-question identification task, children in all three groups were able to identify utterances as statements or questions, and performance was comparable across groups. Children who used bimodal hearing technology, and children who had normal hearing performed with high accuracy when identifying statements and questions, whereas children who were bilateral cochlear implant users performed with high accuracy, but were more likely to identify utterances as statements. Children who used bimodal technology were sensitive to the distinction between statements and questions even when they completed the task without their contralateral hearing aid. They showed somewhat better performance when listening with a cochlear implant in one ear and a hearing aid in the other, compared with a cochlear implant only, but the difference did not quite reach the .05 significance level. For children with and without hearing loss, sensitivity to the statement-question distinction improved with age, with older participants demonstrating greater sensitivity. For children with hearing loss, longer duration of auditory experience was associated with greater sensitivity to the statement-question distinction.

Prosody Matching Task

In this task participants heard two unfiltered utterances - a statement and a foil, followed by a low-pass filtered version (< 400 Hz) of one of the two unfiltered utterances. They responded by identifying which unfiltered utterance - "1" or "2", matched the low-pass filtered utterance. In each trial, one of the unfiltered utterances was a statement, e.g., "The boy is pouring juice in the glass", and the other utterance was one of three foils:

1) a question, e.g., "The boy is pouring juice in the glass?"
2) a short statement, e.g., "The boy is pouring juice."
3) a statement with alternative pausing, e.g., "The boy is pouring // juice in the glass."

The foils primarily differed from the statement by intonation, duration, and rhythm, respectively. Equal numbers of statement-question, statement-short statement, and statement-alternative pausing trials were administered. Raw numbers of correct responses were converted to percentage correct values, *d*' values, *c* values, and rationalized arcsine units (RAU) for each participant (Tables 3.7 and 3.8). To compute *d*' and *c* values, hits were defined as correct responses on low-pass filtered statement trials, and false alarms were incorrect responses on low-pass filtered foil trials. Hit rates of 1 were converted to .979, and false alarm rates of 0 to .021.

Participants' sensitivity and potential bias in matching low-pass filtered utterances to unfiltered utterances were examined using *d*' and *c* values. Analysis of variance with *d*' as the dependent variable, Group as the between subjects factor, and Foil Type (question, short statement, alternative pausing) as the within subjects factor was conducted. There were significant main effects of Group $F(2, 27) = 5.057$, $p < .014$, $\eta^2_P = .467$, and Foil Type, $F(2, 54) = 30.659$, $p < .001$, $\eta^2_P = .532$. The interaction effect approached significance $F(4, 54) = 2.382$, $p < .063$, $\eta^2_P = .150$ (Figure 3.11).

Planned linear contrasts on the main effect of group demonstrated a significant difference between the normal hearing group and average of the two hearing impaired groups $F(1, 27) = 28.394$, $p < .001$, but not between the means of two hearing impaired groups $F(1, 27) = 0.417$, $p < .524$, indicating that children with normal hearing demonstrated greater sensitivity to matching based on prosodic features than children with hearing loss. Interaction contrasts demonstrated that there no differences, between the normal hearing children and hearing impaired children, in the difference between sensitivity on the statement-short statement trials and statement-alternative pausing trials, $F(1, 54) = 1.376$, $p < .246$. However, there was a significant difference, between normal hearing and hearing impaired children, in sensitivity on the statement-question trials versus the average of statement-short statement trials and statement-alternative pausing trials, $F(1, 54) = 7.112$, $p < .01$. As shown in Figure 3.11, the difference between the performance of the children with normal hearing and those with hearing impairments was primarily on the statement-question items, for which perception of intonation patterns is critical.

Table 3.7. Participants' performance on the Prosody Matching task by group

	ID	**Total Accuracy (%)**	**Total RAU**	**Hit Rate**	**False Alarm Rate**	***d'***	***c***
BILATERAL	CI1	45.8	46.201	0.625	0.708	-0.65	-0.434
	CI2	70.8	69.544	0.625	0.208	1.60	0.247
	CI3	60.4	59.554	0.625	0.417	1.03	-0.054
	CI4	77.1	76.002	0.667	0.125	1.99	0.360
	CI5	64.6	63.469	0.667	0.375	1.25	-0.056
	CI6	77.1	76.002	0.750	0.208	1.91	0.069
	CI7	83.3	83.086	0.792	0.125	2.30	0.169
	CI8	97.9	106.884	0.958	0.021	3.88	0.153
	CI9	91.7	94.424	0.875	0.042	3.08	0.291
	CI10	68.8	67.486	0.583	0.208	1.50	0.301
	Mean	**73.8**	**74.265**	**0.717**	**0.244**	**1.789**	**0.104**
	SD	**15.3**	**17.458**	**0.124**	**0.207**	**1.215**	**0.237**
	SE	**4.8**	**5.521**	**0.039**	**0.065**	**0.384**	**0.075**
BIMODAL	BT1	60.4	59.554	0.667	0.458	1.04	-0.163
	BT2	79.2	78.277	0.750	0.167	2.04	0.146
	BT3	79.2	78.277	0.750	0.167	2.04	0.146
	BT4	57.8	57.101	0.696	0.545	0.88	-0.313
	BT5	85.4	85.656	0.875	0.167	2.44	-0.091
	BT6	89.6	91.276	0.833	0.042	2.92	0.382
	BT7	81.3	80.633	0.750	0.125	2.19	0.238
	BT8	89.6	91.276	0.833	0.042	2.92	0.382
	BT9	78.7	77.773	0.708	0.130	2.06	0.288
	BT10	93.8	97.914	0.958	0.083	3.28	-0.174
	Mean	**79.5**	**79.774**	**0.782**	**0.193**	**2.181**	**0.084**
	SD	**11.9**	**13.167**	**0.091**	**0.171**	**0.776**	**0.251**
	SE	**3.8**	**4.164**	**0.029**	**0.054**	**0.245**	**0.079**
NORMAL HEARING	NH1	91.7	94.424	0.875	0.042	3.08	0.291
	NH2	95.7	101.704	0.917	0.022	3.54	0.318
	NH3	91.7	94.424	0.917	0.083	2.98	0.000
	NH4	95.8	101.926	0.917	0.021	3.56	0.327
	NH5	95.8	101.926	0.979	0.083	3.56	-0.327
	NH6	83.3	83.086	0.792	0.125	2.30	0.169
	NH7	91.7	94.424	0.875	0.042	3.08	0.291
	NH8	85.4	85.656	0.708	0.021	2.83	0.744
	NH9	95.8	101.926	0.917	0.021	3.56	0.327
	NH10	93.8	97.914	0.917	0.042	3.28	0.174
	Mean	**92.1**	**95.741**	**0.881**	**0.050**	**3.177**	**0.231**
	SD	4.5	6.848	**0.077**	**0.036**	**0.412**	**0.272**
	SE	1.4	2.166	**0.024**	**0.011**	**0.130**	**0.086**

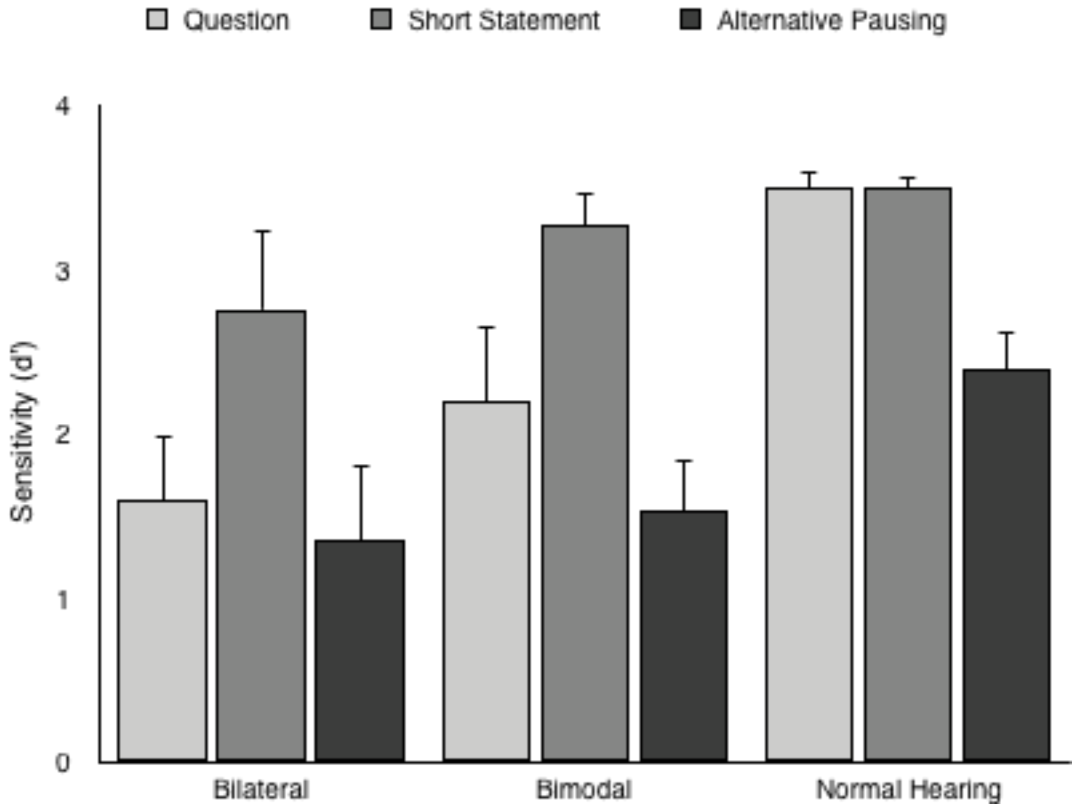
Total trials = 48, RAU = rationalized arcsine units, *d'* = d prime, c = criterion location

Table 3.8. Participants' performance on the Prosody Matching task, by group and foil type

Group	ID	Statement-Question Trials			Statement-Short Statement Trials			Statement-Alt. Pausing Trials		
		Total Accuracy (%)	*d'*	*c*	**Total Accuracy (%)**	*d'*	*c*	**Total Accuracy (%)**	*d'*	*c*
BILATERAL	CI1	56.3	0.83	-0.497	43.8	-0.86	-1.342	37.5	-1.17	0.337
	CI2	62.5	1.33	0.734	100.0	3.24	0.000	50.0	0.00	0.000
	CI3	50.0	0.00	0.000	68.8	1.48	-0.178	62.5	1.14	0.000
	CI4	75.0	1.89	0.416	87.5	2.59	0.000	68.8	1.62	0.575
	CI5	50.0	0.00	0.000	75.0	1.79	0.000	68.8	1.48	-0.178
	CI6	56.3	0.78	0.159	100.0	3.24	0.000	75.0	1.79	0.000
	CI7	75.0	1.79	0.000	100.0	3.24	0.000	75.0	1.89	0.416
	CI8	93.8	2.91	0.192	100.0	3.24	0.000	100.0	3.24	0.000
	CI9	100.0	3.24	0.000	100.0	3.24	0.000	75.0	1.89	0.416
	CI10	62.5	1.21	0.213	93.8	2.92	0.122	50.0	0.00	0.319
	Mean	**68.1**	**1.398**	**0.122**	**86.9**	**2.412**	**-0.140**	**66.3**	**1.188**	**0.188**
	SD	**17.5**	**1.092**	**0.319**	**19.0**	**1.320**	**0.429**	**17.5**	**1.257**	**0.251**
	SE	**5.5**	**0.345**	**0.101**	**6.0**	**0.417**	**0.136**	**5.5**	**0.397**	**0.079**
BIMODAL	BT1	43.8	-0.78	-0.159	85.7	2.12	-0.197	58.8	0.92	-0.215
	BT2	81.3	2.19	0.238	87.5	2.91	0.192	62.5	1.14	0.000
	BT3	68.8	1.48	0.178	100.0	3.24	0.000	68.8	1.48	0.178
	BT4	53.3	0.58	-0.090	75.0	1.70	-0.054	46.7	-0.68	-0.442
	BT5	87.5	2.59	0.000	100.0	2.91	-0.192	75.0	1.79	0.000
	BT6	100.0	3.24	0.000	100.0	3.24	0.000	75.0	1.89	0.416
	BT7	75.0	1.89	0.416	87.5	2.91	0.192	75.0	1.79	0.000
	BT8	93.8	2.91	0.192	100.0	3.24	0.000	75.0	1.89	0.416
	BT9	76.5	1.99	0.360	100.0	3.18	0.034	60.0	1.07	0.283
	BT10	100.0	3.24	0.000	100.0	3.24	0.000	81.3	2.19	-0.238
	Mean	**78.0**	**1.933**	**0.113**	**93.6**	**2.869**	**-0.002**	**66.7**	**1.348**	**0.040**
	SD	**18.8**	**1.259**	**0.192**	**9.0**	**0.535**	**0.130**	**10.2**	**0.825**	**0.287**
	SE	**6.0**	**0.398**	**0.061**	**2.8**	**0.169**	**0.041**	**3.2**	**0.261**	**0.091**
NORMAL HEARING	NH1	100.0	3.24	0.000	100.0	3.24	0.000	75.0	1.89	0.416
	NH2	100.0	3.24	0.000	100.0	3.18	-0.034	93.8	2.89	0.263
	NH3	100.0	3.24	0.000	100.0	3.24	0.000	75.0	1.79	0.000
	NH4	100.0	3.24	0.000	100.0	3.24	0.000	87.5	2.51	0.430
	NH5	100.0	3.24	0.000	93.8	2.91	-0.192	93.8	2.91	-0.192
	NH6	93.8	2.91	0.192	93.8	2.91	-0.192	62.5	1.14	0.000
	NH7	93.8	2.91	0.192	93.8	2.91	-0.192	87.5	2.51	0.430
	NH8	87.5	2.51	0.430	93.8	2.91	0.192	75.0	1.94	0.767
	NH9	93.8	2.91	0.192	93.8	2.91	-0.192	62.5	1.14	0.000
	NH10	100.0	3.24	0.000	100.0	3.24	0.000	81.3	2.19	0.238
	Mean	**96.9**	**3.068**	**0.101**	**96.9**	**3.069**	**-0.061**	**79.4**	**2.091**	**0.235**
	SD	**4.4**	**0.250**	**0.147**	**3.3**	**0.169**	**0.128**	**11.4**	**0.635**	**0.287**
	SE	**1.4**	**0.079**	**0.046**	**1.0**	**0.053**	**0.041**	**3.6**	**0.201**	**0.091**

Statement-Question trials = 16, Statement-Short Statement trials = 16, Statement-Alternative Pausing trials = 16, *d'* = d prime, *c* = criterion location

Figure 3.11. Participants' average sensitivity of the Prosody Matching task by group and foil type. Standard error bars are shown. *d*' value of 3.34 corresponds to 100% accuracy on this task, and *d*' values of 0, 1, 2, and 3 correspond approximately to percentages correct of 50% (chance), 69%, 84%, and 93%, respectively.



An analysis of variance with *c* as the dependent variable, Group as the between subjects factor, and Foil Type as the within subjects factor was conducted. The main effect of Foil Type was significant $F(2, 54) = 8.709$, $p < .001$, $\eta^2_P = .244$, but the main effect of Group $F(2, 27) = 0.140$, $p < .870$, $\eta^2_P = .011$, and the interaction effect $F(4, 54) = 1.438$, $p < .234$, $\eta^2_P = .096$, were not significant. Planned linear contrasts did not demonstrate a significant difference between the normal hearing and average of the two hearing impaired groups, or between the means of two hearing impaired groups. To further investigate the main effect of Foil Type and explore the difference in sensitivity to each foil type, *d*' and *c* values were calculated separately per foil type. See Table 3.8 for individual response accuracy, *d*' and *c* values, per foil type.

For the statement-question trials, where the most salient cue was variation in intonation, 95% confidence intervals around mean *d*' values were on the positive side of zero for the bilateral group, *M* = 1.398, CI [0.617, 2.179], the bimodal group, *M* = 1.933, CI [1.032, 2.834], and the normal hearing group, *M* = 3.068, CI [2.889, 3.247], indicating that children in all the groups were sensitive to the similarities between the low-pass filtered and the matching unfiltered utterance. The 95% confidence intervals around mean *c* values overlapped zero for the bilateral group, *M* = 0.122, CI [-0.107, 0.350], the bimodal group, *M* = 0.113, CI [-0.024, 0.251], and the normal hearing group, *M* = 0.101, CI [-0.005, 0.206], indicating that there was no systematic bias in participants' responses. Figure 3.12 shows that most participants demonstrated sensitivity to matching the low-pass filtered utterance to one of two unfiltered utterances in the statement-question trials.

For the statement-short statement trials, where the most salient cue was variation in duration, 95% confidence intervals around mean *d*' values were on the positive side of zero for the bilateral group, *M* = 2.412, CI [1.468, 3.356], the bimodal group, *M* = 2.869, CI [2.486, 3.252], and the normal hearing group, *M* = 3.069, CI [2.948, 3.190], indicating that children in all the groups were sensitive to the similarities between the low-pass filtered and the matching unfiltered utterance. The 95% confidence intervals around mean *c* values overlapped zero for the bilateral group, *M* = -0.140, CI [-0.446, 0.167], the bimodal group, *M* = -0.002, CI [-0.096, 0.091], and the normal hearing group, *M* = -0.061, CI [-0.153, 0.031], indicating that there was no systematic bias in participants' responses. As shown in Figure 3.13, most participants demonstrated sensitivity to matching the low-pass filtered utterance to one of two unfiltered utterances in the statement-short statement trials.

For the statement-alternative pausing trials, where the most salient cue was variation in rhythm, 95% confidence intervals around mean *d*' values were on the positive side of zero for the bilateral group, *M* = 1.188, CI [0.289, 2.087], the bimodal group, *M* = 1.348, CI [0.758, 1.938], and the normal hearing group, *M* = 2.091, CI [1.637, 2.545], indicating that children in all the groups were sensitive to the similarities between the low-pass filtered and the matching unfiltered utterance. The 95% confidence intervals around mean *c* values were on the positive side for zero for the bilateral group, *M* = 0.188, CI [0.009, 0.368], and the normal hearing group, *M* = 0.235, CI [0.030, 0.440], indicating a tendency towards greater accuracy when matching low-pass filtered foils to unfiltered foils, but overlapped zero for the bimodal group, *M* = 0.040, CI [-0.165, 0.245], indicating no systematic response bias for those participants. As shown in Figure 3.14, there was variability in sensitivity to the statement-alternative pausing trials within the three groups. Two children with normal hearing had *d*' values of less than one, indicating that sensitivity to this foil type might be influenced by factors other than hearing status of the child.

Figure 3.12. Receiver operating characteristic curves for the statement-question trials on the Prosody Matching task. Each panel depicts the hit rates and false alarm rates of individual participants in each group, across the three foil types. The diagonal indicates a *d*' score of 0, and each subsequent curved line indicates *d*' score of 1, 2, 3, and 4 respectively. *d*' scores with zero bias (along the dashed lines) for values of 1, 2, and 3 correspond approximately to percentages correct of 69%, 84%, and 93%, respectively. The letters A-J represent the 10 participants in each group, ordered from youngest (A) to oldest (J).

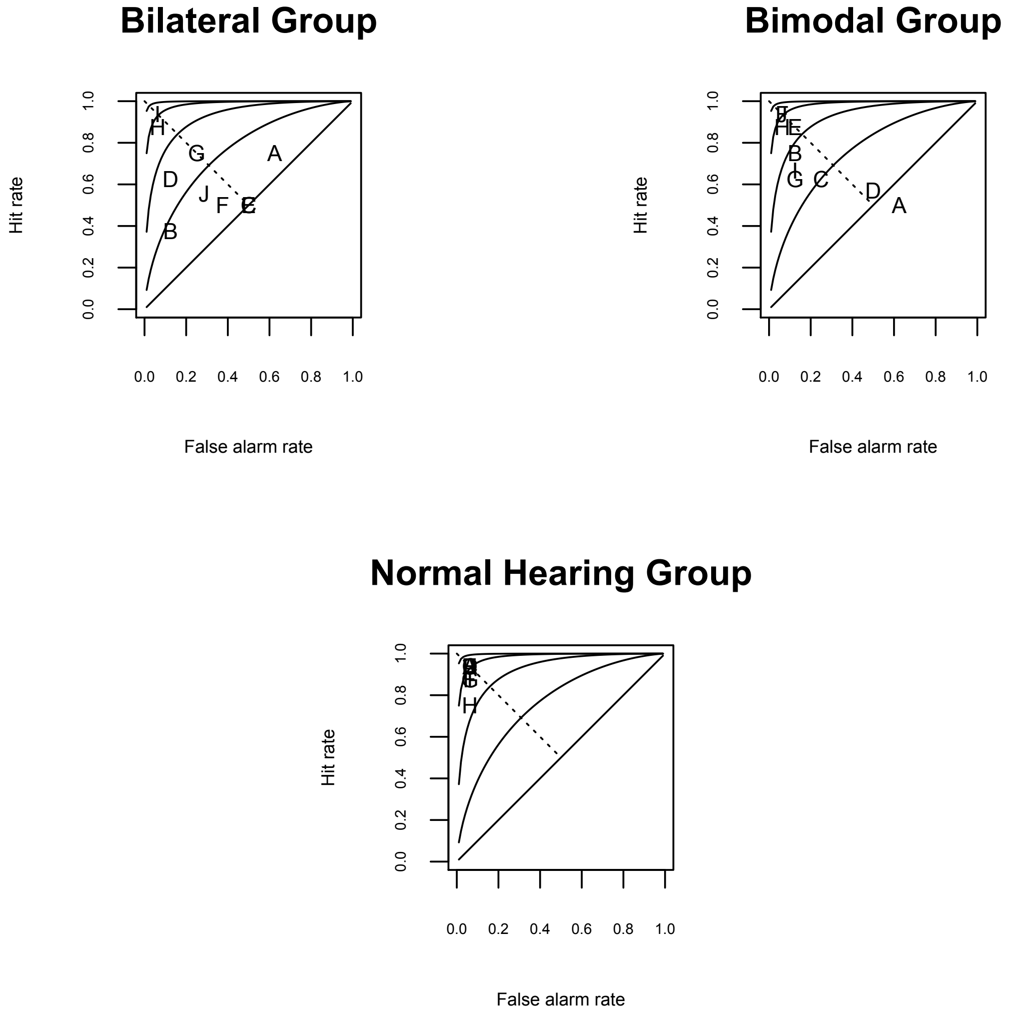
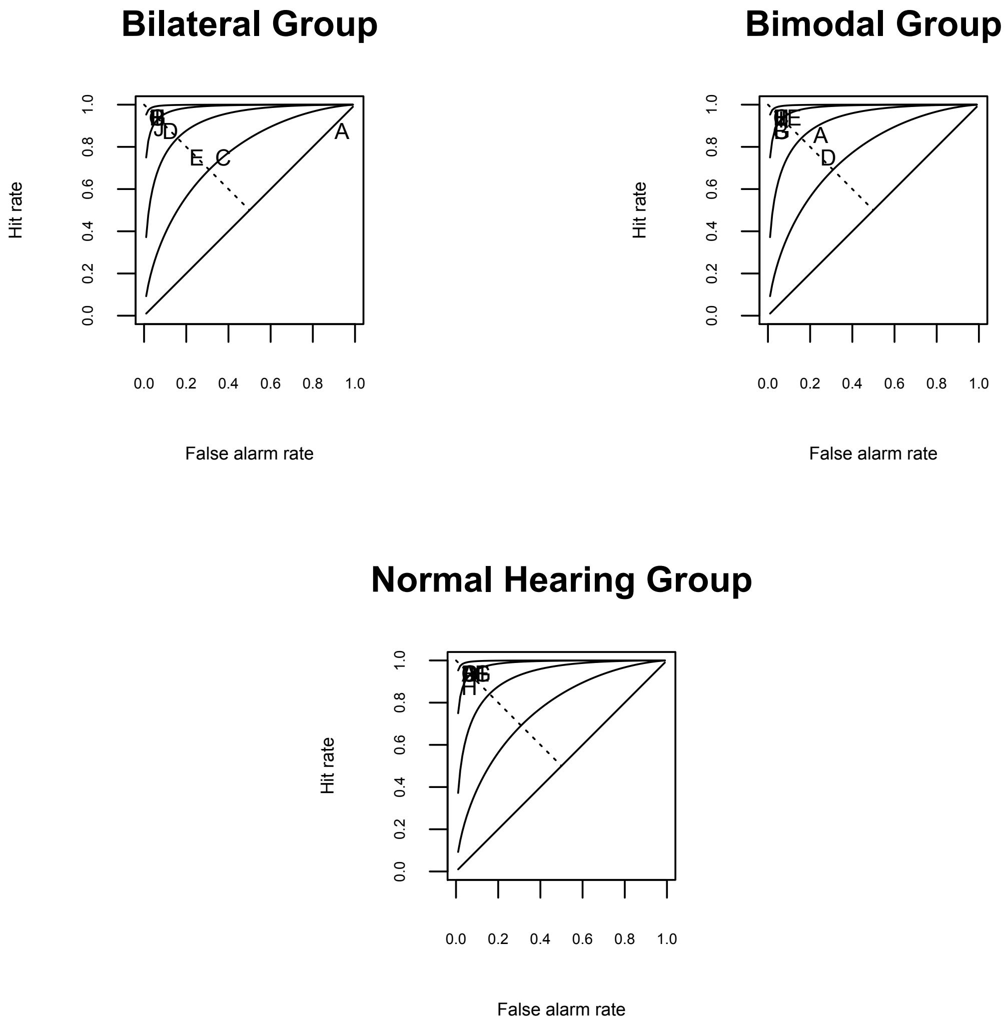


Figure 3.13. Receiver operating characteristic curves for the statement-short statement trials on the Prosody Matching task. Each panel depicts the hit rates and false alarm rates of individual participants in each group, across the three foil types. The diagonal indicates a *d*' score of 0, and each subsequent curved line indicates *d*' score of 1, 2, 3, and 4 respectively. *d*' scores with zero bias (along the dashed lines) for values of 1, 2, and 3 correspond approximately to percentages correct of 69%, 84%, and 93%, respectively. The letters A-J represent the 10 participants in each group, ordered from youngest (A) to oldest (J).

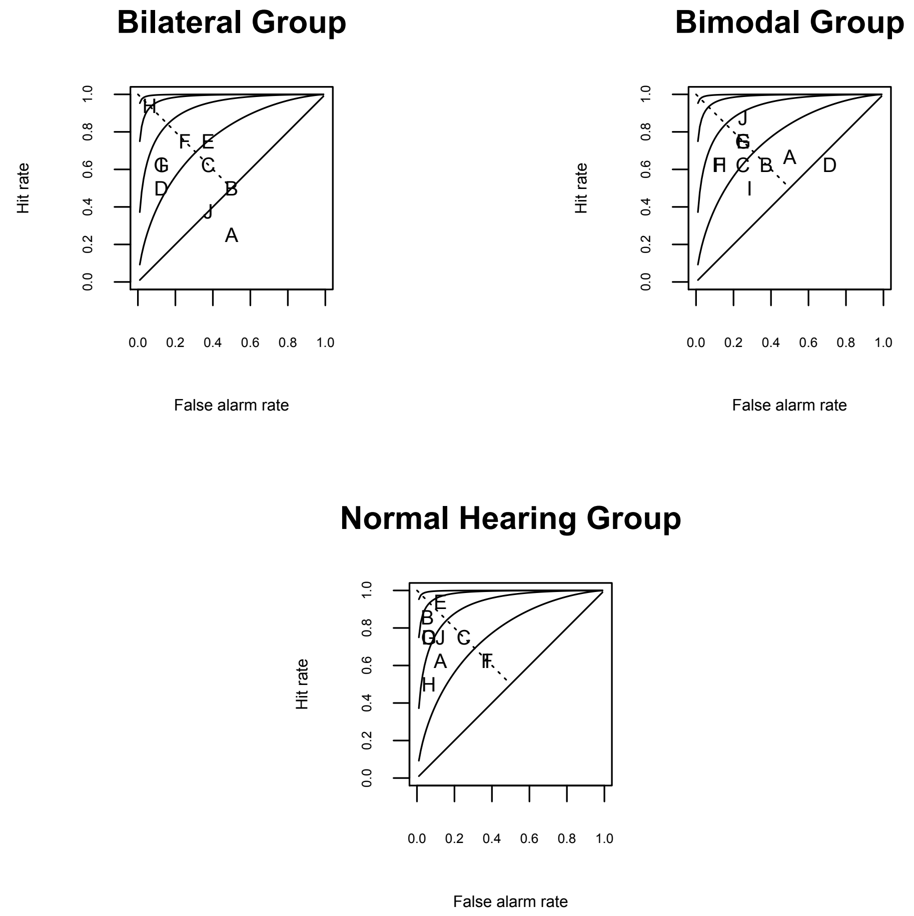


Bilateral Group

Bimodal Group

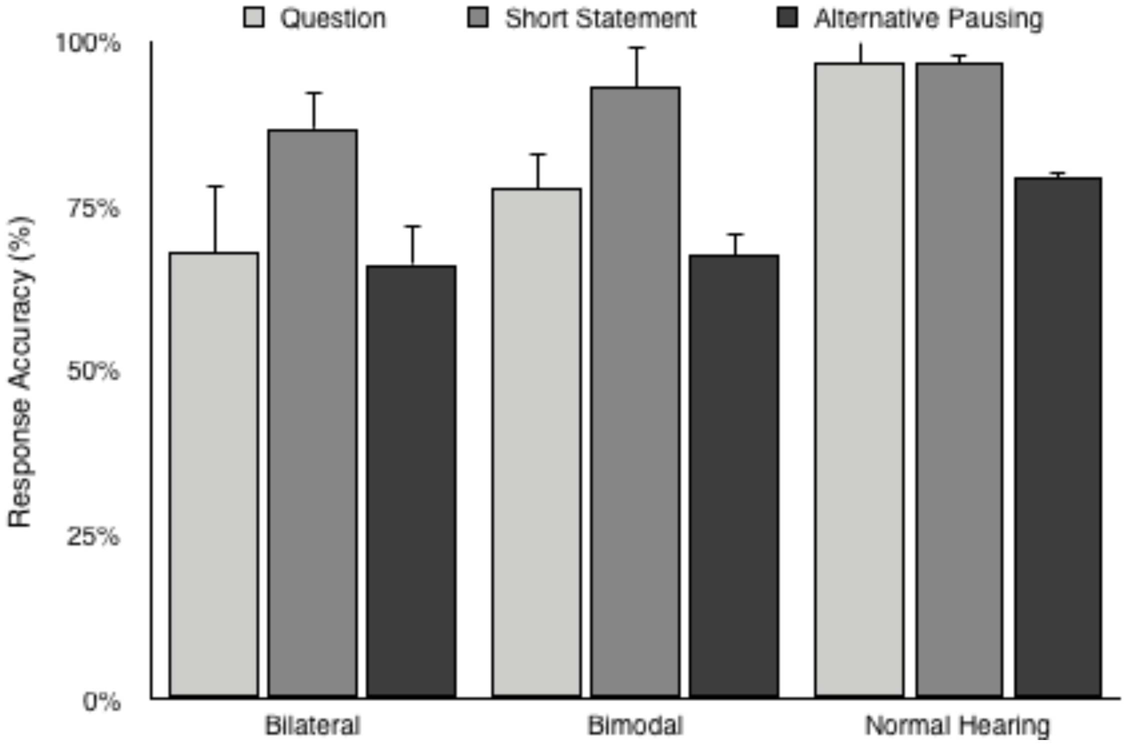
Normal Hearing Group

Figure 3.14. Receiver operating characteristic curves for the statement-alternative pausing trials on the Prosody Matching task. Each panel depicts the hit rates and false alarm rates of individual participants in each group, across the three foil types. The diagonal indicates a *d*' score of 0, and each subsequent curved line indicates *d*' score of 1, 2, 3, and 4 respectively. *d*' scores with zero bias (along the dashed lines) for values of 1, 2, and 3 correspond approximately to percentages correct of 69%, 84%, and 93%, respectively. The letters A-J represent the 10 participants in each group, ordered from youngest (A) to oldest (J).



Differences in response accuracy were evaluated by conducting a mixed model analysis of variance with RAU values for response accuracy as the dependent variable, Group as the between subjects factor, and Foil Type as the within subjects factor. See Figure 3.15. Similar to analyses conducted with *d*' values, there were significant main effects of Group, $F(2, 27) = 4.996, p < .014, \eta^2_P = .481$, and Foil Type $F(2, 54) = 48.960, p < .001, \eta^2_P = .645$, and a significant interaction effect $F(4, 54) = 4.599, p < .003, \eta^2_P = .254$. Planned linear contrasts and interaction contrasts demonstrated the same pattern of findings as the contrasts conducted with *d*' as the dependent variable. These findings indicate that the normal hearing and hearing impaired groups demonstrated similar patterns of sensitivity on the statement-short statement trials and the statement-alternative pausing trials, but differed in their sensitivity on the statement-question trials.

Figure 3.15. Mean response accuracy on the Prosody Matching task by group and stimulus type. Standard error bars are shown.



Correlational analyses between *d*' values across all three foil types and participant characteristics were conducted (Table 3.9). There was a weak, positive correlation between chronological age and *d'* values ($r = .356, p < .05$), indicating that older children demonstrated greater sensitivity on this task. Analyses conducted separately for each foil type indicated that *d*' values on the statement-question trials (Table 3.10) had a positive correlation with digit span measures ($r = .376$, $p < .04$), indicating that the participants' memory skills contributed to performance on the statement-question trials. On the statement-short statement trials (Table 3.11), *d*' values were correlated with chronological age ($r = .393$, $p < .04$) across all groups. On the statement-alternative pausing trials, there was a non-significant, weak, positive correlation between *d'* values and chronological age (Table 3.12). Correlations between audiological factors, such as, hearing age and age at amplification, and *d*' values were significant for some of the foils. The impact of audiological factors on perception of prosody is discussed at the end of this chapter.

Table 3.9. Correlations between *d*' values on Prosody Matching Task and participant characteristics – all foil types

Variable	**All Groups (*n* = 30)**	**Normal Hearing (*n* = 10)**	**Bilateral (*n* = 10)**	**Bimodal (*n* = 10)**	**Hearing Impaired (*n* = 20)**
Chronological Age	**.356**	-.011	.600	**.741**	**.657**
Non-verbal IQ	.173	.406	-.049	.328	.039
Digit Span	.269	.335	-.079	-.190	-.144
Digit Span Forward	.234	.169	-.152	.058	-.075
Digit Span Backward	.243	.455	.353	-.490	-.057
Audiological Factors					
Age at Diagnosis			-.553	-.296	-.374
Age at Amplification			-.313	-.116	-.196
Hearing Age			**.644**	.592	**.620**
Ling Six Sounds					
ah			-.082	-.083	-.018
ee			-.459	-.512	-.391
oo			-.059	-.487	-.183
ss			.218	-.322	.078
sh			-.204	-.113	-.028
mm			.212	**-.647**	-.111

Hearing age = the duration of access to low-frequency auditory information through technology. The *r* values shown in bold are significant at $p < .05$.

Table 3.10. Correlations between *d*' values on Prosody Matching Task and participant characteristics – statement-question trials

Variable	All Groups (*n* = 30)	Normal Hearing (*n* = 10)	Bilateral (*n* = 10)	Bimodal (*n* = 10)	Hearing Impaired (*n* = 20)
Chronological Age	.381	-.381	.541	**.710**	**.628**
Non-verbal IQ	.193	.286	-.088	.455	.113
Digit Span	**.376**	.451	.142	.027	.044
Digit Span Forward	.347	.421	-.079	.251	.081
Digit Span Backward	.225	.223	.529	-.299	-.017
Audiological Factors					
Age at Diagnosis			**-.646**	-.438	**-.483**
Age at Amplification			-.562	-.310	-.389
Hearing Age			**.662**	**.646**	**.662**
Ling Six Sounds					
ah			.023	.118	.128
ee			-.414	-.479	-.368
oo			-.350	-.333	-.247
ss			.101	-.451	-.093
sh			-.228	-.033	.026
mm			-.053	-.493	-.260

Hearing age = the duration of access to low-frequency auditory information through technology. The *r* values shown in bold are significant at $p < .05$.

Table 3.11. Correlations between *d*' values on Prosody Matching task and participant characteristics – statement-short statement trials

Variable	**All Groups (*n* = 30)**	**Normal Hearing (*n* = 10)**	**Bilateral (*n* = 10)**	**Bimodal (*n* = 10)**	**Hearing Impaired (*n* = 20)**
Chronological Age	**.393**	-.339	.573	.574	**.569**
Non-verbal IQ	.082	.268	.046	.138	.030
Digit Span	-.054	.149	-.329	-.130	-.293
Digit Span Forward	-.072	.123	-.387	.074	-.249
Digit Span Backward	.029	.058	.190	-.495	-.100
Audiological Factors					
Age at Diagnosis			-.169	-.198	-.131
Age at Amplification			.035	-.145	-.018
Hearing Age			.518	.480	**.484**
Ling Six Sounds					
ah			-.224	-.083	-.105
ee			-.390	-.372	-.267
oo			.177	-.213	.076
ss			.091	-.212	.087
sh			-.228	.011	.011
mm			.188	-.403	.033

Hearing age = the duration of access to low-frequency auditory information through technology. The *r* values shown in bold are significant at $p < .05$.

Table 3.12. Correlations between *d*' values on Prosody Matching task and participant characteristics – statement-alternative pausing trials

Variable	All Groups (n = 30)	Normal Hearing (n = 10)	Bilateral (n = 10)	Bimodal (n = 10)	Hearing Impaired (n = 20)
Chronological Age	.190	-.311	.383	.539	.440
Non-verbal IQ	.107	-.059	.118	.008	.071
Digit Span	.220	.145	.103	-.296	-.049
Digit Span Forward	.187	-.205	.109	-.128	.027
Digit Span Backward	.198	.261	.330	-.468	-.017
Audiological Factors					
Age at Diagnosis			**-.638**	.011	-.290
Age at Amplification			-.396	.145	-.129
Hearing Age			.468	.339	.414
Ling Six Sounds					
ah			-.032	-.308	-.090
ee			-.407	-.491	-.393
oo			-.020	-.592	-.255
ss			.206	-.075	.113
sh			-.113	-.127	-.055
mm			.376	**-.711**	-.070

Hearing age = the duration of access to low-frequency auditory information through technology. The r values shown in bold are significant at $p < .05$.

In summary, on the Prosody Matching Task, most participants were sensitive to the similarities in utterances based on variations in intonation, duration, and rhythm, as shown by matching low-pass filtered utterances to one of two unfiltered utterances. Children with normal hearing demonstrated greater accuracy than children with hearing loss in trials that required perceiving variations in intonation, but not in trials that required perceiving variations in duration and rhythm. Participants in the bilateral and bimodal groups were similar to one another in sensitivity and response accuracy across foil types. Older participants performed with greater accuracy than younger participants, suggesting that overall maturity might have contributed to accuracy on this task.

Native Language Identification Task

In this task participants heard a short utterance in English (e.g. “The children played inside because it was raining.”) or French (e.g., “Les enfants jouaient dedans parce qu’il pleuvait.”) and identified the language of the utterance as “English” or “not English”. The utterances were presented in two conditions, unfiltered and low-pass filtered (< 700 Hz). The low-pass condition was designed to reduce access to phonemic information present at higher frequencies. Raw numbers of correct responses were converted to percentage correct values, *d*' values, *c* values, and rationalized arcsine units (RAU) for each participant across the two condition (Table 3.13). See Table 3.14 for percentage correct values, *d*' values, *c* values, and rationalized arcsine units (RAU) in the unfiltered condition, and Table 3.15 for values in the low-pass filtered condition. To compute *d*' and *c* values, hits were defined as correct responses on English trials, and false alarms were incorrect responses on French trials. Hit rates of 1 were converted to .979, and false alarm rates of 0 were converted to .021.

Table 3.13. Participants' performance on Native Language Identification task – unfiltered and low-pass filtered condition

	ID	Total Accuracy (%)	English Accuracy (%)	French Accuracy (%)	Total RAU	English RAU	French RAU	Hit Rate	False Alarm Rate	*d'*	*c*
BILATERAL	CI1	77.1	70.8	83.3	76.002	69.144	82.328	0.708	0.167	1.516	0.209
	CI2	77.1	66.7	87.5	76.002	65.152	87.436	0.667	0.125	1.581	0.360
	CI3	75.0	70.8	79.2	73.795	69.144	77.660	0.708	0.208	1.361	0.132
	CI4	79.2	66.7	91.7	78.277	65.152	93.234	0.667	0.083	1.814	0.476
	CI5	75.0	79.2	70.8	73.795	77.660	69.144	0.792	0.292	1.361	-0.132
	CI6	93.8	91.7	95.8	97.914	93.234	100.316	0.917	0.042	3.115	0.174
	CI7	87.5	83.3	91.7	88.373	82.328	93.234	0.833	0.083	2.350	0.208
	CI8	91.7	91.7	91.7	94.424	93.234	93.234	0.917	0.083	2.766	0.000
	CI9	87.5	75.0	100.0	88.373	73.294	113.642	0.750	0.021	2.711	0.681
	CI10	70.8	70.8	70.8	69.544	69.144	69.144	0.708	0.292	1.097	0.000
	Mean	**81.5**	**76.7**	**86.3**	**81.650**	**75.748**	**87.937**	**0.767**	**0.140**	**1.967**	**0.211**
	SD	**7.9**	**9.5**	**10.0**	**9.794**	**10.645**	**13.912**	**0.095**	**0.097**	**0.709**	**0.242**
	SE	**2.5**	**3.0**	**3.2**	**3.097**	**3.366**	**4.399**	**0.030**	**0.031**	**0.224**	**0.077**
BIMODAL	BT1	83.3	79.2	87.5	83.086	77.660	87.436	0.792	0.125	1.963	0.169
	BT2	83.3	66.7	100.0	83.086	65.152	113.642	0.667	0.021	2.468	0.803
	BT3	83.3	79.2	87.5	83.086	77.660	87.436	0.792	0.125	1.963	0.169
	BT4	87.5	83.3	91.7	88.373	82.328	93.234	0.833	0.083	2.350	0.208
	BT5	85.4	87.5	83.3	85.656	87.436	82.328	0.875	0.167	2.118	-0.091
	BT6	89.6	79.2	100.0	91.276	77.660	113.642	0.792	0.021	2.849	0.612
	BT7	87.5	79.2	95.8	88.373	77.660	100.316	0.792	0.042	2.544	0.460
	BT8	91.7	95.8	87.5	94.424	100.316	87.436	0.958	0.125	2.882	-0.291
	BT9	81.3	75.0	87.5	80.633	73.294	87.436	0.750	0.125	1.825	0.238
	BT10	87.5	79.2	95.8	88.373	77.660	100.316	0.792	0.042	2.544	0.460
	Mean	**86.0**	**80.4**	**91.7**	**86.637**	**79.682**	**95.322**	**0.804**	**0.088**	**2.350**	**0.274**
	SD	**3.3**	**7.6**	**5.9**	**4.295**	**9.221**	**11.270**	**0.076**	**0.053**	**0.373**	**0.324**
	SE	**1.0**	**2.4**	**1.9**	**1.358**	**2.916**	**3.564**	**0.024**	**0.017**	**0.118**	**0.102**
NORMAL HEARING	NH1	89.6	91.7	87.5	91.276	93.234	87.436	0.917	0.125	2.533	-0.116
	NH2	100.0	100.0	100.0	116.338	113.642	113.642	0.979	0.021	4.074	0.000
	NH3	93.8	91.7	95.8	97.914	93.234	100.316	0.917	0.042	3.115	0.174
	NH4	93.8	91.7	95.8	97.914	93.234	100.316	0.917	0.042	3.115	0.174
	NH5	91.7	87.5	95.8	94.424	87.436	100.316	0.875	0.042	2.882	0.291
	NH6	91.7	87.5	95.8	94.424	87.436	100.316	0.875	0.042	2.882	0.291
	NH7	93.8	91.7	95.8	97.914	93.234	100.316	0.917	0.042	3.115	0.174
	NH8	100.0	100.0	100.0	116.338	113.642	113.642	0.979	0.021	4.074	0.000
	NH9	89.6	79.2	100.0	91.276	77.660	113.642	0.792	0.021	2.849	0.612
	NH10	91.7	83.3	100.0	94.424	82.328	113.642	0.833	0.021	3.004	0.535
	Mean	**93.5**	**90.4**	**96.7**	**99.224**	**93.508**	**104.358**	**0.900**	**0.042**	**3.164**	**0.214**
	SD	**3.7**	**6.5**	**3.8**	**9.348**	**11.837**	**8.900**	**0.059**	**0.031**	**0.510**	**0.231**
	SE	**1.2**	**2.1**	**1.2**	**2.956**	**3.743**	**2.814**	**0.019**	**0.010**	**0.161**	**0.073**

Total trials = 48, English trials = 24, French trials = 24, RAU = rationalized arcsin unit, *d'* = dprime, *c* = criterion location

Table 3.14. Participants' performance on Native Language Identification task – unfiltered condition

	ID	Total Accuracy (%)	English Accuracy (%)	French Accuracy (%)	Total RAU	English RAU	French RAU	Hit Rate	False Alarm Rate	*d'*	*c*
BILATERAL	CI1	95.8	91.7	100.0	100.316	91.208	109.939	0.917	0.042	3.115	0.174
	CI2	95.8	91.7	100.0	100.316	91.208	109.939	0.917	0.042	3.115	0.174
	CI3	87.5	91.7	83.3	87.436	91.208	80.981	0.917	0.167	2.350	-0.208
	CI4	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	CI5	95.8	100.0	91.7	100.316	109.939	91.208	0.958	0.083	3.115	-0.174
	CI6	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	CI7	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	CI8	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	CI9	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	CI10	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	Mean	**97.5**	**97.5**	**97.5**	**107.024**	**104.320**	**105.170**	**0.946**	**0.058**	**3.247**	**-0.003**
	SD	**4.0**	**4.0**	**5.6**	**9.318**	**9.048**	**10.339**	**0.020**	**0.040**	**0.355**	**0.122**
	SE	**1.3**	**1.3**	**1.8**	**2.947**	**2.861**	**3.269**	**0.006**	**0.013**	**0.112**	**0.039**
BIMODAL	BT1	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	BT2	95.8	91.7	100.0	100.316	91.208	109.939	0.917	0.042	3.115	0.174
	BT3	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	BT4	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	BT5	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	BT6	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	BT7	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	BT8	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	BT9	91.7	100.0	83.3	93.234	109.939	80.981	0.958	0.167	2.699	-0.382
	BT10	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	Mean	**98.8**	**99.2**	**98.3**	**110.269**	**108.066**	**107.044**	**0.954**	**0.054**	**3.352**	**-0.021**
	SD	**2.8**	**2.6**	**5.3**	**7.305**	**5.923**	**9.157**	**0.013**	**0.040**	**0.254**	**0.138**
	SE	**0.9**	**0.8**	**1.7**	**2.310**	**1.873**	**2.896**	**0.004**	**0.013**	**0.080**	**0.044**
NORMAL HEARING	NH1	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH2	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH3	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH4	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH5	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH6	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH7	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH8	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH9	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH10	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	Mean	**100.0**	**100.0**	**100.0**	**113.642**	**109.939**	**109.939**	**0.958**	**0.042**	**3.463**	**0.000**
	SD	**0.0**	**0.0**	**0.0**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
	SE	**0.0**	**0.0**	**0.0**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

Total trials = 24, English trials = 12, French trials = 12, rau = rationalized arcsin unit, *d'* = dprime, *c* = criterion location

Table 3.15. Participants' performance on Native Language Identification task – low-pass filtered condition

	ID	Total Accuracy (%)	English Accuracy (%)	French Accuracy (%)	Total RAU	English RAU	French RAU	Hit Rate	False Alarm Rate	*d'*	*c*
BILATERAL	CI1	58.3	50.0	66.7	57.474	50.000	64.585	0.500	0.333	0.431	0.215
	CI2	58.3	41.7	75.0	57.474	42.800	72.386	0.417	0.250	0.464	0.442
	CI3	62.5	50.0	75.0	61.273	50.000	72.386	0.500	0.250	0.674	0.337
	CI4	58.3	33.3	83.3	57.474	35.415	80.981	0.333	0.167	0.537	0.699
	CI5	54.2	58.3	50.0	53.725	57.200	50.000	0.583	0.500	0.210	-0.105
	CI6	87.5	83.3	91.7	87.436	80.981	91.208	0.833	0.083	2.350	0.208
	CI7	75.0	66.7	83.3	73.294	64.585	80.981	0.667	0.167	1.398	0.268
	CI8	83.3	83.3	83.3	82.328	80.981	80.981	0.833	0.167	1.935	0.000
	CI9	75.0	50.0	100.0	73.294	50.000	109.939	0.500	0.042	1.732	0.866
	CI10	41.7	41.7	41.7	42.526	42.800	42.800	0.417	0.583	-0.421	0.000
	Mean	**65.4**	**55.8**	**75.0**	**64.630**	**55.476**	**74.625**	**0.558**	**0.254**	**0.931**	**0.293**
	SD	**14.3**	**17.1**	**18.0**	**13.968**	**15.637**	**19.360**	**0.171**	**0.174**	**0.877**	**0.309**
	SE	**4.5**	**5.4**	**5.7**	**4.417**	**4.945**	**6.122**	**0.054**	**0.055**	**0.277**	**0.098**
BIMODAL	BT1	66.7	58.3	75.0	65.152	57.200	72.386	0.583	0.250	0.885	0.232
	BT2	70.8	41.7	100.0	69.144	42.800	109.939	0.417	0.042	1.521	0.971
	BT3	66.7	58.3	75.0	65.152	57.200	72.386	0.583	0.250	0.885	0.232
	BT4	75.0	66.7	83.3	73.294	64.585	80.981	0.667	0.167	1.398	0.268
	BT5	70.8	75.0	66.7	69.144	72.386	64.585	0.750	0.333	1.105	-0.122
	BT6	79.2	58.3	100.0	77.660	57.200	109.939	0.583	0.042	1.942	0.761
	BT7	75.0	58.3	91.7	73.294	57.200	91.208	0.583	0.083	1.593	0.586
	BT8	83.3	91.7	75.0	82.328	91.208	72.386	0.917	0.250	2.057	-0.354
	BT9	70.8	50.0	91.7	69.144	50.000	91.208	0.500	0.083	1.383	0.691
	BT10	75.0	58.3	91.7	73.294	57.200	91.208	0.583	0.083	1.593	0.586
	Mean	**73.3**	**61.7**	**85.0**	**71.760**	**60.698**	**85.623**	**0.617**	**0.158**	**1.436**	**0.385**
	SD	**5.3**	**13.7**	**11.7**	**5.390**	**13.244**	**15.867**	**0.137**	**0.105**	**0.397**	**0.411**
	SE	**1.7**	**4.3**	**3.7**	**1.704**	**4.188**	**5.018**	**0.043**	**0.033**	**0.126**	**0.130**
NORMAL HEARING	NH1	79.2	83.3	75.0	77.660	80.981	72.386	0.833	0.250	1.642	-0.146
	NH2	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH3	87.5	83.3	91.7	87.436	80.981	91.208	0.833	0.083	2.350	0.208
	NH4	87.5	83.3	91.7	87.436	80.981	91.208	0.833	0.083	2.350	0.208
	NH5	83.3	75.0	91.7	82.328	72.386	91.208	0.750	0.083	2.057	0.354
	NH6	83.3	75.0	91.7	82.328	72.386	91.208	0.750	0.083	2.057	0.354
	NH7	87.5	83.3	91.7	87.436	80.981	91.208	0.833	0.083	2.350	0.208
	NH8	100.0	100.0	100.0	113.642	109.939	109.939	0.958	0.042	3.463	0.000
	NH9	79.2	58.3	100.0	77.660	57.200	109.939	0.583	0.042	1.942	0.761
	NH10	83.3	66.7	100.0	82.328	64.585	109.939	0.667	0.042	2.162	0.650
	Mean	**87.1**	**80.8**	**93.3**	**89.190**	**81.036**	**96.818**	**0.800**	**0.083**	**2.384**	**0.260**
	SD	**7.5**	**13.1**	**7.7**	**13.384**	**17.189**	**12.662**	**0.118**	**0.062**	**0.609**	**0.285**
	SE	**2.4**	**4.1**	**2.4**	**4.232**	**5.436**	**4.004**	**0.037**	**0.020**	**0.193**	**0.090**

Total trials = 24, English trials = 12, French trials = 12, rau = rationalized arcsin unit, *d'* = dprime, *c* = criterion location

To examine differences in sensitivity to the English-French distinction, an analysis of variance with d' as the dependent variable, Group as the between subjects factor, and Condition (unfiltered, low-pass filtered) as the within subject factor was conducted. See Figure 3.16. There were significant main effects of Group, $F(2,27) = 12.687$, $p < .001$, $\eta^2_P = .551$, and Condition, $F(1,27) = 218.355$, $p < .001$, $\eta^2_P = .89$, as well as a significant interaction effect between Group and Condition, $F(2,27) = 9.249$, $p < .001$, $\eta^2_P = .407$. A set of two planned linear contrasts indicated that the difference between the d' values in the unfiltered vs. low-pass filtered conditions was greater in the combined hearing loss groups than in the normal hearing group, $F(1,27) = 16.672$, $p < .001$, and that the unfiltered vs. low-pass filtered difference was equivalent across the two hearing impaired groups, $F(1,27) = 1.860$, n.s.

Figure 3.17 and Figure 3.18 show hit rates, false alarm rates, and d' values for individual participants in each group in the unfiltered and low-pass filtered condition respectively. As shown in Figure 3.17, most children in the three groups demonstrated a high sensitivity to the English-French distinction in the unfiltered condition. However, in the low-pass filtered condition (Figure 3.18), all but one of the children with normal hearing had d' values of two or more (about 84% accuracy), whereas most of the children with hearing loss had d' values lower than two. As also shown in Figure 3.18, this suggests that children with normal hearing were better able than those with hearing impairments to utilize the low-pass filtered speech to distinguish between English and French. The group 95% confidence intervals around mean d' values were all on the positive side of zero: bilateral group, $M = 0.931$, CI [0.304, 1.558], bimodal group $M = 1.436$, CI [1.152, 1.720], and the normal hearing group, $M = 2.384$, CI [1.948, 2.819]. This indicates that even though children with normal hearing demonstrated greater accuracy than children with hearing loss, most children were sensitive to the English-

French distinction.

Figure 3.16. Participants' average sensitivity on the Native Language Identification task by study group. Standard error bars are shown. *d*' value of 4.074 corresponds to 100% accuracy on this task, and *d*' values 0, 1, 2, and 3 correspond approximately to percentages correct of 50% (chance), 69%, 84%, and 93%, respectively.

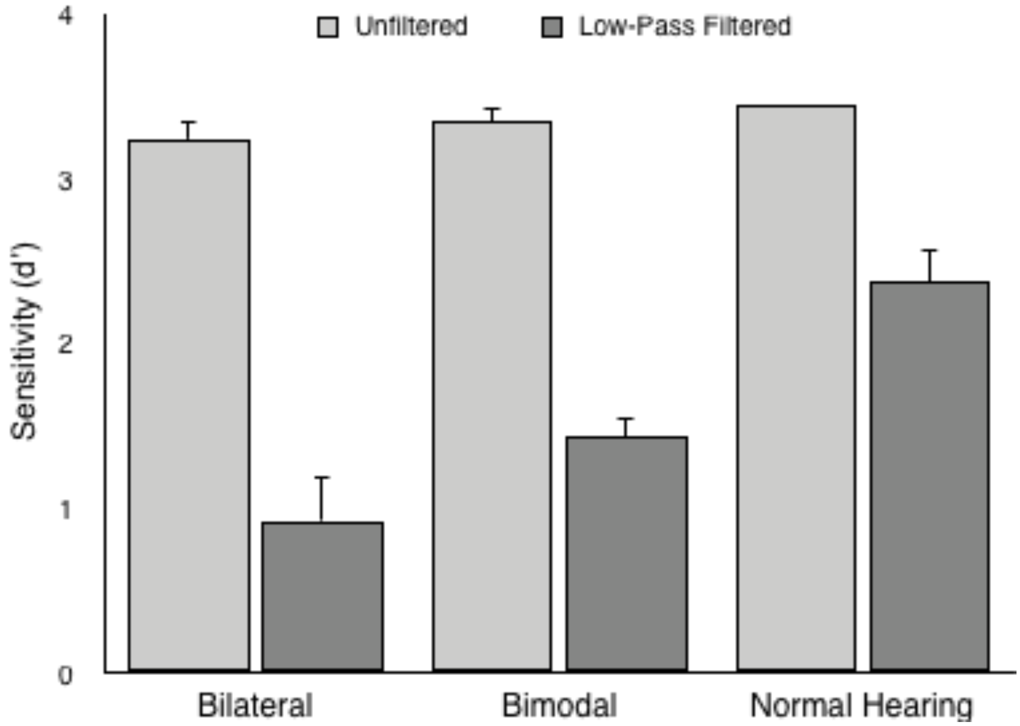


Figure 3.17. Receiver operating characteristic curves on the Native Language Identification task – unfiltered condition, per group. Each panel depicts the hit rates and false alarm rates of individual participants in each group, across the three foil types. The diagonal indicates a *d*' score of 0, and each subsequent curved line indicates *d*' score of 1, 2, 3, and 4 respectively. *d*' scores with zero bias (along the dashed lines) for values of 1, 2, and 3 correspond approximately to percentages correct of 69%, 84%, and 93%, respectively. The letters A-J represent the 10 participants in each group, ordered from youngest (A) to oldest (J).

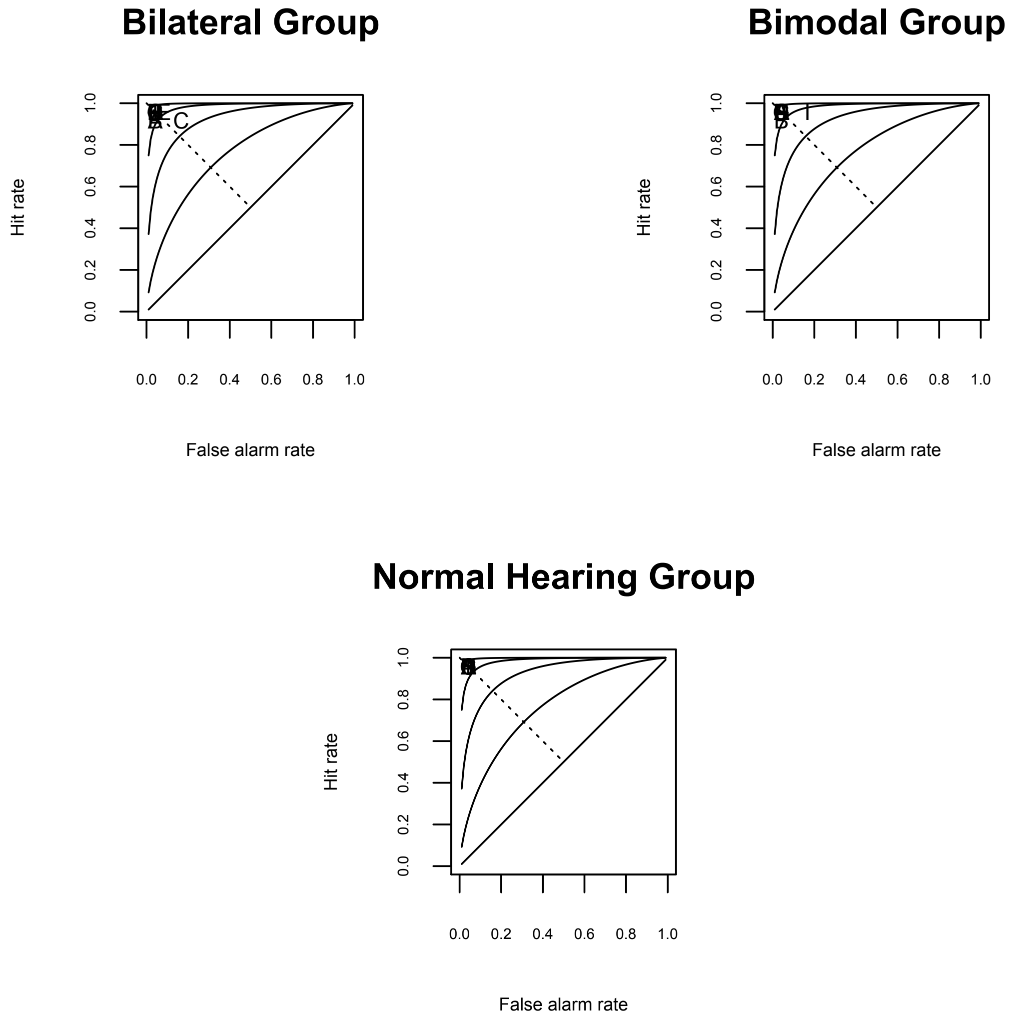
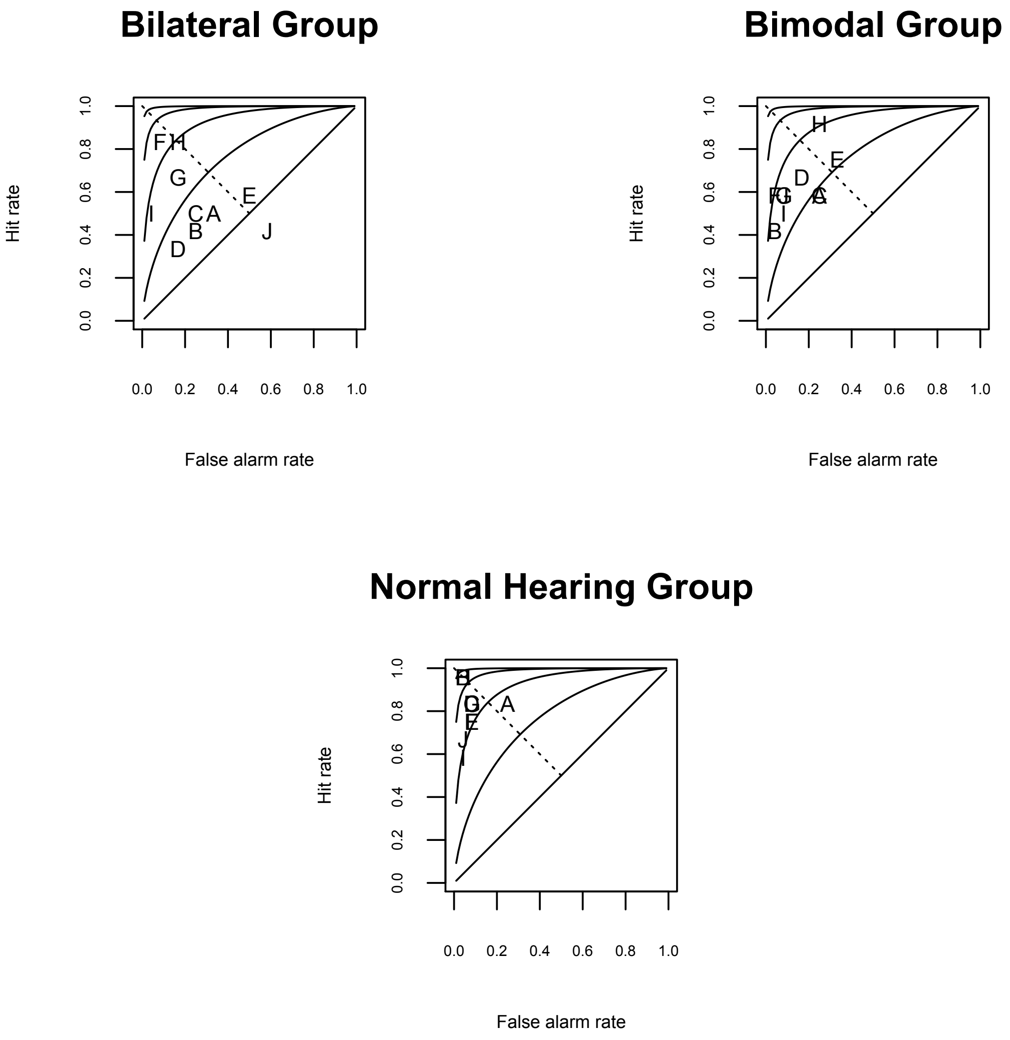
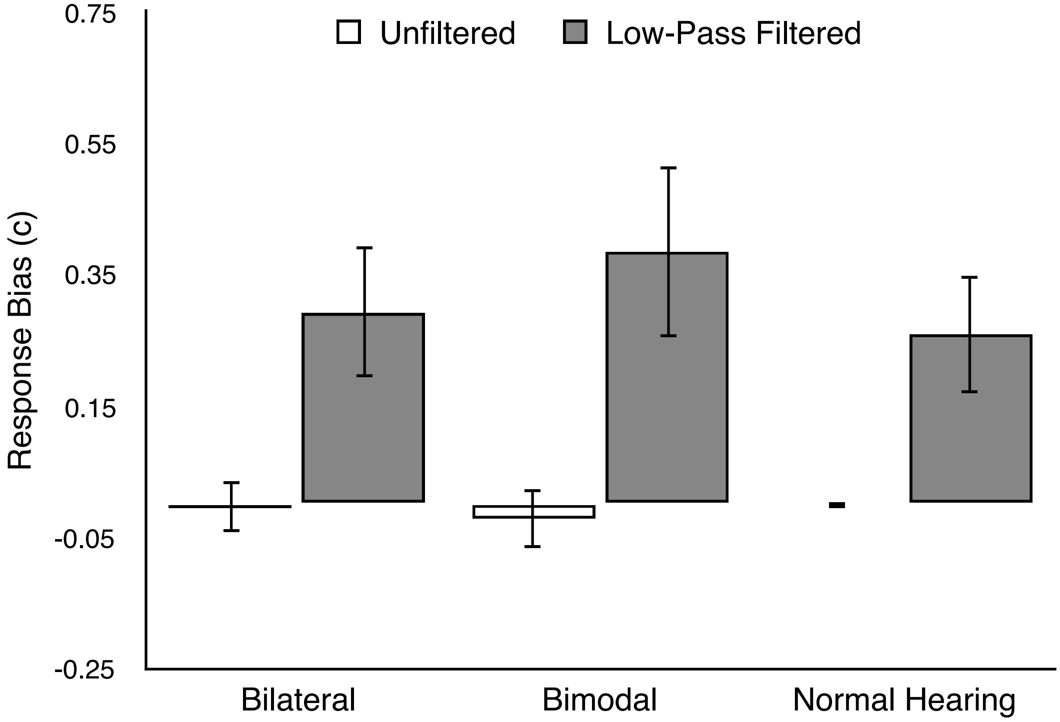


Figure 3.18. Receiver operating characteristic curves on the Native Language Identification task – low-pass filtered condition, per group. Each panel depicts the hit rates and false alarm rates of individual participants in each group, across the three foil types. The diagonal indicates a *d'* score of 0, and each subsequent curved line indicates *d'* score of 1, 2, 3, and 4 respectively. *d'* scores with zero bias (along the dashed lines) for values of 1, 2, and 3 correspond approximately to percentages correct of 69%, 84%, and 93%, respectively. The letters A-J represent the 10 participants in each group, ordered from youngest (A) to oldest (J).



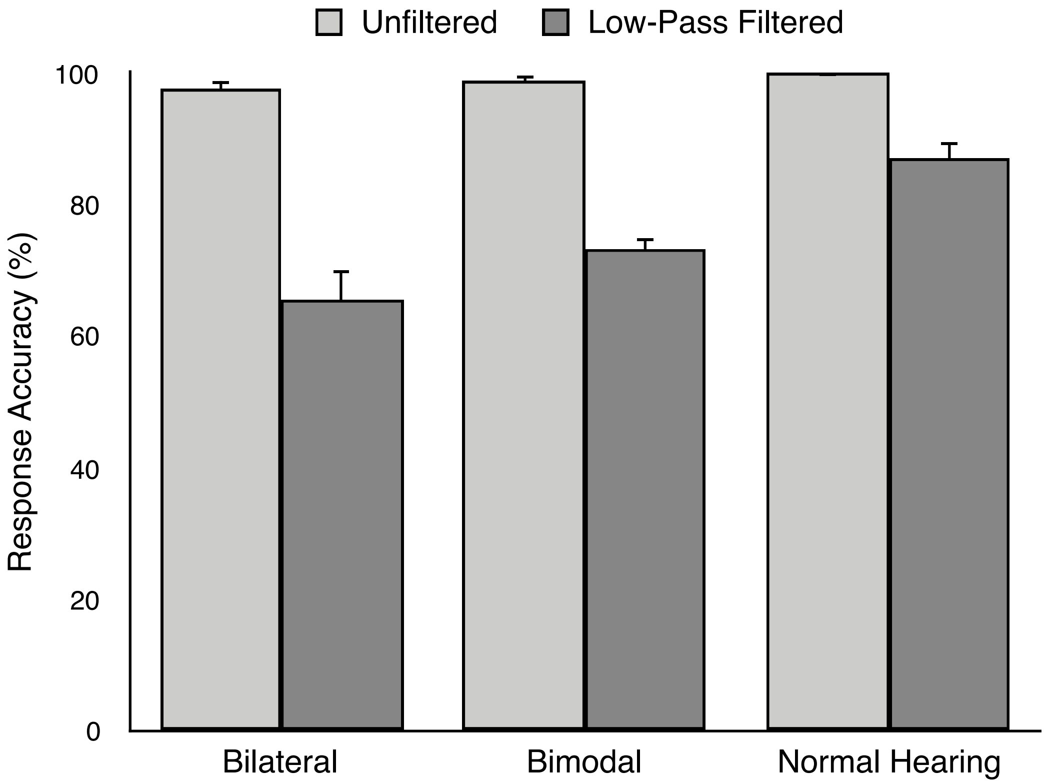
To examine differences in tendency to identify the utterances as being in one language over another, an analysis of variance was conducted, with c values as the dependent variable, Group as the between subjects factor, and Condition (unfiltered, low-pass filtered) as the within subject factor. See Figure 3.19. There was a significant main effect of Condition, $F(1,27) = 25.210$, $p < .001$, $\eta^2_P = .483$, indicating that there was a greater tendency to identify utterances as being "not English" in the low-pass filtered condition $M = 0.313$, $SE = 0.061$, than the unfiltered condition, $M = -0.008$, $SE = 0.019$. The main effect of group $F(2,27) = 0.222$, $p < .803$, $\eta^2_P = .017$, and the interaction effect $F(2,27) = 0.473$, $p < .628$, $\eta^2_P = .034$, were not significant, indicating that there was no systematic difference in bias across the three groups. Additionally, 95% confidence intervals around mean c values were also on the positive side of zero for all groups: bilateral group, $M = 0.293$, CI [0.072, 0.514], bimodal group $M = 0.385$, CI [0.091, 0.679], and the normal hearing group, $M = 0.260$, CI [0.056, 0.463]. Collectively, these findings on the d' and c measures suggest that sensitivity to the English-French distinction was poorer in the low-pass filtered condition, that this effect of low-pass filtering was stronger in the groups with hearing impairment than the group with normal hearing, and that across all groups there was a tendency to identify utterances as "not English" in the low-pass filtered condition. This could be attributed to the utterance not sounding "English enough", or lack of experience with listening to low-pass filtered utterances.

Figure 3.19. Participants' response bias on the Native Language Identification Task, by group and condition. A negative *c* value indicates a tendency toward identifying an utterance as "English", a positive *c* value indicates a tendency toward identifying an utterance as "not English".



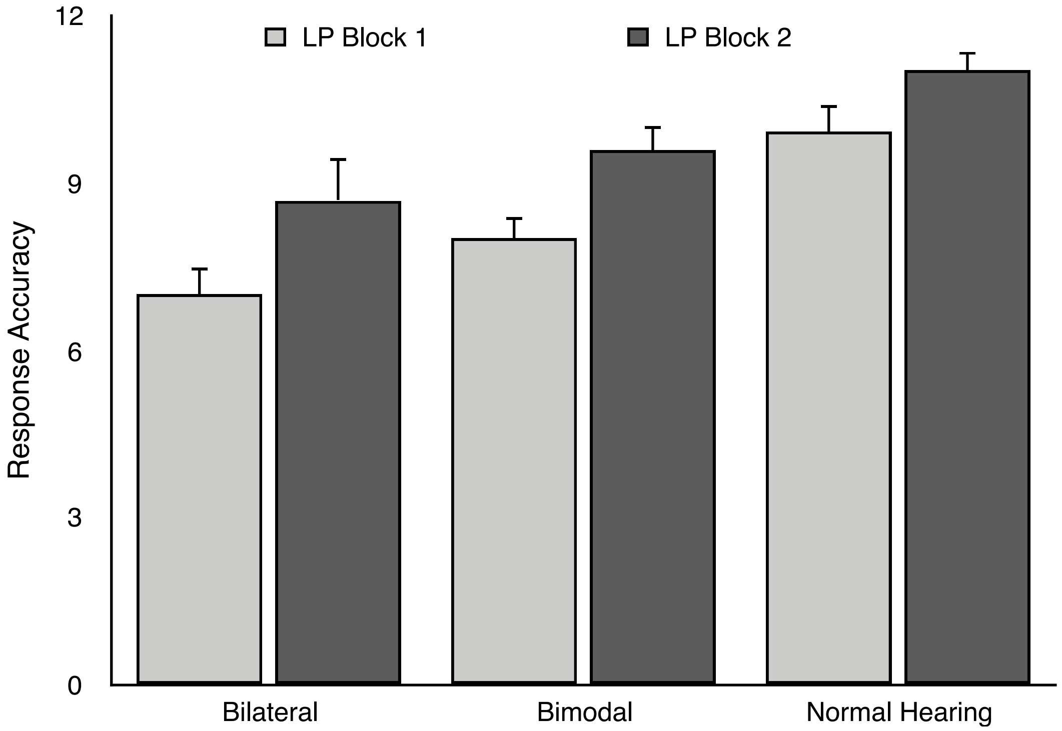
The findings for response accuracy (in RAU) were mirrored by those for the *d'* measure, as expected. For response accuracy there were significant main effects of Group $F(2,27) = 12.037$, $p < .001$, $\eta^2_P = .556$, Condition, $F(1,27) = 236.482$, $p < .001$, $\eta^2_P = .898$, and the interaction, $F(2,27) = 7.272$, $p < .003$, $\eta^2_P = .350$. As shown in Figure 3.20, across all three groups accuracy approached or reached 100% in the unfiltered condition, whereas accuracy in the low-pass filtered condition averaged 65.4% in the bilateral group, 73.3% in the bimodal group, and 87.1% in the normal hearing group. Together, these findings indicate that the low-pass filtered condition was more challenging than the unfiltered condition for all children. Compared to children with normal hearing, children with hearing loss did worse in low-pass filtered condition.

Figure 3.20. Participants' mean response accuracy on the Native Language Identification task, by study group and condition. Vertical bars indicate standard error.



An interesting trend was observed in the bilateral and bimodal groups, which suggested that repeated exposure to low-pass filtered speech in combination with unfiltered speech, might improve response accuracy. In this task, the unfiltered and low-pass filtered conditions were presented in four blocks of 12 trials, in a constrained, alternating order, i.e., all participants started with the unfiltered condition, followed by the low-pass filtered condition, and this sequence of conditions was repeated. In other words, the first and third blocks of trials were the unfiltered condition, whereas the second and fourth block of trials were the low-pass filtered condition. There were no differences in response accuracy between the two blocks of the unfiltered condition for any of the groups. However, there was a significant difference in response accuracy between the two blocks of the low-pass filtered condition for the bilateral group, with 14.1% increase in response accuracy, $t_{(9)} = -2.613$, $p < .028$, and the bimodal group with 13.3% increase in response accuracy, $t_{(9)} = -2.333$, $p < .045$, but not the normal hearing group (Figure 3.21). This indicates that for children with hearing loss, exposure to low-pass filtered utterances (block 2 of 4), followed by exposure to unfiltered utterances (block 3 of 4), might contribute to greater accuracy in a subsequent task involving low-pass filtered stimuli (block 4 of 4).

Figure 3.21. Participants' mean response accuracy in the low-pass filtered condition by block of presentation. Standard error bars are shown.



Correlational analyses were conducted to explore the relationship between sensitivity to the English-French distinction (*d'* values) in the unfiltered and low-pass filtered conditions and participant characteristics (Tables 3.16 and 3.17). In the low-pass filtered condition, there was a significant positive correlation between *d*' values and digit span forward measure, ($r = .466$, $p < .01$), indicating that participants' memory skills were associated with greater sensitivity to the English-French distinction. Correlations between audiological factors, such as, hearing age and age at amplification, and *d*' values were significant for some of the foils. The impact of audiological factors on perception of prosody is discussed at the end of this chapter.

Table 3.16. Correlations between *d*' values on Native Language Identification task – unfiltered condition and participant characteristics

Variable	**All Groups (*n* = 30)**	**Normal Hearing (*n* = 10)**	**Bilateral (*n* = 10)**	**Bimodal (*n* = 10)**	**Hearing Impaired (*n* = 20)**
Chronological Age	.253	NA	.617	-.103	.376
Non-verbal IQ	.157	NA	.160	.169	.134
Digit Span	.164	NA	.149	-.214	-.015
Digit Span Forward	.038	NA	-.043	-.321	-.141
Digit Span Backward	.337	NA	.583	.273	.332
Audiological Factors					
Age at Diagnosis			-.581	.212	-.152
Age at Amplification			-.409	.317	-.042
Hearing Age			**.687**	-.202	.330
Ling Six Sounds					
ah			-.523	-.398	-.400
ee			**-.734**	-.251	-.438
oo			-.612	-.351	-.356
ss			-.519	-.225	-.292
sh			-.309	-.271	-.146
mm			-.284	-.455	-.320

Hearing age = the duration of access to low-frequency auditory information through technology. The *r* values shown in bold are significant at $p < .05$.

Table 3.17. Correlations between *d*' values on Native Language Identification task – low-pass filtered condition and participant characteristics

Variable	All Groups (n = 30)	Normal Hearing (n = 10)	Bilateral (n = 10)	Bimodal (n = 10)	Hearing Impaired (n = 20)
Chronological Age	.092	-.106	.230	**.639**	.370
Non-verbal IQ	.186	-.293	.320	.382	.253
Digit Span	**.477**	-.010	.315	.325	.224
Digit Span Forward	**.466**	-.354	.323	.608	.365
Digit Span Backward	.243	.267	.122	-.279	-.151
Audiological Factors					
Age at Diagnosis			-.428	-.464	-.329
Age at Amplification			-.231	-.458	-.247
Hearing Age			.280	**.652**	.396
Ling Six Sounds					
ah			.128	.426	.372
ee			-.215	-.185	-.079
oo			.083	-.235	.059
ss			.214	-.231	.193
sh			.057	.034	.226
mm			.348	-.231	.177

Hearing age = the duration of access to low-frequency auditory information through technology. The r values shown in bold are significant at $p < .05$.

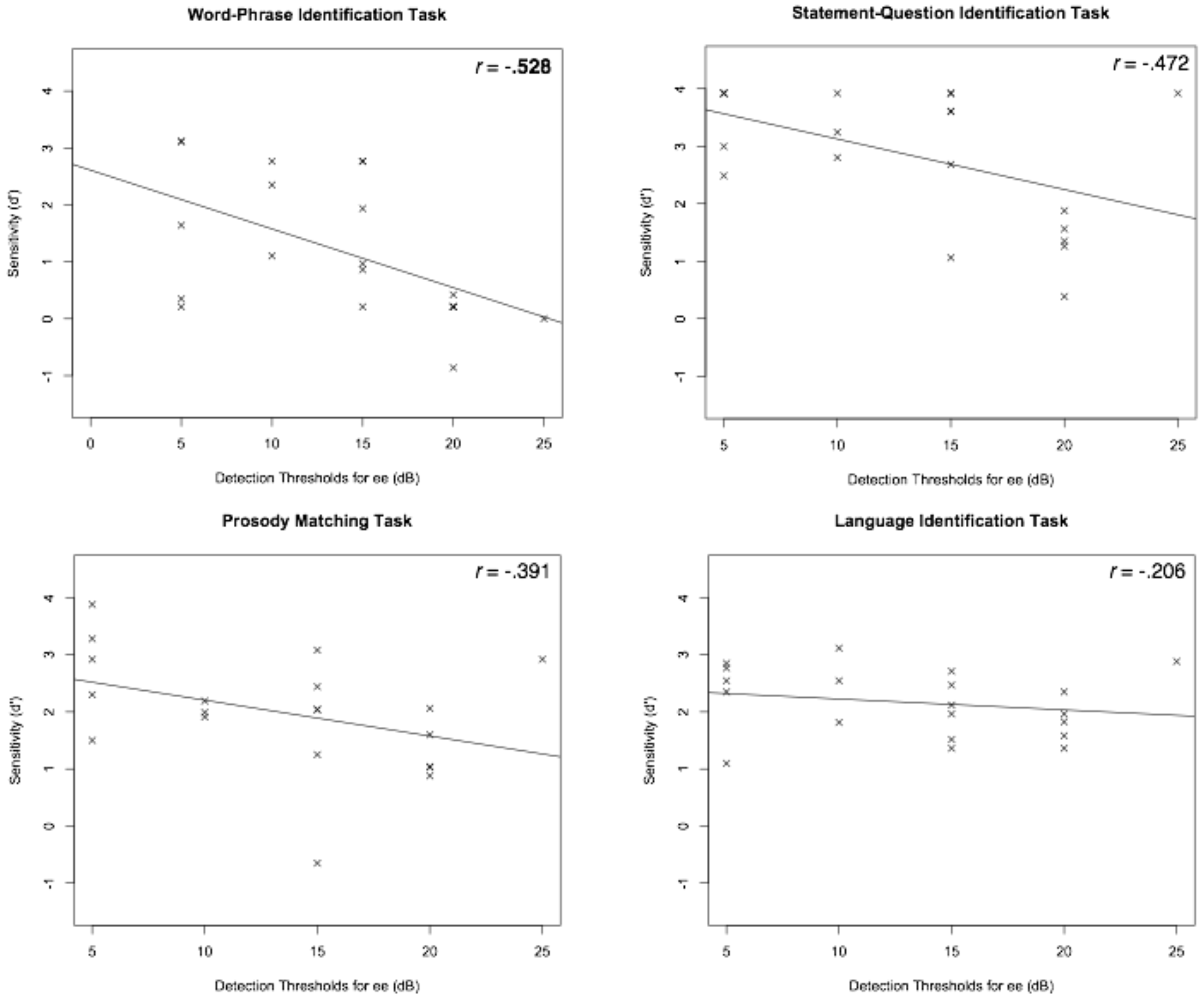
In summary, on the Native Language Identification task, children with and without hearing loss were more accurate in identifying the language of the utterance when phonemic and prosodic cues were available in the unfiltered condition, compared to the low-pass filtered condition where only some phonemic cues were available. In the low-pass filtered condition, across groups most children were more likely to reject an utterance as being in English. Additionally, children with hearing loss were less accurate than children with normal hearing in this condition, but demonstrated an increase in accuracy after repeated exposure to the low-pass filtered stimuli, suggesting that performance on this task could be improved with training.

Impact of Audiological Factors

Overall, children with hearing loss performed similarly to children with normal hearing in perception of word-level stress, intonation, and rhythm. However, compared to children with normal hearing, children with hearing loss demonstrated less sensitivity to distinguishing between languages when minimal phonemic cues were available. This suggests that on certain tasks children with hearing loss who were using hearing technology were able to perform similarly to their hearing peers. Correlational analyses were conducted to explore the relationship between sensitivity (*d*' values) and the audiological characteristics of the participants with hearing loss. The contribution of low-frequency auditory access to perception of prosody, and the impact of how early participants started using hearing technology, and how long they had been using it, were examined. For each of the four primary tasks, correlations between *d*' values and audiological characteristics were analyzed separately for the bilateral and bimodal group, as well as together as one group of hearing-impaired participants.

To evaluate low-frequency auditory access available to each participant, the Phonak Ling Six Sound Test was administered at the beginning of the study visit. Detection thresholds for “ee” (F_1 = 370 Hz) and “mm” (F_1 = 250-350 Hz) from this test were used as measures of access to low-frequency information. Across the two hearing-impaired groups, there were weak to moderate, negative correlations between *d*' values and detection threshold for “ee” on all four tasks (Figure 3.22). The correlation was significant for *d*' values on the Word-Phrase Discrimination Task ($r = -.528$, $p < .017$). Similar patterns of weak to moderate, negative correlations between *d*' values and detection threshold for “ee” were observed within the Bilateral group and the Bimodal group when analyzed separately (Figure 3.23). These findings indicate that lower (better) detection thresholds for “ee” were correlated with greater sensitivity, and thereby accuracy, on all four primary tasks.

Figure 3.22. Correlation between *d*' and thresholds for “ee” in the two hearing impaired groups combined, per task. Solid lines indicate linear regression. The *r* values shown in bold are significant at $p < .05$.



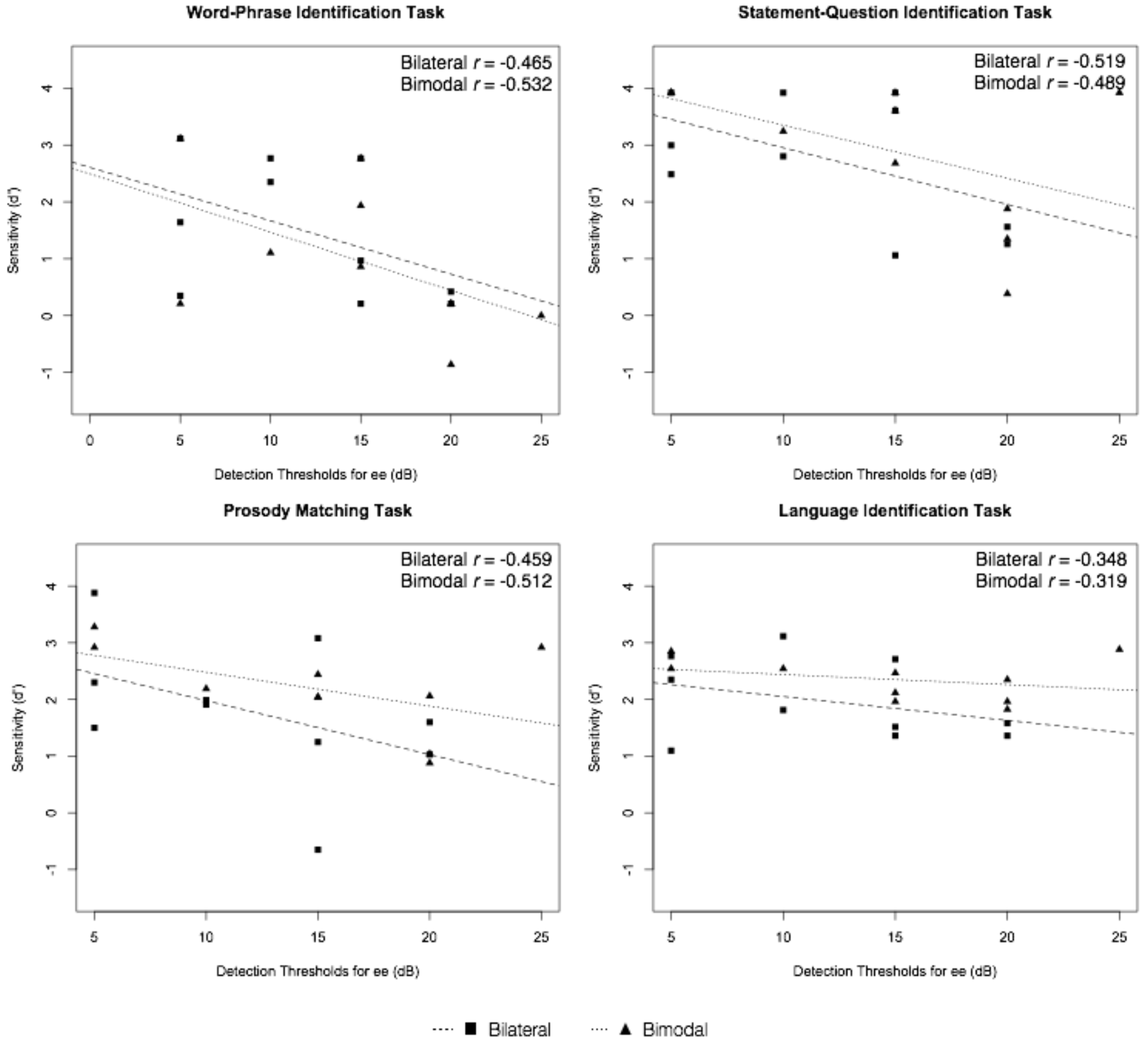
Word-Phrase Identification Task

Statement-Question Identification Task

Prosody Matching Task

Language Identification Task

Figure 3.23. Correlations between *d*' values and thresholds for "ee" in the bimodal and bilateral group per task. Solid lines indicate linear regression. The *r* values shown in bold are significant at $p < .05$.



Across the two hearing-impaired groups, there were weak, negative correlations between *d*' values and detection threshold for "mm" on all four tasks (Figure 3.24). However, when relationships between *d*' values and detection threshold for "mm" were analyzed separately for the two hearing impaired groups, there were non-significant weak, positive relationships in the bilateral group, but moderate, negative relationships in the bimodal group (Figure 3.25). In the bimodal group, the negative correlation was significant for *d*' values on the Word-Phrase Identification Task ($r = -.653$, $p < .04$), and the Prosody Matching Task ($r = -.647$, $p < .043$). Correlations between detection thresholds for "mm" and *d*' values on the other tasks were non-significant. These findings indicate that lower (better) detection thresholds for "mm" were correlated with greater sensitivity and thereby accuracy on all four primary tasks in the bimodal group, but not the bilateral group. This seemingly contradictory finding might be attributed to limited access to frequencies below 300 Hz available through cochlear implants.

Figure 3.24. Correlation between *d*' and thresholds for "mm" in the two hearing impaired groups combined, per task. Solid lines indicate linear regression. The *r* values shown in bold are significant at $p < .05$.

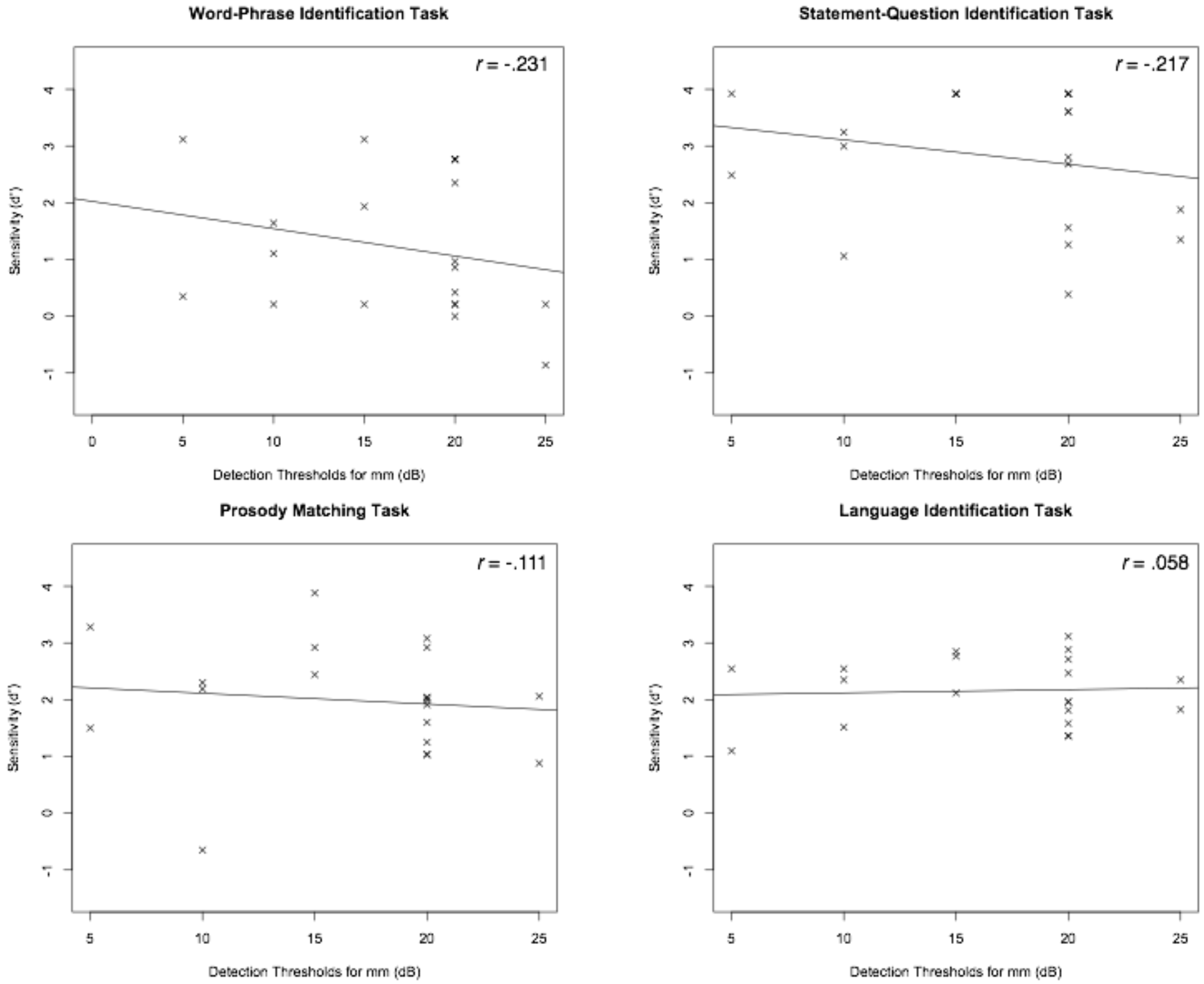
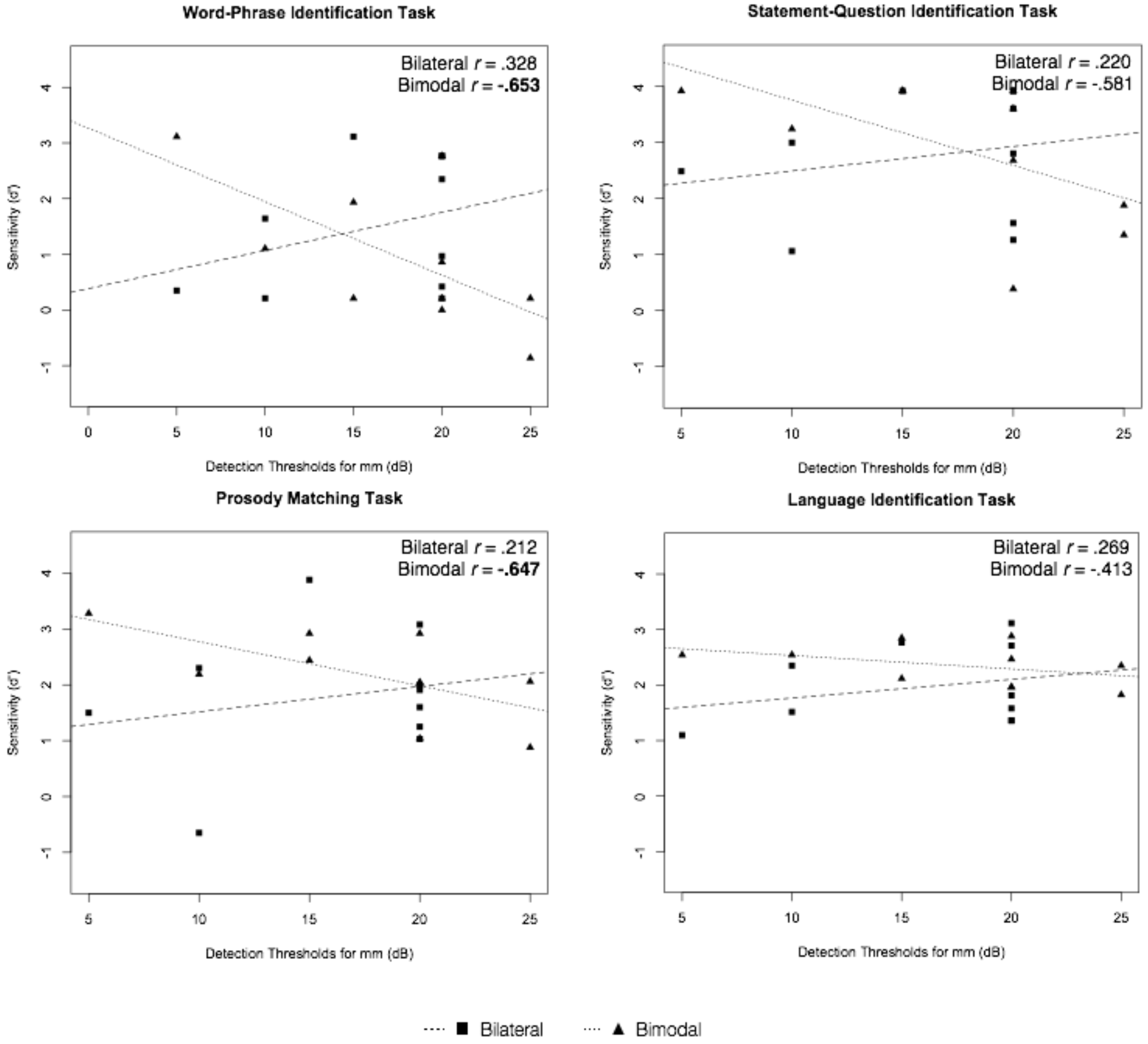


Figure 3.25. Correlations between *d*' values and thresholds for "mm" in the bimodal and bilateral group, per task. Solid lines indicate linear regression. The *r* values shown in bold are significant at $p < .05$.



Multiple regression analyses with detection thresholds for “ee” and “mm” as predictors, were conducted to evaluate how well access to low-frequency information predicted sensitivity and thereby accuracy on the four primary tasks (Table 3.18).

Table 3.18. Multiple regression analyses for *d*' values across tasks and audiological factors

Predictors	Hearing Age	Age at Amplification	Hearing Age + Age at Amplification	Detection Threshold “ee”	Detection Threshold “mm”	Detection Thresholds “ee” + “mm”
Word-Phrase Identification Task						
Hearing Impaired	.028	.009	.028	**.279**	.053	**.321**
Bilateral	.276	**.429**	.511	.216	.107	**.791**$^{\#}$
Bimodal	.008	.085	.133	.283	**.427**	.428
Statement-Question Identification Task						
Hearing Impaired	**.312**	.077	**.317**	.223	.047	.251
Bilateral	**.467**	.198	.502	.269	.048	**.711**$^{\#}$
Bimodal	.200	.031	.273	.239	.337	.340
Prosody Matching Task						
Hearing Impaired	**.384**	.039	**.432**	.153	.012	.210
Bilateral	**.415**	.098	.418	.211	.045	**.583**$^{\#}$
Bimodal	.350	.014	**.644**$^{\#}$	.263	**.419**	.419
Native Language Identification Task						
Hearing Impaired	.170	.045	.172	.042	.003	.127
Bilateral	.173	.097	.198	.121	.072	.479
Bimodal	.150	.036	.181	.102	.171	.171

“Hearing Impaired” indicates r^2 values obtained when data from the Bilateral and Bimodal groups were combined. The r^2 values shown in bold are significant at $p < .05$, # indicates r^2 values where the full model (two predictors) accounted for significantly more variance than the restricted model (one predictor).

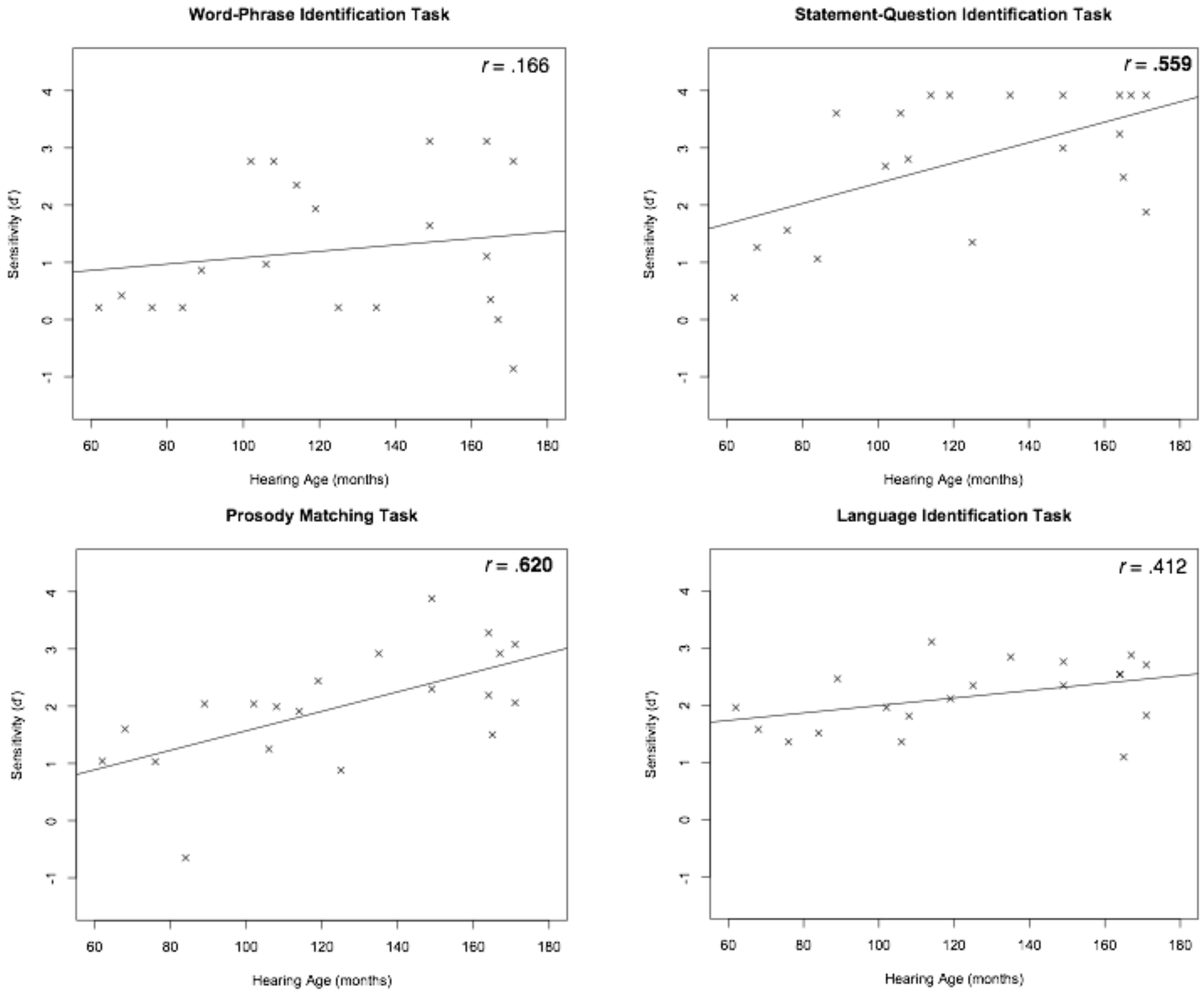
Given the contrasting relationship between detection thresholds for “mm” and *d’* values in the bilateral and bimodal group, multiple regression analyses were conducted separately for each group. In the bilateral group, detection thresholds for “ee” and “mm” accounted for 79.1% of the variance in sensitivity, $F(2,7) = 13.27$, $p < .003$, on the Word-Phrase Identification Task, 71.1% of the variance in sensitivity, $F(2,7) = 8.601$, $p < .013$, on the Statement-Question Identification Task, 58.3% of the variance in sensitivity, $F(2,7) = 4.89$, $p < .047$, on the Prosody Matching

Task. On the Native Language Identification Task, detection thresholds for “ee” and “mm” accounted for 47.9% of the variance in sensitivity, but the variance was non-significant. In the bimodal group, variance predicted by detection thresholds of “ee” and “mm”, was not significantly different than variance predicted by detection thresholds for “mm” alone (Table 3.17). Detection thresholds for “ee” and “mm” accounted for 42.8% of the variance in sensitivity on the Word-Phrase Discrimination task, 34% on the Statement-Question Identification Task, 41.9% on the Prosody Matching Task, and 17.1% on the Native Language Identification Task, but the variances were non-significant. In summary, access to low-frequency auditory information, as measured by detection thresholds for “ee” and “mm” was a stronger predictor of sensitivity to perceiving prosodic features in children who used bilateral cochlear implants, than in children who used bimodal hearing technology.

The impact of auditory experience on sensitivity to prosodic features was examined using two measures - “age at amplification”, i.e., the age at which participants started using hearing technology that provided low-frequency auditory access, and “hearing age”, i.e., the duration of auditory experience which was calculated by subtracting age at amplification from chronological age. When data from the bilateral and bimodal group were analyzed together, hearing age was positively correlated with *d*' values on all four tasks, indicating that longer duration of auditory experience was correlated with greater sensitivity to prosodic features. (Figure 3.26) There was a significant, moderate relationship between hearing age and *d’* values on the Statement-Question Identification Task (r = .559, $p < .01$), and on the Prosody Matching Task (r = .62, $p < .003$). There were weak, negative correlations between age at amplification and *d’* values on all four tasks, but none were significant (Figure 3.27).

Multiple regression analyses demonstrated that variance predicted by hearing age and age at amplification was not significantly different than variance predicted by hearing age alone (Table 3.18). Hearing age and age at amplification accounted for 31.7% of the variance in sensitivity, $F(2, 17) = 3.945$, $p < .039$, on the Statement-Question Identification Task, and 43.2% of the variance in sensitivity, $F(2, 17) = 6.373$, $p < .008$, on the Prosody Matching Task. Hearing age and age at amplification accounted for 2.8% of the variance in sensitivity on the Word-Phrase Discrimination task, and 17.2% on the Native Language Identification Task, but the variances were non-significant. In summary, duration of auditory experience contributed to sensitivity to some features of prosody in children with hearing loss who use bilateral cochlear implants or bimodal hearing technology.

Figure 3.26. Correlation between *d*' and hearing age in the two hearing impaired groups combined, per task. Solid lines indicate linear regression. The *r* values shown in bold are significant at $p < .05$.



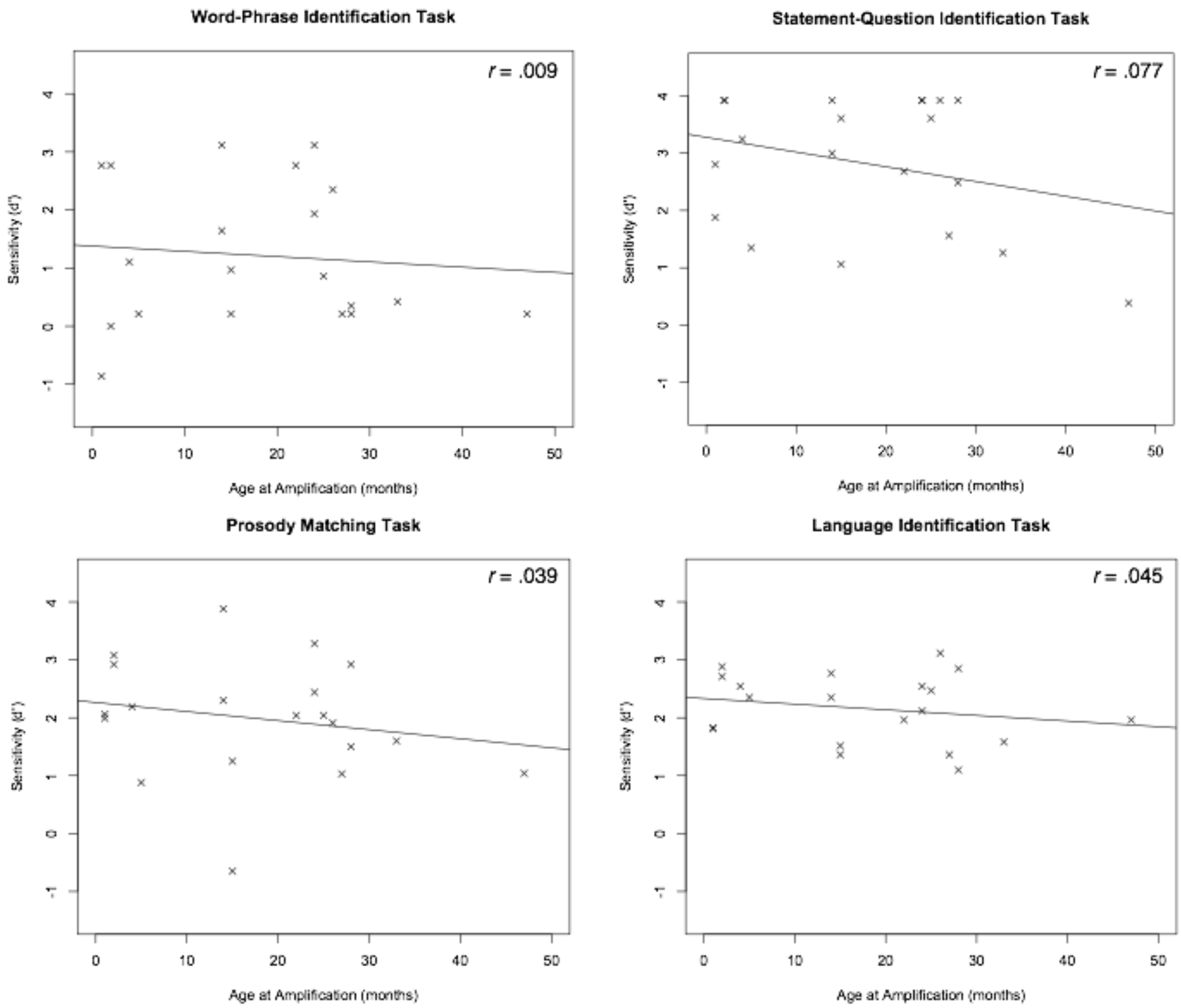
Word-Phrase Identification Task

Statement-Question Identification Task

Prosody Matching Task

Language Identification Task

Figure 3.27. Correlation between *d*' and age at amplification in the two hearing impaired groups combined, per task. Solid lines indicate linear regression. The *r* values shown in bold are significant at $p < .05$.



Summary

In summary, the purpose of this study was to characterize and compare perception of prosodic features, specifically stress, intonation, and rhythm in spoken language, in school-age children with and without hearing loss. The findings of this study indicate that children with hearing loss performed similarly to children with normal hearing on perception of stress and rhythm. Perception of intonation was comparable when stimuli were unfiltered, but deficient in children with hearing loss when the stimuli were low-pass filtered. Additionally, compared to children with normal hearing, children with hearing loss had worse performance when identifying the language of an utterance based on prosodic cues, and minimal phonemic cues. Children with hearing loss who used bimodal hearing technology were comparable in perception of stress, intonation, and rhythm compared to children with hearing loss who used bilateral cochlear implants. Additionally, better access to low-frequency auditory information, along with receiving access to low-frequency auditory information at an early age, and using hearing technology for an extended period of time had a positive impact on performance of children with hearing loss.

CHAPTER IV

DISCUSSION

This study characterized utilization of prosody in children with normal hearing and children with hearing loss, who used bilateral cochlear implants or bimodal hearing technology. Adequate perception of auditory prosodic features in spoken language utterances is important for language comprehension. Prosodic features of stress, intonation, and rhythm were examined through four experimental tasks, in which children either identified or matched speech stimuli based on their prosodic features. Performance on these tasks indicated that compared to children with normal hearing, children with hearing loss who used bilateral cochlear implants or bimodal technology were comparable in their use of phrase-level stress and rhythm but had problems with intonation under certain circumstances. Also, children with normal hearing were more accurate than those with hearing loss at identifying the language of an utterance when they had limited access to phonemic features and relied primarily on prosodic features. The discussion in this chapter is organized by each of the constructs of interest – stress, intonation, and rhythm, followed by native language identification, and contribution of audiological factors to perception of prosody.

Stress

In this study, perception of stress at the phrase-level (e.g., **green**house vs. green **house**) was comparable between children with and without hearing loss, and between those with hearing loss who used bilateral cochlear implants or bimodal technology. Most children were sensitive to the word-phrase distinction, but there was variability in their sensitivity, with some children performing near chance level and some performing near ceiling level. Of the ten children in each group, five in the bilateral group, six in the bimodal group, and three in the normal hearing group had a *d*' score below one, i.e., less than 69% accuracy on this task. And one child from the bilateral group, one from the bimodal group, and two from normal hearing group had a *d*' score above three, i.e. greater than 93% accuracy on this task. The finding that sensitivity to phrase-level stress was statistically comparable in children with and without hearing loss is in contrast to prior studies that have examined stress perception at the word- and phrase-level in children with hearing loss. However, there are certain trends that have been observed in the present study that align with findings from prior studies. The trends and factors that might have contributed to the contrasting results are discussed below.

Chronological age has been associated with development of phrase-level stress perception, with typically developing children demonstrating adult-like accuracy by age 12. In the study conducted by O'Halpin (2010) comparing children with normal hearing to children who used cochlear implants, response accuracy on the stress perception task was correlated with chronological age. Children with normal hearing demonstrated close to 100% accuracy by age 12, and even though 12-year-old children with cochlear implants demonstrated greater accuracy than younger children, their accuracy was not close to 100% (O'Halpin, 2010). In the study conducted by Torppa et al., (2014), improvement on response accuracy for stress perception was also associated with chronological age. In fact, out of 24, seven children with cochlear implants who had exposure to music improved over time, and their response accuracy was comparable to their hearing peers. However, 17 children with cochlear implants who did not have exposure to music did not improve over time and were deficient compared to their hearing peers (Torppa et al., 2014). It is important to note that only a small number of children with hearing loss in Torppa et al. demonstrated stress perception comparable to children with normal hearing. In the present study, chronological age was not significantly correlated with sensitivity to phrase-level stress. However, as shown in Figure 3.2, younger children with and without hearing loss were more likely to demonstrate reduced sensitivity, i.e., be closer to chance level compared to older children. Information about exposure to music is not available for the children with hearing loss in this study, but the finding that children with hearing loss demonstrated stress perception comparable to children with normal hearing is in line with the trend observed in a small sample of cochlear implant users in the study by Torppa et al. In summary, in the present study, most children in all three groups demonstrated greater sensitivity to phrase-level stress perception. Most children who were 12 years of age or older demonstrated greater sensitivity to stress than younger children, but there was variability in sensitivity to phrase-level stress, ranging from chance level to near ceiling level in all the groups, and children with and without hearing loss were comparable in their perception of phrase-level stress.

Another factor that might have contributed to comparable performance of children with and without hearing loss in the present study is auditory perception. Auditory perception of variations in duration, amplitude, and fundamental frequency facilitates perception of stress. Prior studies have demonstrated that individuals who used cochlear implants relied on duration and amplitude cues to perceive stress at the word and phrase level (Meister et al., 2009; O'Halpin, 2010; Torppa et al., 2014). In this study, perception of variations in duration and amplitude was not independently evaluated and thus direct comparisons are not possible. However, research in music perception indicates that current hearing technology – cochlear implants and hearing aids can provide adequate access to duration and amplitude cues (Limb &

Rubinstein, 2012; McDermott, 2004). So presumably, similar to prior studies, children with hearing loss in this study, had adequate access to duration and amplitude cues present in speech that convey variations in stress. However, in this study, on average, a majority of children had received access to sound through hearing aids or cochlear implants prior to 18 months of age, and had hearing age of 5-14 years, compared to hearing age of 1-6 years in O'Halpin (2010), and 2-9 years in Torppa et al. (2014). Even though hearing age was not strongly correlated with sensitivity to stress in the present study, longer duration of auditory experience might have facilitated better perception of variations in duration and amplitude cues and influenced perception of phrase-level stress.

As mentioned previously, perception of stress improves with age and reaches adult-like proficiency by age twelve in typically developing children (Vogel & Raimy, 2002). Additionally, during the development of sensitivity to stress, in spite of equal perceptual sensitivity (as observed by event-related potentials; McCauley et al., 2013), children with normal hearing demonstrate a bias towards interpreting utterances as compound words rather than phrases (Vogel et al., 2013). In typically developing children, this bias has been attributed to the child's linguistic proficiency, i.e., when there are two possible interpretations of an utterance, e.g., "bluebell" (flower) and "blue bell" (a bell that is blue), children are likely to interpret it as the meaning they are most familiar with. In most instances that is the compound word. A similar preference for compound words was observed in children with hearing loss in this study. Thus, it is possible that in the context of word- and phrase-level stress perception, chronological age is in fact a proxy for linguistic maturity/proficiency.

In this study, children's language proficiency was not evaluated and thus it is not possible to examine its association with phrase-level stress perception directly. However, language proficiency of children with hearing loss has been associated with audiological factors such as age at amplification and hearing age (Ching et al., 2008; Moeller et al., 2007; Niparko et al., 2010; Yoshinaga-Itano, 2003). In this study, early amplification and longer duration of implant use was associated with greater sensitivity to stress for the bilateral cochlear implant users, but not the bimodal technology users. But, given that these correlations are based on a small sample size, the findings should be interpreted with caution. Additionally, future studies should compare perception of stress in children with and without hearing loss based on their language age.

Language proficiency has also been associated with working memory in children with hearing loss (Pisoni, Kronenberger, Roman, & Geers, 2011). In this study, working memory, as measured by digit span backward test, was significantly correlated with sensitivity for children with and without hearing loss combined. Prior studies have discovered an impact of short-term memory, as measured by digit span forward test, on stress perception, but not working memory (Carter et al., 2002; Torppa et al., 2014). It is possible that the correlation with working memory in our study is attributable to the task demands, and not perception of stress. Children had to look at two pictures, listen to the stimuli, and make a judgment. This involves being able to hold the auditory representation of the stimulus in one's memory while comparing it to the two pictures that are presented. Thus it is possible that better working memory allowed the child to meet the cognitive demands of this task, and was not directly related to perception of stress.

In summary, perception of phrase-level stress was comparable in children with hearing loss and children with normal hearing, and there were no differences based on hearing technology. This finding is in contrast to previous studies but it can be speculated that this discrepancy might be attributed to a combination of factors including, 1) some children with hearing loss demonstrating near perfect accuracy similar to their hearing peers; 2) earlier age of amplification and longer duration of auditory experience of children in this study compared to previous studies; and 3) better sensitivity to variations in amplitude and duration cues accessible through bilateral cochlear implants and bimodal hearing technology. Additionally, it is important to note that a majority of the children with hearing loss in this study had received specialized intervention from a very young age, and had parents who were involved in their education and rehabilitation. It is possible that similar to previous studies where some children did not receive cochlear implants until after they were six years old, children with hearing loss who do not receive timely and effective intervention from parents and professionals might not perceive phrase-level stress comparably to their hearing peers. While it is not possible to identify the contribution of specific interventions and how they relate to the variability in sensitivity, comparable performance demonstrated by the children in this study is an important finding. This finding suggests that for most children with hearing loss, the interventions they had received until now, including the hearing technology they used – cochlear implants and hearing aids, had facilitated sensitivity to phrase-level stress. Future studies should examine the correlations between audiological factors, language measures, and sensitivity to stress perception in a larger sample of children with hearing loss to better understand the factors influencing development of stress perception in children with hearing loss.

Intonation

Perception of intonation is informed by variations in fundamental frequency as a primary cue and variations in duration and amplitude as secondary cues (Lehiste, 1970). Sensitivity to the intonation of an utterance allows the listener to make judgments about the talker's intent, e.g., declarative vs. interrogative. In this study, perception of intonation was evaluated in two tasks. In the Statement-Question Identification task, children heard phonemically congruent but prosodically incongruent utterances, and identified them as questions or statements (e.g., “The cat is in the **kitchen**.” Or “The cat is in the **kitchen**?”). Children in all three groups had comparable accuracy, demonstrating that on average children with hearing loss who used hearing technology were sensitive to intonation and could identify an utterance as a question or a statement. Also, children who used bimodal technology had comparable accuracy when they performed this task with their cochlear implant only and when they used a hearing aid in addition to their cochlear implant, indicating that their perception of intonation was comparable with and without access to the additional acoustic cues available through their hearing aids. In the Prosody Matching Task, in which children matched a low-pass filtered utterance to one of two unfiltered utterances based on three prosodic features - duration, intonation, or rhythm, across all three groups there was a significant difference between response accuracy on the three prosodic features, indicating that perception of certain prosodic features was more difficult than others for children with and without hearing loss. Across the three groups, children demonstrated greatest accuracy in matching by duration, i.e., statement-short statement trials (92%), followed by matching by intonation, i.e., statement-question trials (81%), and matching by rhythm, i.e., statement-alternative pausing trials (71%). However, statistical analyses indicated that, compared to children with normal hearing, children with hearing loss had significantly lower performance when matching based on intonation, i.e. statement vs. question, than on trials matching utterances by duration or rhythm, indicating that perception of intonation was more difficult for children with hearing loss than their hearing peers.

In this study, the Statement-Question Identification task was based on the intonation perception task implemented by Peng, Tomblin, and Turner (2008). The average response accuracy of children with normal hearing in this study was similar to the average response accuracy of children with normal hearing in Peng et al. (2008), i.e., 97% accuracy in both studies. However, the average response accuracy of children in the bilateral group (88%) in this study was greater than the average response accuracy of cochlear implant users in Peng et al. (70%). In spite of a similar range of response accuracy in both studies, (approximately 50% to 100%), average accuracy was greater in the bilateral implant users in the present study. The response accuracy of the bimodal group (89%) was similar to the bilateral group. In contrast to findings from Peng et al. there were no significant differences in sensitivity to intonation between children with normal hearing, bilateral cochlear implant users and bimodal technology users in this study. The greater response accuracy of the children with hearing loss in this study and the contrasting finding of comparable performance of children with and without hearing loss could be attributed to factors related to task design and participant characteristics.

In this study, the stimuli varied in intonation of the final word of the utterance. For example, in the utterance “the cat is in the kitchen”, the intonation of the word “kitchen” indicated whether is was statement or a question. However, in the intonation perception task by Peng et al. (2008), any element in the utterance (subject, verb, or object/location) could vary in intonation to indicate intent. It is possible that children in the present study picked up on the pattern of variation in the last word, which made the task easier for children with and without hearing loss compared to the task by Peng et al. Given that children with normal hearing had near perfect accuracy in both studies, it is possible that variation in the element that carries the intonation does not influence sensitivity to intonation in children with normal hearing, but might in children with hearing loss. An analysis of trials by the element (subject, verb, object) that was emphasized in the Peng et al. study is not available, so further comparisons regarding perception of intonation are not possible at the time. Additionally, the sample size of this study was smaller than Peng et al., i.e., ten bilateral implant users, and ten bimodal technology users, compared to 26 cochlear implant users. Additionally, children in this study were administered 40 trials in the bilateral and normal hearing group, and 80 trials in the bimodal group, whereas children in the Peng et al. study were administered 60 or 120 trials, providing them with a larger dataset for analysis of intonation perception in children with hearing loss.

There were several differences between the characteristics of children with hearing loss in this study and Peng et al., which might have contributed to the differences in sensitivity to intonation. First, it is unclear whether children in Peng et al. used unilateral cochlear implants, bilateral cochlear implants, or bimodal hearing technology (Peng et al., 2008). Second, compared to cochlear implant technology used by children in 2008, presumably hearing technology used by children in this study, in 2016, provided improved access to auditory information. So it is possible that differences in response accuracy are attributable to the previous study's participants' poorer access to auditory information. Additionally, 19 of 26 children in Peng et al.'s study attended total communication programs, i.e., used spoken and sign language to communicate, compared to the children in this study who were in oral communication programs, i.e. used spoken language to communicate. Presumably the presence of and reliance on a visual mode of communication might have impacted sensitivity to intonation in the children in the Peng et al. study. It is possible that if Peng et al., had presented the intonation perception task in an audiovisual or total communication format, the children in their study would have demonstrated greater response accuracy, that would have been comparable to their normal hearing peers.

In a previous study conducted by Most and Peled (2007), Hebrew-speaking children with hearing loss who used hearing aids demonstrated greater response accuracy than children who used cochlear implants in identifying whether an utterance was a statement or a question, based on its intonation (Most & Peled, 2007). The study did not compare performance of children with hearing loss to children with normal hearing. In the present study, sensitivity to intonation was comparable in bilateral cochlear implant users and bimodal technology users. Even within the bimodal group, sensitivity to intonation was comparable in the unilateral and bimodal condition. Most and Peled (2007) speculated that poorer response accuracy in cochlear implant users could be attributed to inadequate access to intonation cues, especially variations in fundamental frequency, available through the cochlear implant. Additionally, a majority of the implant users in that study received cochlear implants after age six and had 1-6 years of auditory experience, which might have negatively influenced the development of their auditory perception skills (McConkey Robbins, Koch, Osberger, Zimmerman-Phillips, & Kishon-Rabin, 2004). In the present study, comparable sensitivity to intonation, observed in the bilateral and bimodal groups, might be attributed to adequate access to intonation cues available through their current hearing technology, as well as the longer duration of auditory experience, which was positively associated with greater sensitivity to intonation.

It is interesting to note that even though children who used bimodal technology had comparable sensitivity to intonation when listening with unilateral cochlear implant only, and when listening with bimodal input, children reported that they preferred to listen when they were wearing their hearing aid and cochlear implant, presumably due to their comfort and familiarity with the bimodal input. A 13-year-old bimodal technology user shared that, “without the hearing aid I hear less of their expressions”, suggesting that she was deriving some benefit related to perceiving the intent or emotion of the talker when wearing her hearing aid. Also, during the task, children seemed to take longer when making judgments about the intonation in the unilateral condition compared to the bimodal condition, suggesting that the unilateral listening condition was indeed a more difficult listening situation for them. The benefit of adding acoustic access to speech and music perception is well established (e.g., Gifford et al., 2007; McDermott et at., 2011; Sheffield et al., 2016). In this study exploring the benefit of the contribution of acoustic access provided through the hearing aid is confounded by children's discomfort or unfamiliarity with listening with one cochlear implant only. Additional replications of this task are required to further investigate the contribution of acoustic access through hearing aid to perception of intonation.

In this study, children who used bilateral cochlear implants demonstrated a trend in error type or response bias that has been previously observed by Most and Peled (2007) in children with hearing loss who used hearing aids and cochlear implants. In the Statement-Question Identification task, children who used bilateral cochlear implants were more likely to identify an utterance as a statement, and had poorer accuracy on the question trials compared to the children who used bimodal technology. This tendency toward identifying an utterance as a statement was also seen in the bimodal group, when they completed the task with their unilateral cochlear implant only, but the difference was not statistically significant. This error pattern is difficult to explain in terms of perception. It is possible that when children were unsure, or when the rising intonation at the end of the utterance was not salient, children identified it as a statement – the type of utterance that they encounter most often.

Unlike the Statement-Question Identification task, on the Prosody Matching task children with hearing loss performed worse than children with normal hearing. We hypothesize that lower sensitivity to intonation observed in this task might be attributable to the task design and demands. The Statement-Question Identification task is presumably an easier task than the

Prosody Matching task because all utterances in the Statement-Question Identification task were unfiltered and therefore provided a robust auditory signal. It is then possible that compared to children with normal hearing, for children with hearing loss, listening to low-pass filtered utterances is more difficult than listening to unfiltered utterances. However, performance of children with and without hearing loss was comparable when matching low-pass filtered utterances to unfiltered utterances based on their duration and rhythm. So this suggests, that matching low-pass filtered utterances to unfiltered utterances was more difficult for the children with hearing loss when matching was based on intonation. It is possible that variations in fundamental frequency that are key to perception of intonation are not clearly accessible to children with hearing loss when presented with low-pass filtering. Thus, the deficits observed in children with hearing loss when matching low-pass and unfiltered utterances based on intonation, might be attributable to the limitations of their hearing technology. Future studies should examine how individuals with hearing loss perceive variations in fundamental frequency when the signal is low-pass filtered at 400Hz.

In the present study children with hearing loss and children with normal hearing demonstrated comparable sensitivity to intonation of an unfiltered utterance. This finding is in contrast to the studies conducted by Most and Peled (2007) and Peng, Tomblin, and Turner (2008). This contrasting finding is attributable to a combination of factors, including task design, improved access to intonation cues through advanced hearing technology, as well as early intervention. However, compared to children with normal hearing, children with hearing loss were not as sensitive to variations in intonation when matching a low-pass filtered utterance to an unfiltered utterance. This discrepancy in performance between the two intonation perception tasks should be further investigated in future studies that examine perception of intonation at the sentence level, and perception of variations in fundamental frequency at a syllable level when stimuli are low-pass filtered.

In summary, the children with hearing loss in this study had comparable sensitivity to intonation when compared to their hearing peers, within a simple task and when they had access to a natural, unfiltered signal. While this is an exciting finding, it is important to note that it is only a small step in having comparable perception and production of intonation in real world situations. Children with hearing loss continue to demonstrate deficits in their production of intonation (Lenden & Flipsen, 2007; Nakata et al., 2012; Peng et al., 2008). A recent study comparing adolescents with normal hearing, to adolescent cochlear implant users, similar to the children in this study, identified deficits in the hearing impaired children's use of questions and statements, and general understanding of how prosodic features indicate intent (Holt et al., 2016).

Also, it is important to note that in this study, in spite of this being a simple task presented in a quiet environment, children with hearing loss were variable in their performance and were not performing with near-perfect accuracy like their hearing peers. When the same perceptual demands are transferred to real world situations, other factors including background noise, language deficits, and linguistic context might impact sensitivity to intonation. Future studies should examine how children who perform well in a study setting, i.e., have the auditory capabilities to perceive the intent of the utterance based on intonation, perform in real world situations. Factors that might negatively impact sensitivity to intonation in real world situations should be identified and intervention should be provided. It is possible that children who are performing at the top of the their auditory potential will need alternative strategies, such as, paying attention to talker’s face to gather visual cues about the intent (raised eyebrows, “questioning” look, etc.) or ask for repetition and clarification – are you asking me or telling me?

Rhythm

The rhythm of a phrase or sentence is determined by variations in fundamental frequency, amplitude, and duration. In this study, perception of speech rhythm was examined in the Alternative Pausing trials of the Prosody Matching task. Children matched a low-pass filtered utterance to one of two unfiltered utterances that differed by rhythm. One utterance was said with pauses that marked phrases, and the other utterance had an illegal or unexpected pause between the verb and object. On average, children had the lowest accuracy when matching by rhythm, i.e., statement-alternative pausing trials (71%), compared to matching by duration, i.e., statement-short statement trials (92%), and matching by intonation, i.e., statement-question trials (81%). This indicates that matching utterances based on rhythm was not an easy task for children with and without hearing loss, and their performance was comparable. Of the ten children in each group, nine in the bilateral group, nine in the bimodal group, and five in the normal hearing group had a *d*' score below two, i.e., less than 84% accuracy on this task, indicating that while most children with and without hearing loss had some sensitivity to the variations in speech rhythm, they did not have near-perfect accuracy.

In an ongoing study of 5-7 year old children with normal hearing, Gordon and colleagues have administered the Prosody Matching task and have observed a similar pattern of lowest accuracy when matching by rhythm compared to matching by duration or intonation (Vaughn et al., 2016). In a study of children who were good readers or poor readers, and were asked to match a low-pass filtered utterance to one of two unfiltered utterances based on its rhythm, Wood and Terrell (1988) observed a similar pattern of less than perfect sensitivity to rhythm, The good readers demonstrated average accuracy of approximately 73%, whereas the poor readers were slightly above chance level at 56%, neither group had near-perfect accuracy (Wood & Terrell, 1998). It is possible that this pattern is indicative of the task design and demands, and not in fact children's sensitivity to variation in speech rhythm. Future studies should examine sensitivity to speech rhythm using a variety of rhythm matching tasks to tease out the influence of task design and demands.

Perception of speech rhythm has not been previously investigated in children with hearing loss. The findings of the present study could be compared to prior studies investigating perception of rhythm in the context of music. In musical contexts, perception of rhythm relies on perception of variation in duration (Hausen et al., 2013). A review of the literature indicates that current hearing technology provides adequate access to durational cues, and perception of rhythm as measured by asking individuals to identify whether pairs of stimuli match, is comparable between individuals with and without hearing loss (Drennan & Rubinstein, 2008; Limb & Rubinstein, 2012; McDermott, 2004). In this study, children with hearing loss and children with normal hearing were comparable in their perception of speech rhythm. This proficiency could be attributable to auditory access through hearing technology, and a longer duration of auditory experience. The small sample size and limited number of trials in this study limits the interpretation of relationship between duration of auditory experience and sensitivity to speech rhythm. Future studies should recruit a larger sample and administer more trials to further investigate the potential relationship between audiological factors and sensitivity to speech rhythm.

In summary, children with hearing loss who used cochlear implants and hearing aids were sensitive to rhythm of spoken language utterances. Their performance was comparable to children with normal hearing. These findings align with the findings from music perception studies that have observed comparable perception of rhythm in music. These findings could have implications for studies examining language and literacy outcomes in children with hearing loss. Typically, when examining language and literacy outcomes in this population, researchers have focused on examining the impact of factors such as duration of auditory experience, phoneme perception, and phonological awareness on literacy development (Johnson & Goswami, 2010; Nicholas & Geers, 2007; Spencer & Oleson, 2008; Spencer & Tomblin, 2009). Converging evidence from normally hearing, typical and atypical populations has associated superior rhythmic sensitivity with better outcomes in acquisition of grammar and reading (Gordon, Jacobs, et al., 2015; Goswami et al., 2009; Holliman et al., 2016; Wood & Terrell, 1998). Whether rhythmic sensitivity contributes to language and literacy outcomes in children with hearing loss is unknown. Future studies examining language and literacy outcomes of children with hearing loss should include measures of rhythm perception to examine its impact in development of children with hearing loss.

Native Language Identification

The ability to attend to and identify an utterance as being in one's native language, or perceptual attunement to native language, is an early emerging skill, which is considered to be foundational for language acquisition (Kuhl, 2004; Maurer & Werker, 2014). Fast and accurate identification of utterances as being in one's native language depends on several factors including the perception of underlying rhythm (Molnar et al., 2014; Nazzi et al., 2000; Nazzi &

Ramus, 2003), phonemes (Jusczyk et al., 1994; Kuhl, 2004), and the lexical information. For typically developing infants, one of the first cues that becomes prominent for native language identification is the underlying rhythm of the utterance (Nazzi & Ramus, 2003). This study evaluated school-age children's perception of underlying rhythm of speech by presenting English and French utterances in an unfiltered condition, in which children had access to the prosodic and phonemic information in the utterance, and in a low-pass filtered condition, in which minimal phonemic information was available, and children were asked to identify the utterance as being in "English" or "not English".

In this study, children with and without hearing loss had near perfect accuracy when identifying the language of the utterance in the unfiltered condition. In the low-pass filtered condition where minimal phonemic information was available, all the children had more difficulty identifying the language of the utterance, and none of the groups had near perfect accuracy. However, children with normal hearing outperformed children with hearing loss in their ability to identify the language of the utterance, which could be indicative of a difference in the type of cues that children with and without hearing loss rely on when identifying the language of an utterance. It is possible that while children with normal hearing can make judgments about the language of an utterance when minimal phonemic information is available by relying on prosodic cues, such as rhythm, children with hearing loss need additional phonemic and lexical cues to make the same judgment.

Alternatively, differences in response accuracy might be attributed to children with normal hearing having better auditory access to the auditory information presented in a filtered, somewhat degraded auditory signal, and children with hearing loss not having adequate access through their hearing technology. Not only is the low-pass filtered stimulus lacking key phonemic features that are important for clarity, it is also a novel type of auditory signal that children with hearing loss might have more difficulty adjusting to than children with normal hearing. The data suggest that this lack of experience might be a factor that contributed to differences in response accuracy. Twelve trials were presented in each of the four blocks. A block of 12 unfiltered trials followed by a block of 12 low-pass filtered trials were administered, and this sequence was repeated once. Children with normal hearing accurately identified 10 of 12 trials in the first block, and 11 of 12 trials in the second block of low-pass filtered trials. While there was some increase in accuracy, it was not significant, suggesting that there wasn't a significant impact of repeated exposure to low-pass filtered stimuli. Children with hearing loss demonstrated improved response accuracy for the second block of low-pass filtered utterances, compared to the first block of low-pass filtered utterances, i.e., of the 12 trials in each block, accurate identification on 10 or 11 trials in the second block compared to accurate identification of 8 or 9 trials in the first block, suggesting that there was a learning effect (Figure 3.21). There were only two cycles of unfiltered trials followed by low-pass filtered trials, but the increase in response accuracy was significant for children with hearing loss. It is then plausible that multiple cycles or repeated exposure could have helped children "learn" to listen to this novel and somewhat diminished auditory signal and improve their response accuracy. Future studies should include a training or habituation component to examine this learning effect and identify if differences in response accuracy persist once children with hearing loss have extended exposure to the low-pass filtered signal.

In the low-pass filtered condition, children with normal hearing and children with hearing loss were more likely to identify an utterance as not being in English, i.e., they were more likely to misidentify an English utterance as a non-English utterance. It is possible that English utterances in the low-pass filtered conditions did not sound “English” enough and were thus identified as “not English”. Once again, given that performance of children with hearing loss improved after repeated exposure to the low-pass filtered stimuli, it is possible that this bias towards rejection might have been reduced with training and a larger number of trials.

The research literature on perceptual attunement to native language has focused on evaluating this phenomenon in infants and adults, and little is known about the performance on school-age children. It is hypothesized that infants develop adult-like attunement to their native/ambient language(s) by 15 months of age, and that attunement remains constant into adulthood (see Maurer & Werker, 2014). Little is known about perceptual attunement to spoken language in individuals with hearing loss. In a pilot study that examined how quickly and accurately children and adults with hearing loss identified unfiltered utterances as being in English or not-English, response accuracy was comparable between individuals with normal hearing and individuals with hearing loss (Soman, Dunn, Tharpe, & Ashmead, 2016). However, there was a significant difference between the two groups, in the amount of time it took to make a judgment about the language of the utterance. Taken together with the findings from the current study, this suggests that similar to children with normal hearing, children with hearing loss can attend to and identify the language of an utterance. However, the process involved in making a judgment about the language of the utterance might be a more demanding/difficult task for individuals with hearing loss. Further studies are required to examine to factors that contribute to these difficulties and potential interventions for addressing these differences.

While a deficit in distinguishing between native language and non-native language might not impact functioning in day to day life of children with hearing loss living in a predominantly monolingual environment, it provides insights into how perception and comprehension of language might be influenced by different weighting of phonemic and prosodic cues. It also prompts the question, if quick and accurate perception of underlying linguistic rhythm does not play the same role in language acquisition of children with hearing loss, how might the role and development of other processes, such as, prosodic bootstrapping be different for this population? Potential differences in the development of these fundamental processes for language acquisition might explain why some children with hearing loss struggle to learn a second language, or don't understand a foreign accent. Additionally, even though the current study was conducted with children who live in predominantly monolingual environments, an estimated 50% of the children in this world live in bilingual and multilingual environments. Future studies in the area of perceptual attunement to native language(s) could provide insights in developing effective interventions for children with hearing loss in bilingual home environments.

Contribution of Audiological Factors to Perception of Prosody

Perception of prosodic features is an integral component of language acquisition, comprehension, and social competence. In this study, children with hearing loss were comparable to children with normal hearing in their sensitivity to phrase-level stress and speech rhythm. They demonstrated comparable perception of intonation when stimuli were unfiltered. As discussed previously, the comparable perception of stress and intonation is in contrast to prior studies and some of these differences might be attributable to factors such as auditory access and auditory experience. Presumably, the audiological interventions that a child receives, including the type of hearing technology, age at which hearing technology is received, duration of experience with hearing technology, and auditory access provided by the hearing technology influence sensitivity to prosodic features. Correlations between these audiological factors and sensitivity to prosodic features were examined, but given the modest sample size, these correlations should be interpreted with caution, and viewed as trends that warrant further investigation.

The age at which a child with congenital hearing loss starts using hearing aids or cochlear implants is important in the context of neuroplasticity (Sharma, Nash, & Dorman, 2009). Many studies have demonstrated superior language outcomes in children who received early amplification (Moeller et al., 2007; Niparko et al., 2010; Yoshinaga-Itano, 2003). While there isn't yet consensus on the influence of age at amplification on perception of prosody, it is presumed that similar to development of phonemic perception, prosodic perception benefits from early amplification. In this study, age at amplification was not significantly correlated with sensitivity to prosody, but there was a negative correlation, suggesting that early auditory access was beneficial to developing perception of prosody.

The "hearing age" of a child, or duration of auditory experience through hearing technology is another factor that is considered when examining phonemic perception and language acquisition in children with hearing loss. In this study, hearing age had a significant correlation with perception of intonation in children with hearing loss, suggesting that a longer duration of auditory experience increased sensitivity to intonation. While not significant, the positive correlation between hearing age and perception of stress, rhythm, and native language identification suggest that longer duration of auditory experience positively affects perception of prosodic features.

Finally, a large body of research has examined the limitations of cochlear implant technology, especially the limited spectral resolution, and attributed deficits in perception of stress and intonation due to lack of access to low-frequency auditory information (Chatterjee &

Peng, 2008; Green et al., 2005; Limb & Roy, 2014). In this study, there were no differences between bilateral cochlear implant users, i.e., those with presumably poor access to low-frequency auditory information, and bimodal technology users, i.e., those with presumably better access to low-frequency auditory information through the contralateral hearing aid. Detection thresholds for “ee” (F_1 = 370 Hz) and “mm” (F_1 = 250-350 Hz) from the Phonak Ling Sound Test were used as measures of access to low-frequency information. The correlation between low-frequency access and sensitivity to prosody had distinct patterns in the bilateral and bimodal group. Detection thresholds for “ee” had an overall negative correlation with sensitivity to prosody in the bilateral and bimodal groups, suggesting that lower (better) thresholds were correlated with greater sensitivity, and accounted for 20-25% variance in perception of stress, intonation, and rhythm. However, detection thresholds for “mm” had negative correlation with sensitivity to prosody in the bimodal group, but not the bilateral group. Additionally, thresholds for “mm” predicted approximately 40% of the variance in perception of stress, intonation, and rhythm in the bimodal group, but less than 10% in the bilateral group. However, as shown in Table 3.16, thresholds for “ee” and “mm” together, accounted for 60-70% of the variance in perception of stress, intonation, and rhythm in the bilateral group. This finding aligns with prior research suggesting that low-frequency access contributes to perception of prosodic features (Most et al., 2011). Additionally, the difference in variance accounted for by low-frequency access in bilateral and bimodal groups suggests that cochlear implant users might differ from individuals who use hearing aids in how they perceive and weigh auditory cues when making judgments about prosody (Chatterjee & Peng, 2008; O’Halpin, 2010; Torppa et al., 2014), but they continue to have comparable sensitivity to prosodic features (Cullington & Zeng, 2011).

These correlations between audiological factors and sensitivity to prosody provide a starting point to further investigate the contribution of each factor or a combination of factors. It is interesting that while these audiological factors have moderate correlations with sensitivity to stress, intonation, and rhythm, they have relatively weak correlations with the ability to identify the language of an utterance. This suggests that perceptual attunement to one's native language, which typically develops in the first year of life, might not be heavily influenced by audiological factors. Alternatively, the process of perceptual attunement reaches completion in early childhood and the impact of audiological factors on this process might not be evident in a sample of school-age children. Future studies should investigate the influence of audiological factors on perceptual attunement in infants, toddlers, and preschoolers with hearing loss.

Summary

This study characterized and compared perception of prosody in children with and without hearing loss. This study also examined how attuned children with and without hearing loss were to their native language when minimal phonemic cues were present. The results of this study indicate that compared to children with normal hearing, children with hearing loss were comparable in their sensitivity to stress, intonation, and rhythm present in unfiltered, connected speech. Children with normal hearing demonstrated greater sensitivity to intonation of low-pass filtered utterances than children with hearing loss. Children with normal hearing outperformed children with hearing loss when identifying the language of low-pass filtered utterances, but not unfiltered utterances. Children who used bilateral cochlear implants performed similarly to children who used bimodal technology, indicating that sensitivity to prosodic features was possible with either of the hearing technologies. The finding that children with hearing loss were comparable to children with normal hearing in perception of stress and intonation when stimuli were unfiltered is in contrast to previous findings. It is speculated that the contrasting findings of this study could be attributed to differences in task design, and in the intervention characteristics of children with hearing loss in this study compared to previous studies. Audiological factors such as early amplification, longer duration of auditory exposure, and adequate low-frequency access had a positive impact on perception of prosody in speech.

While it is exciting to discover that children with hearing loss performed similarly to children with normal hearing, it is important to acknowledge that there was variability in performance of children with hearing loss, and average response accuracy and sensitivity to prosodic features was objectively lower in children with hearing loss compared to children with normal hearing. This study demonstrates that in certain circumstances (e.g., quiet environment, simple task, etc.), children with hearing loss are comparable to children with normal hearing. Presumably, the interventions that have been available to children with hearing loss in this study have facilitated this performance. The next step would be to characterize sensitivity to prosodic features in real world environments compared to lab environments, and develop interventions to address any deficits. Perception of prosody plays an important role in early language acquisition, language comprehension, and social competence. Demonstrating performance comparable to children with normal hearing is a first step towards cultivating sensitivity to prosodic features that signal the talker's intent, affect, and meaning of the utterance, in all environments including at home, at school, and in extracurricular activities. It is hoped that the findings from this study will serve as a basis for future research and intervention that can support language acquisition, language comprehension, and social competence for children with hearing loss.

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Appendix A

Parent Questionnaires

Parents of children who participated in this completed the following questionnaires.

Intake Questionnaire

Study ID ____________________

Study Code ____________________

E-prime Code ____________________

Date of consent ____________________

Date of assent ____________________

Demographic Information

Date of birth ____________________

Age (years) ____________________

Gender
○ Female
○ Male
○ Unknown

Ethnicity
○ Hispanic or Latino ○ NOT Hispanic or Latino ○ Unknown / Not Reported
○ Declined

Race
○ American Indian/Alaska Native
○ Asian
○ Native Hawaiian or Other Pacific Islander
○ Black or African American
○ White
○ More Than One Race
○ Unknown / Not Reported
○ Declined
○ Hispanic
○ Other

Response to Ling Test

	Correct ID	Incorrect ID	No response
ah	○	○	○
ee	○	○	○
oo	○	○	○
s	○	○	○
sh	○	○	○
m	○	○	○

Verifit results

____

Hearing Screening Results
☐ Pass
☐ Fail

Results from vision screening

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What is your child's dominant hand?	○ Right ○ Left ○ Ambidextrous
Is English your child's native language?	○ Yes ○ No
If no, explain	______________________________
Does your child listen to/speak/use any other languages?	______________________________
Has your child ever attempted to learn French?	______________________________

Does your child have any other diagnosis that might impact his/her ability to

	Yes	No
see	○	○
hear	○	○
speak	○	○
pay attention	○	○
respond by pushing buttons	○	○

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Audiology-Education-Environment Questionnaire

Study ID	________________________

To better understand your child's performance we would like to collect some more information about your child's audiological history, education, and environment. Please answer the questions to the best of your ability. We will verify audiological and medical history by reviewing your child's audiological and medical records.

Audiological History

Has your child ever been diagnosed with hearing loss?	○ Yes ○ No
When was the hearing loss diagnosed?	______________________________
If known, what was the severity of hearing loss at time of diagnosis?	______________________________
What is the type and degree of hearing loss? (unilateral/bilateral, progressive, conductive/ sensorineural/mixed, degree)	______________________________
If known, what is the cause of hearing loss?	______________________________
Does your child use hearing aids and/or cochlear implants?	○ Yes ○ No
Describe the child's hearing technology in the right ear.	○ Hearing aid ○ Cochlear implant ○ None ○ N/A
Describe the child's hearing technology in the left ear.	○ Hearing aid ○ Cochlear implant ○ None ○ N/A
At what age did your child receive hearing aids and/or cochlear implants?	______________________________
What percent of the waking hours does your child wear the his/her hearing technology?	○ 100% ○ 90-99% ○ 75-89% ○ 60-74% ○ less than 59%
Has anybody in your immediate and extended family been diagnosed with hearing loss?	○ Yes ○ No
If yes, please explain	______________________________
Does your child wear glasses or contacts?	○ Yes ○ No

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Other comments regarding glasses or contacts	______________________
Has your child ever been diagnosed with blindness or visual impairment?	○ Yes ○ No
Description/Comments of Blindness or visual impairment.	______________________

The next set of questions are about your child's educational performance. Please answer them to the best of your ability.

What grade is your child in?	__________________
What kind of school does your child attend?	○ Public School ○ Private School ○ Charter School ○ School for the Deaf ○ Home School ○ Other
Does you child have an IEP or other educational plan to address language or academic difficulties.	○ Yes ○ No
If your child took a standardized language assessment in the last year, how did he/she score on the assessment?	○ Above Average ○ Within the average range ○ Below Average ○ Not applicable

Family History

The following questions are about the child's parents, caregivers or legal guardians.

Please indicate which of the following individuals interact or provide care to your child outside of the school environment.	○ Biological mother ○ Biological father ○ Non-biological mother ○ Non-biological father ○ Grandmother ○ Grandfather ○ Nanny or Babysitter ○ Other
If other, please specify	__________________
Biological mother's highest level of education	○ High School ○ Associate Degree ○ Bachelors Degree ○ Masters Degree ○ AUD, JD, MD ○ PhD
Non-Biological mother's highest level of education	○ High School ○ Associate Degree ○ Bachelors Degree ○ Masters Degree ○ AUD, JD, MD ○ PhD

Biological father's highest level of education

○ High School
○ Associate Degree
○ Bachelors Degree
○ Masters Degree
○ AUD, JD, MD
○ PhD

Non-biological father's highest level of education

○ High School
○ Associate Degree
○ Bachelors Degree
○ Masters Degree
○ AUD, JD, MD
○ PhD

Grandmother's highest level of education

○ High School
○ Associate Degree
○ Bachelors Degree
○ Masters Degree
○ AUD, JD, MD
○ PhD

Grandfather's highest level of education

○ High School
○ Associate Degree
○ Bachelors Degree
○ Masters Degree
○ AUD, JD, MD
○ PhD

The next set of questions is about your child's participation in music-related activities. Please indicate to what extent you agree with the following statements

	Strongly agree	Agree	Disagree	Strongly disagree
My child participates in routine music-related activities at school	○	○	○	○
My child participates in extracurricular music-related activities at school (e.g., school musical, band, choir, etc.)	○	○	○	○
In the last year, my child participated a music-related performance (e.g., recital, school musical, etc.)	○	○	○	○
My child takes voice lessons.	○	○	○	○
My child is learning to play a musical instrument.	○	○	○	○
My child sings as well as other children his/her age, i.e., carries a tune, taps a rhythm, etc.	○	○	○	○

Other comments about your child's music-related experiences or abilities

____

Social skills

The next set of questions is about your child's social participation. Please indicate to what extent you agree with the following statements

	Strongly agree	Agree	Disagree	Strongly disagree	Not applicable
My child interacts with other children his/her age independently and without any difficulties.	○	○	○	○	○
My child interacts with adults independently and without any difficulties.	○	○	○	○	○
My child is most comfortable interacting with other children with hearing loss.	○	○	○	○	○
My child is most comfortable interacting with other children who don't have hearing loss	○	○	○	○	○
My child has difficulty understanding the intent of the talker (asking a question, making a statement, being sarcastic, etc.)	○	○	○	○	○
My child has difficulty understanding the affect of the talker (happy, sad, angry, etc.)	○	○	○	○	○
My child is most comfortable interacting with adults.	○	○	○	○	○

Other comments about your child's social interactions or social skills. ________________________

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Appendix B

Perceiving Stress: Word-Phrase Identification Task

In this task, participants discriminated between a compound word and a phrase that were phonemically congruent, but differed in prosody, specifically, stress and duration of pauses between words (e.g., "*green house"* vs. "*greenhouse"*). Six pairs of phrases and compound words, similar to the tokens used by O'Halpin (2010) were used in this study. *Bluebottle* (type of fly) and *blue bottle*, have been replaced with "*bluejay"* (bird) and *"blue J"* (letter J colored blue), and *redhead* (person with red hair) and *red head* (head that is red) have been replaced with "*White House"* (the residence of the President) and "*white house"* (house with white roof and exterior).

Stimuli:

Compound Word	Phrase
"Show me the ***blackboard."*** (chalkboard)	"Show m the ***black board."*** (board that is black)
"Show me the ***bluebell***." (type of flower)	"Show me the ***blue bell***." (bell that is colored blue)
"Show me the ***bluejay."*** (bird)	"Show me the ***blue J."*** (letter J colored blue)
"Show me the ***greenhouse."*** (glass enclosure for growing plants)	"Show me the ***green house."*** (house that has green roof and exterior)
"Show me the ***hotdog."*** (food item)	"Show me the ***hot dog."*** (dog that is panting)
"Show me the ***White House."*** (residence of the president of USA)	"Show me the ***white house."*** (house that has white roof and exterior)
~~Show me the redhead.~~	~~Show me the red head.~~
~~Show me the bluebottle~~	~~Show me the blue bottle~~

Stimulus preparation

- Two male and two female talkers were recruited to record the stimuli. The range of F0 was 88 – 392 Hz. (Table B1).

Table B1. Fundamental frequency characteristics of talkers on stimuli for the Word-Phrase Identification Task

Talker	Average	SD	Range
Male talker 1 (TD)	107.502 Hz	23.938 Hz	88-205 Hz
Male talker 2 (BM)	136.888 Hz	21.544 Hz	109-176 Hz
Female talker 1 (DK)	209.424 Hz	57.553 Hz	114-297 Hz
Female talker 2 (AR)	204.471 Hz	59.006 Hz	101-392 Hz

- Stimuli were recorded in a sound attenuated room, using a Realistic Cardioid microphone connected to a MacBook Pro. Adobe Audition 2015 was used to record the utterances. For the recording, first, each talker was asked to say the phrase "*Show me the*" five times. Next, talkers were shown images depicting each pair side-by-side and asked to label each of the illustrations three times. The phrases that were judged to be the best samples for each talker by the principal investigator and one other person were included in the task. The perceptual criterion for "best" was that the compound word and the corresponding phrase strongly suggested the contrasting meanings (e.g., hotdog (food item) vs. hot dog (panting dog).
    - A prior recording where talkers were asked to say all the compound words first and then the phrases resulted in limited acoustic contrasts between the stimuli. Those stimuli were not used.

  - One of the female talkers "BB" produced the target compound words and phrases with a questioning tone. Another female talker "DK" recorded additional stimuli, which was used in the study.

- Average rms value for each selected token was measured, and equalized across tokens and speakers using Adobe Audition 2015. For each token, silences, defined as being below -60 dB, and equal to or less than 50 ms, were identified and deleted. Finally, the token was amplified until it reached the desired average rms value and saved as a new audio file. (Table B2)

Table B2. rms characteristics of stimuli for the Word-Phrase Identification Task

	Male 1	Male 2	Female 1	Female 2	All Speakers
Average	-32.674	-32.144	-32.564	-32.480	**-32.465**
SD	0.335	0.483	0.289	0.470	**0.394**
Min	-32.96	-32.82	-33.02	-33.29	**-33.023**
Max	-31.98	-31.31	-32.17	-31.62	**-31.770**
Range	0.98	1.51	0.85	1.67	**1.253**

  - Average rms values for the carrier phrase, "*Show me the*", compound words and phrases were calculated separately, and were matched across types of utterances and talkers.
  - The carrier phrase and the target were concatenated into a single new audio file. For example, "Show me the" and "greenhouse" were concatenated into a single file.

    - Calibration noise was created by first concatenating all the audio files, next removing silences, and then matching the frequency spectrum to a speech shaped noise.
- Acoustic analyses of the selected tokens were conducted using PRAAT software. The following features were measured and compared
    - Fundamental frequency, amplitude and duration of the second element in the phrase vs. compound word.
        - "green", as in "green house" was lower in fundamental frequency, amplitude and longer in duration than "green", as in "greenhouse".
        - "house", as in "green house" was higher in fundamental frequency, amplitude and longer in duration than "house", as in "greenhouse".
    - Pause between the two words (e.g. "green" and "house") in the phrase and compound word.
    - Total duration of the utterance.
- Each token started with a 300 ms silence, followed by the carrier phrase "Show me the", followed by a 500 ms silence, followed by the target phrase or compound word.
    - For example, (300 ms) "Show me the" (500 ms) "greenhouse"
- Each token was visually represented by a colored illustration of the token (see Figure 2.2).
- The task was programmed in E-Prime and piloted with 2 adults with normal hearing. Both adults responded with 100% accuracy. The task was also be piloted with 2 normal hearing children who were 8 years old.

Stimulus Presentation

- Participants saw a screen with visual representations of one pair of tokens and heard the target phrase. The visual representations were presented along with the auditory presentation of the target phrase. The numbers “1” and “2” were seen underneath each picture (see Figure 2.1). Position of the token (i.e, phrase on the right and compound word on the left, or vice versa) was equiprobable during the trial. Participants responded by telling the PI whether “1” or “2” is the correct answer. The PI recorded the response.
- Each phrase (e.g. “Show me the greenhouse.”) was presented twice, once by a male talker and once by a female talker.
- Total = 24 trials
- Presentation order for phrases was randomized to ensure that the same token (e.g. “greenhouse” and “greenhouse”) or two versions of the tokens (e.g., “greenhouse” and “green house”) were not presented in consecutive trials.
- Tokens were presented in the carrier phrase at 60 dB A.
- The task was programmed in E-Prime and was played on a Windows desktop, and presented through the right channel GSI 61 Clinical Audiometer at 60 dB HL. (Calibration of stimuli was verified at a level of 60 dB HL +/- 0.5 A weighted slow. This was conducted under the supervision of Dr. Dunn)
- Approximate time = 15 minutes
- Task instructions were given to the participants by the principal investigator
  - This game is a following directions game. You will see two pictures on the computer, the direction will tell you the name of one of the pictures and you will tell me the correct answer.

  - Let’s just practice without the computer first.
  - On this table I have a red pen and a blue pen. The red pen is number 1, and the blue pen is number 2. I will ask you to show me one of the two pens and you can tell me if it is number 1 or number 2.
    - Show me the red pen
    - Show me the blue pen
  - The positions might change, but just need to tell me the number. (Switch pen positions) now the blue pen is number 1 and the red pen is number 2.
    - Show me the red pen
    - Show me the blue pen
  - Excellent job! We are going to do the same thing on the computer.
  - Let me show you all the pictures you will see in this game
    - This is a bird called a bluejay. What is it called?
    - Look at this dog, it is sweating. It is a hot dog. What is it called?
  - Now when we play the game you will see two pictures on the computer number one and number two and you will hear the direction just one time. I want you to give me your answer by saying one or two
  - Great job now let’s do this on the computer remember it could be tricky so listen carefully.
- Before the task was administered to children, children were familiarized with the vocabulary and the pictures.

Appendix C

Perceiving Intonation: Statement-Question Identification Task

In this task, participants listened to an utterance and determined if the utterance is “asking something” or “telling something”. The utterances were phonemically congruent, but differed in prosody, specifically the intonation – interrogative or declarative. Ten utterances presented as statements and interrogatives, and previously used by Peng, Tomblin & Turner (2008) were used in this study. Dr. Peng had made the original stimuli available to the PI for use in this study. However, those stimuli were variable in the element that is emphasized. Some talkers have emphasized the subject, “THEY all went to the circus?”, whereas other talkers emphasized the object, “they all went to the CIRCUS?”. The same two male talkers (TD & BM) and one female talker (AR) who recorded stimuli for the Word-Phrase Discrimination Task recorded stimuli for this task. Another female talker (BB) recorded stimuli for this task. They were instructed to emphasize the object or the final element in the utterance.

Stimuli

Statement	Question
“They all went to the circus.”	“They all went to the circus?”
“He didn’t take their tickets.”	“He didn’t take their tickets?”
“He rode a bike in circles.”	“He rode a bike in circles?”
“He took the ball from the tigers.”	“He took the ball from the tigers?”
“He gave the ball to the monkeys.”	“He gave the ball to the monkeys?”
“The boy likes the sandwich.”	“The boy likes the sandwich?”

“The cat is in the kitchen.”	“The cat is in the kitchen?”
“The girl is on the playground.”	“The girl is on the playground?”
“The mom likes the popcorn.”	“The mom likes the popcorn?”
“The mouse likes the pizza.”	“The mouse likes the pizza?”

Stimulus Preparation

- Two male (TD & BM) and two female talkers (BB & AR) recorded the stimuli. Three of these talkers were the same as the ones from Task 1. The range of F0 for each talker was analyzed. (Table C1)

Table C1. Fundamental frequency characteristics of talkers on stimuli for the Statement-Question Identification Task

Talker	Average	SD	Range
Male talker 1 (TD)	118.785 Hz	10.076 Hz	104 – 134 Hz
Male talker 2 (BM)	151.081 Hz	10.717 Hz	137 – 178 Hz
Female talker 1 (BB)	199.008 Hz	15.259 Hz	161 – 226 Hz
Female talker 2 (AR)	225.888 Hz	16.726 Hz	189 – 249 Hz

- Stimuli were recorded in a sound attenuated room, using a Realistic Cardioid microphone connected to a MacBook Pro. Adobe Audition 2015 was used to record the utterances. For the recording, talkers were instructed to emphasize the object or the final element in the utterance. Each talker was asked to say the target utterance three times. The phrases that were judged to be the best samples for each talker by the PI and one other person were included in the task. The perceptual criterion for “best” was that the intonation strongly suggested the contrasting intent, i.e, statement vs. interrogative.

- Average rms value for each selected token was measured (Table C2), and equalized across tokens and speakers using Adobe Audition 2015. For each token, silences, defined as being below -60 dB, and equal to or less than 50 ms, were identified and deleted. Finally, the token was amplified until it reached the desired average rms value and saved as a new audio file.
    - Calibration noise was created by first concatenating all the audio files, next removing silence, and then matching the frequency spectrum to a speech shaped noise.

Table C2. rms characteristics of talkers on stimuli on the Statement-Question Identification Task

	Male 1	Male 2	Female 1	Female 2	All Speakers
Average	-32.470	-32.360	-32.831	-32.730	**-32.598**
SD	0.720	0.588	0.792	0.610	**0.678**
Min	-33.84	-33.64	-34.34	-33.97	**-33.948**
Max	-31.48	-31.34	-31.50	-31.40	**-31.430**
Range	2.36	2.3	2.84	2.57	**2.518**

- Each token started with a 250 ms silence, followed by the target utterance.
    - For example, (250 ms) "They all went to the circus?"
- Acoustic analyses of the utterances by each talker were conducted using PRAAT software. The following features were measured and compared:
    - Fundamental frequency, amplitude and duration of the final word in the statement vs. interrogative.

        - “Circus”, in “They all went to the circus,” was lower in fundamental frequency and amplitude than “circus”, in “They all went to the circus?”
        - “Circus”, in “They all went to the circus,” was longer in duration than “circus”, in “They all went to the circus?”
    - Total duration of the utterance
- The task was programmed in E-Prime and piloted in 1 adult with normal hearing who responded with 100% accuracy. The task was piloted with two normal hearing children who were eight years old.

Stimulus Presentation

- Participants were instructed to listen to the utterance and determine if the stimuli was “asking something” or “telling something”. Participants saw a dark screen. A fixation cross with a square around it was presented along with the auditory presentation of the target utterance. Participants responded by telling the PI whether the sentence was “asking something” or “telling something”. The PI recorded the responses.
- For the Bilateral and Normal Hearing group each statement and question were presented twice, once by a male talker and once by a female talker. Total trials = 40
- For the Bimodal group, each statement and question were presented four times, once by each talker.
    - Participants in this group repeated this task while wearing their cochlear implant only. There were 40 trials in each block. Odd-numbered participants (501,503, 505, 507 and 509) used bimodal technology in the first block of trials and cochlear implant only for the second block of trials. Even-numbered participants

(502, 504, 506, 508 and 510) used cochlear implant only in the first block of trials and bimodal technology for the second block of trials.

- Presentation order of the utterances was randomized.
- Targets were presented at 60 dB A.
- The task was programmed in E-Prime and played on a Windows desktop, and presented through the right channel GSI 61 Clinical Audiometer at 57 dB HL. (Calibration of stimuli was verified at a level of 60 dB A +/- 0.5 A weighted slow. This was conducted under the supervision of Dr. Dunn)
- Estimated time = 20 minutes

Appendix D

Prosody Matching Task

In this task, participants listened to the target stimuli - low-pass filtered version of a short speech sample, and match it to one of two unfiltered speech samples. Of the two unfiltered speech sample, one was the target and the other a foil that differed by one of three features – intonation, number of syllables, or rhythm. This task design was based on the "Rhythmic Matching" task previously used by Wood & Terrell (1998).

Stimulus Preparation

- Two male and two female talkers recorded the stimuli. These talkers were the same as the ones from Task 2. The F0 of the talkers ranged from (Table D1)

Table D1. Fundamental frequency characteristics of talkers on stimuli for the Prosody Matching Task

Talker	Average	SD	Range
Male talker 1 (TD)	112.215 Hz	13.980 Hz	97 – 178 Hz
Male talker 2 (BM)	142.563 Hz	7.188 Hz	128 – 171 Hz
Female talker 1 (BB)	186.770 Hz	10.754 Hz	157 – 206 Hz
Female talker 2 (AR)	224.245 Hz	12.767 Hz	184 – 247 Hz

- Stimuli were recorded in a sound attenuated room, using a Realistic Cardioid microphone connected to a MacBook Pro. Adobe Audition 2015 was used to record the utterances. Each talker recorded three versions of 24 target utterances and three variations for each utterance. Target utterances are 8-9 word long sentences with the syntactic structure subject-verb-object-prepositional phrase. This syntactic structure is mastered by typically developing children by five years of age. Simple vocabulary was used in these sentences and should be familiar to 8 – 16 years old children with and without hearing loss.

  - Target utterance – "*The boy / is pouring juice / in the glass*."
  - Foil differing in intonation – "*The boy / is pouring juice / in the glass*?"
  - Foil differing in number of syllables – "*The boy / is pouring juice."*
  - Foil differing in stress & rhythm – "*The boy is pouring / juice in the glass*."

- Complete list of target utterances and foils

1. The boy is pouring juice in the glass.
    i. The boy is pouring juice in the glass?
    ii. The boy is pouring juice.
    iii. The boy is pouring / juice in the glass.
2. The boy is reading a book in the garden.
    i. The boy is reading a book in the garden?
    ii. The boy is reading a book.
    iii. The boy is reading a / book in the garden.
3. The boy is playing a game in the living room.
    i. The boy is playing a game in the living room?
    ii. The boy is playing a game.
    iii. The boy is playing a / game in the living room.
4. The boy is bathing the dog in the bathroom.
    i. The boy is bathing the dog in the bathroom?
    ii. The boy is bathing the dog.

    iii. The boy is bathing the / dog in the bathroom.

5. The girl   is eating breakfast   at the table.

    i. The girl   is eating breakfast   at the table?

    ii. The girl   is eating breakfast.

    iii. The girl is eating / breakfast at the table.

6. The girl   is skipping rope   on the porch.

    i. The girl   is skipping rope   on the porch?

    ii. The girl   is skipping rope.

    iii. The girl is skipping / rope on the porch.

7. The girl   is singing a song   in her room.

    i. The girl   is singing a song   in her room?

    ii. The girl   is singing a song.

    iii. The girl is singing a / song in her room.

8. The girl   is riding the horse   in the field.

    i. The girl   is riding the horse   in the field?

    ii. The girl   is riding the horse.

    iii. The girl is riding the / horse in the field.

9. The man   is baking cookies   in the oven.

    i. The man   is baking cookies   in the oven?

    ii. The man   is baking cookies.

    iii. The man is baking / cookies in the oven.

10. The man   is painting the fence   in the backyard.

    i. The man   is painting the fence   in the backyard?

    ii. The man   is painting the fence.
    iii. The man is painting the / fence in the backyard.

11. The man   is cooking hamburgers   on the grill.
    i. The man   is cooking hamburgers   on the grill?
    ii. The man   is cooking hamburgers.
    iii. The man is cooking / hamburgers on the grill.

12. The man   is reading the newspaper   at the table.
    i. The man   is reading the newspaper   at the table?
    ii. The man   is reading the newspaper.
    iii. The man is reading the / newspaper at the table.

13. The woman   is cooking dinner   in the kitchen.
    i. The woman   is cooking dinner   in the kitchen?
    ii. The woman   is cooking dinner.
    iii. The woman is cooking / dinner in the kitchen.

14. The woman   is watering the flowers   in the backyard.
    i. The woman   is watering the flowers   in the backyard?
    ii. The woman   is watering the flowers.
    iii. The woman is watering the / flowers in the backyard.

15. The woman   is carrying apples   in a basket.
    i. The woman   is carrying apples   in a basket?
    ii. The woman   is carrying apples.
    iii. The woman is carrying / apples in a basket.

16. The woman   is stirring the soup   in the pot.

    i. The woman   is stirring the soup   in the pot?

    ii. The woman   is stirring the soup.

    iii. The woman is stirring the / soup in the pot.

17. The cat   is chasing the mouse   in the barn.

    i. The cat   is chasing the mouse   in the barn?

    ii. The cat   is chasing the mouse.

    iii. The cat is chasing the / mouse in the barn.

18. The cat   is drinking water   from the faucet.

    i. The cat   is drinking water   from the faucet?

    ii. The cat   is drinking water.

    iii. The cat is drinking / water from the faucet.

19. The dog   is sniffing the dirt   in the garden.

    i. The dog   is sniffing the dirt   in the garden?

    ii. The dog   is sniffing the dirt.

    iii. The dog is sniffing the / dirt in the garden.

20. The dog   is playing fetch   in the backyard.

    i. The dog   is playing fetch   in the backyard?

    ii. The dog   is playing fetch.

    iii. The dog is playing / fetch in the backyard.

21. The baby   is drinking milk   from the cup.

    i. The baby   is drinking milk   from the cup?

    ii. The baby   is drinking milk.

    iii. The baby is drinking / milk from the cup.

The baby   is eating goldfish   from the bowl.

   iv. The baby   is eating goldfish   from the bowl?
   v. The baby   is eating goldfish.
   vi. The baby is eating / goldfish from the bowl.

22. The baby   is looking outside   through the window.
   i. The baby   is looking outside   through the window?
   ii. The baby   is looking outside.
   iii. The baby is looking / outside through the window.

23. The baby   is eating a snack   in her highchair.
   i. The baby   is eating a snack   in her highchair?
   ii. The baby   is eating a snack.
   iii. The baby is eating a / snack in her highchair.

- The PI and one other person judged the utterances and included one token of each utterance for the task. The perceptual judgment of "best" utterance was made on the basis of clarity of the utterance, as well as maximum contrast to the foils.
- All utterances were low-pass filtered at 400 Hz.
- Average rms value for each selected token was measured, and equalized across tokens and speakers using Adobe Audition 2015. For each token, silences, defined as being below -60 dB, and equal to or less than 50 ms, were identified and deleted. Average rms value was calculated using the "amplitude statistics" panel. Finally, the token was amplified until it reached the desired average rms value and saved as a new audio file.

Table D2. rms characterisitcs of talkers on stimuli for the Prosody Matching Task

	Male 1	Male 2	Female 1	Female 2	All Speakers
Average	-34.22	-34.37	-35.08	-34.48	**-34.537**
SD	0.58	0.84	0.73	0.61	**0.689**
Min	-35.67	-36.90	-36.66	-35.57	**-36.200**
Max	-32.88	-31.95	-32.76	-33.03	**-32.655**
Range	2.79	4.95	3.90	2.54	**3.545**

  - Calibration noise was created by first concatenating all the audio files, next removing silence, and then matching the frequency spectrum to a speech shaped noise.
- Low-pass filtered utterances were matched to unfiltered utterances based on "Perceived Loudness" as indicated in the "Amplitude Statistics" panel in Adobe Audition 2015.
- Each token, unfiltered and low-pass filtered, was preceded by a 300 ms silence, followed by the target utterance.
  - For example, (300 ms) "The boy is pouring juice."
- Acoustic analysis of all the tokens (unfiltered and low-pass filtered) was conducted using PRAAT software. Specific acoustic characteristics were contrasted between the target utterance and the foil.
  - Foil differing by intonation:
    - Fundamental frequency and amplitude of the object in the statement vs. interrogative.

        - “Juice”, in “The boy is pouring juice in the glass,” was higher in fundamental frequency and amplitude than “juice”, in “The boy is pouring juice in the glass?”
    - Fundamental frequency, amplitude and duration of the final word in the statement vs. interrogative.
        - “Glass”, in “The boy is pouring juice in the glass,” was lower in fundamental frequency and amplitude than “glass”, in “The boy is pouring juice in the glass?”
        - “Glass”, in “The boy is pouring juice in the glass,” was longer in duration than “glass”, in “The boy is pouring juice in the glass?”
- Foil differing by syllables:
    - Total duration of the two utterances
        - “The boy is pouring juice in the glass,” was longer in duration than “The boy is pouring juice.”
    - Number of syllables in the two utterances
        - “The boy is pouring juice in the glass,” had 8 syllables, while the “The boy is pouring juice,” had 5 syllables.
- Foil differing by rhythm:
    - Fundamental frequency of the verb in the target vs. foil.
        - “Pouring”, in “The boy / is pouring juice / in the glass,” was higher in fundamental frequency than “pouring”, in “The boy is pouring / juice in the glass.”
    - Duration between the verb and the object in the target vs. foil.

    - Duration between “pouring” and “juice”, in “The boy / is pouring juice / in the glass,” was shorter than “pouring” and “juice”, in “The boy is pouring / juice in the glass,”

- The task was programmed in E-Prime and was piloted with one normal hearing adult, with the same criterion for perfect performance as described for Task 1. The task was also be piloted with two normal hearing children who were 8 years old.

Stimulus Presentation

- Participants were asked to identify which of the two unfiltered utterances matches the low-pass filtered target. Participants saw a dark screen. The tokens were presented along with a visual. During the 1st presentation, participants saw the number “1” in the top left area and heard the first unfiltered token. During the 2nd presentation, participants saw the number “2” in the top right area and heard the second unfiltered token. During the 3rd presentation, participants saw a picture of a star in middle and heard the low-pass filtered token, which matched one of the two previously presented tokens (see Figure 2.3). Participants responded by telling the PI whether “1” or “2” matches the “star” sentence. The PI recorded the response.
- Participants completed a practice task where they matched a low-pass filtered utterance to one of two unfiltered utterances. The low-pass filtering gradually increased across trials (e.g., 2000 Hz, 1000 Hz, 700 Hz, 400 Hz) on the practice task. Participants received corrective feedback.
- Each target utterance was presented twice, for a total of 48 trials, presented in 2 sets of 24 trials each. Talker gender was equiprobable on all trials. An equal number of each type of foil were presented, i.e., 8 presentation per foil type. Low-pass filtered tokens matched

the target 50% of the time, and the foils 50% of the time (see sample sequence in Table D3)

- All stimuli were presented at 60 dB A in quiet.
- The task was programmed in E-Prime and played on a Windows desktop, and presented through the right speaker GSI 61 Clinical Audiometer at 60 dB A. (Calibration of stimuli was verified at a level of 60 dB A +/- 0.5 weighted slow. This was conducted under the supervision of Dr. Dunn)
- Total duration = 20 minutes

Table D3. Sample of sequence of stimuli presentation is listed in the table below.

Talker	**Unfiltered Presentation 1**	**Unfiltered Presentation 2**	**Low-Pass Filtered Presentation**	**Correct Answer**	**Correct Answer**
SET 1					
F1	#2 - Statement	#2-Foil	#2-Statement	1	Statement
M1	#5-Foil	#5-Statement	#5-Foil	1	Foil
F2	#1-Statement	#1-Foil	#1-Foil	2	Foil
M1	#3-Statement	#3-Foil	#3-Statement	1	Statement
F1	#4-Foil	#4-Statement	#4-Statement	2	Statement
M2	#6 -Statement	#6-Foil	#6-Foil	2	Foil
SET 2					
M1	#4-Foil	#4-Statement	#4-Foil	1	Foil
M2	#2-Foil	#2-Statement	#2-Statement	2	Statement
F2	#3-Foil	#3-Statement	#3-Statement	2	Statement
M2	#1 - Statement	#1-Foil	#1-Foil	2	Foil
F1	#6-Foil	#6-Statement	#6-Foil	1	Foil
F2	#5-Statement	#5-Foil	#5-Statement	2	Statement
Utterances F1 = 3 F2 = 3 M1 = 3 M2 = 3	**Set 1** Statement = 3 Foil = 3 **Set 2** Statement = 3 Foil = 3	**Set 1** Statement = 3 Foil = 3 **Set 2** Statement = 3 Foil = 3	**Set 1** Statement = 3 Foil = 3 **Set 2** Statement = 3 Foil = 3	Correct answer 1=6 times 2=6 times	Correct answer Statement = 6 times Foil = 6 times

Appendix E

Native Language Identification Task

In this task, participants listened to sentences in English or French and identify if the utterance were in “English” or “not English”. All of the utterances for each language were low-pass filtered to create tokens that provided access to prosodic information while limiting access to phonemic information. This task design was based on the “Native Language Discrimination” task developed by the PI and implemented in a previous project. Two aspects of the original task were modified. All stimuli were presented in the auditory only condition and not in the audiovisual and visual only condition. The stimuli were modified from continuous speech samples from The Little Prince, to short sentences that are similar to the utterances in Prosody Matching Task.

Stimulus Preparation

- Stimuli were recorded in a sound attenuated room, using a Realistic Cardioid microphone connected to a MacBook Pro. Adobe Audition 2015 was used to record the utterances. Two female talkers who have native accents in English and French recorded three versions of 30 target utterances in English and 30 target utterances in French. The F0 range for the talkers was 144 – 218 Hz (Table E1).

Table E1. Fundamental frequency characteristics of Talkers on Stimuli for the Native Language Identification Task

Talker	Average	SD	Range
Female talker 1 (J)	199.697 Hz	13.917 Hz	168 – 218 Hz
Female talker 2 (M)	160.132 Hz	8.116 Hz	144 – 171 Hz

- Target utterances were 7-11 words long sentences that had simple vocabulary and syntactic structures that typically developing children master by five years of age. Utterances were matched for number of syllables.
    - English – *The girl brushes her teeth before going to bed.*
    - French – *La fille se brosse les dents avant d'aller au lit.*

English	French
The boy sits in the chair that is blue and far away from the door.	Le garçon s'assoit sur la chaise qui est bleu et loin de la porte.
Every morning, the man drinks coffee before going to work.	Chaque matin, L'homme boit du café avant d'aller au travail.
The boy eats at the table before playing with his friends.	Le garçon dine à la table avant de jouer avec ses amis.
The boy loves singing and playing the piano.	Le garçon aime chanter et jouer du piano.
The girl brushes her teeth before going to bed.	La fille se brosse les dents avant d'aller au lit.
The girl clapped her hands in the school.	La fille s'est battue les mains dans l'école.
The girl drinks milk and eats apples in the morning.	La fille boit du lait et mange des pommes dans le matin.
The girl loved running and skipping in the park.	La fille aimait courir et sautiller dans le parc.
The cat ran away to hide under the bed.	Le chat s'est enfuit pour se cacher sous

	le lit.
The dog went to look for the ball to bring it back.	Le chien est allé chercher la balle pour la rapporter.
The teacher sings and the children dance during the afternoon.	La maîtresse chante et les enfants dansent pendant l’après midi.
The boy read and the girl did her homework.	Le garçon lisait et la fille faisait ses devoirs.
The girl practiced writing while her mom cooked.	La fille pratiquait écrire pendant que sa mère cuisinait.
The man cleaned the kitchen and the woman washed the dishes.	L’homme range la cuisine et la femme fait la vaisselle.
The teacher played the piano and the children read.	La maitresse jouait du piano et les enfants lisaient.
The children played inside because it was raining.	Les enfants jouaient dedans parce qu’il pleuvait.
The children run to the park and the adults walk.	Les enfants courent au parc et les adultes marchent.
The children watched movies in the afternoon.	Les enfants regardqrent des films dans l’après midi.
The dog leapt from the wall because he saw a rabbit.	Le chien a sauté du mur parce qu’il a vu un lapin.
The girl listens to music while she walks.	La fille écoute de la musique pendant qu’elle marche.

The bird sits on the tree and pecks at the fruit.	L’oiseau s’assoit sur l’arbre et picore du fruit.
The bird flew away when the cat climbed the tree.	L’oiseau s’est envolé quand le chat a grimpé sur l’arbre
The children sit down when the teacher rings the bell.	Les enfants s’assoient quand la maitresse sonne la cloche.
The boy swept the floor and the girl cleaned the living room.	Le garçon balayait la cuisine et la fille rangeait le salon.
The girl was swimming when the the boy dived in the pool.	La fille nageait quand le garçon a plongé dans la piscine.
The children eat some apples in the park before throwing the ball.	Les enfants mangent des pommes dans le parc avant de lancer la balle.
The children go to the movie theater and eat candy.	Les enfants vont au cinéma et mangent des bonbons
The farmer milks the cows and feeds the chickens.	Le fermier traite les vaches et nourrit les poules.
The man always mows the grass before planting flowers.	L’homme tond toujours la pelouse avant de planter des fleurs.
The children raked in the garden and jumped on the leaves.	Les enfants ratissent dans le jardin et sautent sur les feuilles.

- The PI and one other person judged the utterances and selected one token of each utterance from each talker for the task. The perceptual judgment of "best" utterance was made on the basis of clarity and pace of the utterance.
- All target utterances were low-pass filtered at 700 Hz.
    - Originally, the utterances were to be low-pass filtered at 400 Hz. When we piloted stimuli low-pass filtered at 400 Hz, 700 Hz, and 1000 Hz, we discovered that normal hearing participants were at chance performance at 400 Hz. After consulting with Dr. Ashmead it has been determined that stimuli for this task will be low-pass filtered at 700 Hz.
- Average rms value for each selected token was measured (Table E2), and equalized across tokens and speakers using Adobe Audition 2015. For each token, silences, defined as being below -60 dB, and equal to or less than 50 ms, were identified and deleted. Average rms value was calculated using the "amplitude statistics" panel. Finally, the token was amplified until it reached the desired average rms value and saved as a new audio file.
    - Calibration noise was created by first concatenating all the audio files, next removing silence, and then matching the frequency spectrum to a speech shaped noise.
- Low-pass filtered utterances were matched to unfiltered utterances based on "Perceived Loudness" as indicated in the "Amplitude Statistics" panel in Adobe Audition 2015.
- Each token, unfiltered and low-pass filtered, was preceded by a 300 ms silence.
    - For example, (300 ms) "The cat ran away to hide under the bed."

- Acoustic analyses of all the selected target utterances (unfiltered and low-pass filtered) were conducted using PRAAT software to record total duration of utterance and range of F0 for each utterance by each talker.
- The task was programmed in E-Prime and was piloted with 1 normal hearing adult. The task was also piloted with 2 normal hearing children who are 8-10 years old.

Table E2. rms characteristics of Talkers on Stimuli for the Native Language Identification Task

	Female 1	Female 2	All Speakers
Average	-34.71	-34.42	**-34.562**
SD	0.58	0.58	**0.584**
Min	-35.64	-35.52	**-35.580**
Max	-33.53	-33.19	**-33.360**
Range	2.11	2.33	**2.220**

Stimulus Presentation

- Participants were instructed to listen to the utterance and determine if the stimuli was in “English” or “not in English”. Participants saw a dark screen. A fixation cross with a square around it was presented along with the auditory presentation of the target utterance. Participants responded by telling the PI whether the sentence was “English” or “not in English”. Participants were given the option of responding with “yes” or “no. The PI recorded the response.
- All stimuli were presented at 60 dB A in quiet.

- Participants were presented unfiltered versions of 24 utterances (12 in each language), and asked to identify whether the utterance was English or not English. Utterances were divided in 2 blocks of 12 trials each.
- Participants were presented low-pass filtered versions of an additional 24 utterances (12 in each language), and asked to identify whether the utterance was English or not English. Utterances were divided in 2 blocks of 12 trials each.
- The first and third blocks of trials were unfiltered utterances, whereas the second and fourth blocks were low-pass filtered utterances.
- Presentation of utterances within each condition was randomized.
- Total trials = 48,
    - 24 utterances in each language
    - 24 utterances in each condition – unfiltered and low-pass filtered
    - 24 utterances per talker
    - 12 utterances per language, and per version
- The task was programmed in E-Prime and was played on a Windows desktop, and presented through the right channel GSI 61 Clinical Audiometer at 59 dB HL. (Calibration of stimuli was verified at a level of 60 dB A +/- 0.5 A weighted slow. This was conducted under the supervision of Dr. Dunn)
- Total duration = 20 minutes