Abstract

BINAURAL INTERFERENCE IN NORMAL HEARING CHILDREN

by

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This study was conducted to determine if the phenomenon of binaural interference occurs in normal hearing children. To investigate the possible presence of binaural interference, comparisons of the participants' right, left, and binaural performance was measured for word recognition test scores and speech-in-noise test scores. To provide evidence of the possible breakdown within the auditory system associated with binaural interference, sub-cortical and cortical tests were used within the test battery. Tonal and speech masking level difference tests (MLDs) were used as sub-cortical tasks. The pitch pattern sequence [motor (MPPS) and verbal (VPPS) response] tests were used as cortical tasks. Normative data was developed for the masking level difference tests and pitch pattern sequence tests.

A total of 96 normal hearing children, aged 7 years, 0 months to 12 years, 11 months, were participants. Children were grouped according to age with 16 participants in each of the 6 age groups. Word recognition scores were obtained using the Northwestern University Children's Perception of Speech (NU-CHIPS) test. The Bamford-Kowal-Bench Speech-in-Noise (BKB-SIN) Test was used for sentence-in-noise

testing. One of 96 participants (P92) showed significant binaural interference on word recognition testing. Mean group scores (ages 7- 12 years) for the VPPS test ranged from 81.5% to 97.8%. Mean group scores (ages 7- 12 years) for the MPPS test ranged from 87.1% to 98.1%. The mean masking level differences were 7.3 dB for speech stimuli and 12.81 dB for tonal stimuli.

Although our original hypothesis, that a small percentage of children would demonstrate binaural interference, was not supported in this study, the data provides a foundation for future research with other populations, such as hearing impaired children and children with (central) auditory processing disorders. The identification of binaural interference in children will provide the audiologist with valuable information useful for hearing aid fittings and counseling of parents with (central) auditory processing disordered children. In addition, this study provides normative data for the pitch pattern sequence tests and the speech and tonal masking level difference tests in children.

Binaural Interference in Normal Hearing Children

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CHAPTER I: Review of Literature

Numerous studies have shown the advantages of binaural hearing versus monaural hearing (Chappell, Kavanagh, & Zerlin, 1963; Cox, DeChicchis, & Wark, 1981; Feuerstein, 1992; Hawley & Litovsky, 2004; Ross, 2006; & Yonovitz, Dickenson, Miller, & Spydell, 1979). However, there are also research studies that show evidence of binaural disadvantages (Allen, Schwab, Cranford, & Carpenter, 2000; Arkebauer, Mencher, & McCall 1971; Chmiel, Jerger, Murphy, Pirozzolo, & Tooley-Young, 1997; & Jerger, Silman, Lew, & Chmiel, 1993). The present research project explored binaural interference, the phenomenon that occurs when individuals perform worse when an auditory stimulus is presented binaurally than when presented monaurally (Jerger, 1994). The following review is a discussion of binaural hearing.

Binaural Advantages

Ross (2006) discussed advantages to binaural hearing. He described these advantages as better localization, better understanding of speech in background noise, binaural fusion, and reduction in communication effort. Dillon (2001) also reviewed and discussed some of these binaural advantages. Listening with two ears gives an advantage to sound localization. Studies have shown the ability to perceive sound with two ears increases performance in horizontal, vertical, and front-back localization (Butler, 1969; Mills, 1958; Musicant & Butler, 1985). The interaural time difference (the difference in arrival time between the two ears) and interaural phase difference (the phase delay between the two signals) play an important role in horizontal localization. Sounds will arrive to the nearer ear faster than the opposite ear. The shorter travel time to the nearer ear provides cues that the auditory signal is coming from a particular direction (Dillon, 2001). Sound intensity differences will also be observed due to head shadow effects. Sounds produced on the near side of the head will be perceived louder than at the opposite ear, creating an interaural intensity difference. Studies have shown time differences to be dominant for low frequency sounds, and intensity differences to be dominant for high frequency sounds (Dillon study (as cited in Zurek, 1993)). Vertical localization is dependent on reflections and resonances that occur within the pinna before sound enters the ear canal (Dillon, 2001). High frequency sounds above 5 kHz, due to the small wavelength, are used to calculate the reflections and resonances within the pinna, resulting in a three-degree detectable vertical angle in humans (Peter, Moore, & Baer, 1998). The pinna also plays an important role in front to back localization. The pinna increases high-frequency sounds from the front and attenuates them from the back, providing some cues to the direction of the sound source (Dillon, 2001).

In addition to sound localization, binaural hearing contributes to increased clarity of speech in noisy and/or reverberant environments. Head diffraction effects (level differences between ears due to the direction at which sound reaches the head), binaural squelch (the combination of different signals received at both ears), and binaural redundancy (the combination of similar signals received at both ears) play a role in this binaural advantage. Head diffraction effects allow the individual to attend to the ear with the better signal-to-noise-ratio (SNR). The speech will be perceived louder by the ear closest to the sound source, therefore having a greater SNR than the opposite ear (Dillon, 2001). Secondly, binaural squelch is used to increase SNR. The auditory signals from each ear are centrally combined. This central representation attempts to cancel the noise perceived at one ear with the noise received from the other ear. The amount of noise that can be suppressed is dependent on the amplitude and phase difference of the two signals. This has been referred to as the binaural masking level difference (BMLD or MLD) (Dillon, 2001). Lastly binaural redundancy produces an advantage by listening with two ears when the signals to both ears are identical (diotic summation). Studies have shown that a 1 to 2 dB improvement in SNR occurs when listening diotically (Cox, DeChicchis, & Wark, 1981). Dillion (2001) discussed the advantage of increased loudness when listening binaurally vs. monaurally. The author states, “binaural summation of loudness increases from around 3 dB or lower near threshold to some value in the range of 6 to 10 dB at high levels” (Dillon study (as cited in Dermody & Byrne, 1975)).

Supporting research has been conducted to show better binaural performance as opposed to monaural performance on tasks such as word recognition and sentence in noise testing. Chappell, Kavanagh, and Zerlin (1963) researched monaural versus binaural speech recognition in normal listeners. Eighteen participants, with a mean age of 24 years, were involved in the study. Participants were evaluated under earphones for the following conditions: left ear, right ear, and binaural presentations. Participants were asked to repeat words presented in the carrier phrase “say the word…” in the presence of multi-speaker background noise (i.e., several voices simulating a crowded room). The participants repeated 60 words from the CID W-22 word lists (Hirsh, 1952) in each condition with words and noise presented at 80 dB SPL for the monaural condition, and

74 dB SPL for the binaural condition. Chappell et al. found that participants showed an average 20% improvement in word intelligibility when listening binaurally.

Similar binaural improvement in word intelligibility scores has also been shown in children. In 1979, Yonovitz, Dickenson, Miller, and Spydell investigated speech recognition in children using auditory and auditory/visual processing with binaural and monaural presentations. Yonovitz et al. studied 30 normal hearing participants ranging from 6 to 14 years of age. Words from the Word Intelligibility by Picture Identification test (WIPI) (Ross & Lerman, 1970) were used as the stimuli. Each child was tested under the following conditions: monaural only, binaural only, monaural and visual, and binaural and visual. In the auditory only conditions, all children performed better with binaural stimulation over monaural stimulation. This improvement was determined by comparing the children's speech recognition scores on the WIPI test at different signal to noise ratios. The maximum advantage was noted at a -6 dB S/N ratio, which showed a 21% intelligibility improvement in the binaural condition compared to the monaural condition. The same binaural advantage was seen under the auditory/visual condition (Yonovitz et al., 1979). The largest advantage was seen under the binaural auditory/visual condition. Therefore, Yonovitz et al. concluded that this finding suggests that normal hearing listeners use visual cues as well as auditory cues to aid in speech understanding.

A study by Feuerstein (1992) compared monaural versus binaural hearing on ease of listening and word recognition, while taking into consideration attentional effort. Participants included 48 normal hearing adults. Listening conditions included: 1) unimpeded binaural listening, and 2) simulated unilateral hearing loss. The Revised Speech in Noise (SPIN) test (Bilger, 1984) was presented through a loudspeaker and was used as the stimulus for all conditions. The monaural condition was categorized by monaural near (MN) where the unoccluded ear was nearest to the speaker, and monaural far (MF) where the occluded ear was nearest to the speaker (Feuerstein, 1992). To determine ease of listening, participants were asked to rate their ease of listening to each sentence from 0 to 100. A score of 0 represented "very, very difficult to understand" and a score of 100 represented "very, very easy to understand". Word recognition scores (WRSs) were calculated based on the last word of each sentence (i.e., conventional scoring). Results for perceived ease of listening showed binaural listening to be the easiest, followed by MN and MF, respectively. The MF condition was never rated easier than the binaural or MN conditions; however, the MN condition was rated easier than the binaural condition 21% of the time (Feuerstein, 1992). Word recognition results showed similar results as ease of listening results. The binaural condition yielded the best results for word recognition and the poorest recognition was observed in the MF condition. There was no significant difference between the binaural condition and the MN condition in 44% of the subjects. Feuerstein (1992) concluded that a unilateral mild hearing loss may reduce ease of listening and word recognition scores. He emphasized the impairing effects that a mild unilateral hearing loss could have on a person's ability to understand speech. He also concluded that children are more vulnerable to a unilateral loss and should be monitored closely to ensure normal progress in language development (Feuerstein, 1992).

Binaural Interference

Arkebauer, Mencher, and McCall (1973) were the first to study what was later described as binaural interference. Arkebauer and colleagues believed that a bilateral asymmetrical hearing loss might impair the patient's ability to interpret sounds received from both ears. They summarized that the poorer ear might interfere with the better ear and cause a decrease in speech recognition ability. The researchers hypothesized that occluding the poorer ear could lead to an improvement in speech recognition.

In an effort to study this, Arkebauer et al. (1973) examined the listening skills of ten subjects with bilateral asymmetrical hearing losses. Each of these subjects were tested under four different conditions: 1) poorer ear under earphones; 2) better ear under earphones; 3) sound field, ears unoccluded; and 4) sound field, poorer ear occluded. Subjects were divided into two groups depending on the severity of their hearing loss. Group I demonstrated a milder hearing loss in both ears than that of Group II. The etiologies for subjects' hearing loss included Meniere's disease, presbycusis, and noise. Subjects were tested using recorded CID W-1 materials to establish speech recognition thresholds (SRTs) and CID W-22 lists to determine speech recognition scores.

Speech recognition scores were measured for each subject for each of the four conditions. When comparing results from condition 2 (better ear under earphones) to condition 3 (sound field-no occlusion), they found that nine of the ten subjects did better in condition 2, although not all differences were statistically significant. This offered initial evidence of binaural interaction causing poorer speech recognition scores (Arkebauer et al., 1973). Arkebauer et al. then sought to determine if occluding the poorer ear would increase speech recognition scores. This was carried out in a sound field environment with the poorer ear occluded and compared to condition 3 (sound field-no occlusion). They found a 2-18% improvement in speech recognition scores by occluding the poorer ear. When comparing Group I (mild losses) to those with greater loss (Group II), Arkebauer et al. determined that the greater the impairment, the greater improvement in speech recognition scores with occluding the poorer ear. Finally, Arkebauer et al. (1973) concluded, “the application of binaural amplification to children whose audiometric responses are not fully determined may have to be restricted in fear of creating more difficulty for the child in their effort to develop normal language.”(p. 212).

Jerger, Silman, Lew, and Chmiel (1993) further investigated binaural interference. The authors presented four cases of binaural interference exhibited by behavioral and electrophysiologic measures. The first case involved a 71-year-old woman, AW, who had worn a hearing aid on her left ear for approximately ten years. She had a symmetrical, moderately severe sensorineural hearing loss. Her unaided word recognition testing, using CID W-22 word lists and presented at 30 dB sensation level, was 50% and 0% for the left and right ears, respectively. Binaural behind-the-ear hearing aids were fitted to AW to compare her performance on monaural vs. binaural word recognition tasks. Her hearing aids were selected on the basis of real-ear measures of frequency response according to Berger’s prescription. Results showed a significant improvement of 42% in the word recognition task under left ear monaural amplification vs. binaural amplification. Jerger et al. noted that if the right ear was not interfering with the signal, the monaural left ear results should be equal to the binaural results in word recognition.

Since this was not the case, the right ear was contributing to binaural interference causing a decrease in performance when listening binaurally (Jerger et al., 1993).

Jerger et al. (1993) also investigated binaural interference from an electrophysiologic standpoint. RC, a 66-year-old man, was studied using the middle latency response (MLR) by means of topographic brain mapping. RC had a history of viral encephalitis and decreased hearing in his left ear. Maps were compared for right ear stimulation, left ear stimulation, and binaural stimulation. The authors found the response from the right ear to be greater than that of the left ear alone and binaural stimulation. Jerger et al. concluded, “In the binaural mode, the presence of the left ear input apparently interfered with the right ear input in such a way that the binaural response was substantially poorer than the response to right ear stimulation alone” (p.125).

The final cases in this study involved the combination of electrophysiological and behavioral testing. Subject BV, an 80-year-old man with a history of left-sided cerebrovascular insult, had bilateral hearing loss with the right ear being worse than the left ear. Word recognition scores, using CID W-22 word lists, were 80% in the left ear and 36% in the right ear. Jerger et al. monaurally amplified each ear and tested aided word recognition abilities, yielding results of 76% and 8% for the left and right ears, respectively. Aided testing was repeated and results remained the same. Jerger et al. noted that not only was the right ear not contributing to word recognition, it was interfering with the input by left ear stimulation (Jerger et al., 1993). Middle latency responses were measured on BV under the same three conditions: stimulation right, stimulation left, and binaural stimulation. The positive peak (Pa) of the middle latency response was compared for these conditions. The amplitude of the positive peak (P_a) for the right ear was reduced compared to the amplitude in the left ear. However, the MLR waveform for the binaural stimulation showed lower (P_a) amplitude than that of either the right or left ear. Therefore, Jerger et al. concluded that the right ear had interfering effects with the left ear response during binaural stimulation.

In the fourth case in the Jerger et al. (1993) study, similar effects were seen in the MLR results of subject JB, an 81 year-old male with a bilateral mild hearing loss. JB’s hearing thresholds were better in his right ear than his left ear. A cued-listening task was carried out on subject JB in soundfield. JB, while wearing amplification, was asked to localize to either the right or left side depending on which side he heard the signal and saw a precued visual target (a signal light labeled “listen right” or “listen left”). Results showed 21% errors in the right condition, 29% errors in the left condition, and 56% errors in the binaural condition. Jerger et al. concluded that receiving binaural information impaired the participant’s ability to localize left or right. After examining all four cases, the authors believed that, under certain conditions, stimulation of the poorer ear interfered with the better ear causing a decrease in binaural abilities (Jerger et al., 1993).

Silman (1995) presented a case study describing binaural interference in a young man with multiple sclerosis. The patient was a 36 year old male who initially presented with normal hearing in the right ear and a left, unilateral, normal sloping to profound sensori-neural hearing loss of sudden onset. The patient also reported high pitched tinnitus for the left ear. Additional testing indicated retrocochlear pathology. Auditory electrophysiology testing and magnetic resonance imaging of the head were conducted. One week after the initial evaluation, auditory brainstem response testing was conducted. Results indicated a normal waveform response in the right ear and an absent response in the left ear. Binaural testing revealed an absent response, providing evidence of binaural interference. Similar results were found in middle latency response testing.

During the patient's second retest evaluation, only the middle latency response was tested. Results were similar to previous findings. The patient demonstrated a robust Pa for the right ear, and increased amplitude of P_a for the left ear (compared to the absent response documented previously); however the response to binaural stimulation was less than for the monaural right stimulation. Silman stated that binaural interference was seen in both the ABR and MLR testing for this patient with multiple sclerosis, which could suggest that binaural interference is due to involvement of the brainstem, and/or cortical regions. Silman suggested that more research is needed in areas where binaural interference is documented and hearing sensitivity is normal bilaterally.

In 1997, to better understand the phenomenon of binaural interference, Chmiel, Jerger, Murphy, Pirozzolo, and Tooley-Young ran numerous tests on a ninety-year-old woman who preferred unilateral amplification to bilateral amplification. They presented the following data: basic audiometric data, monaural auditory evoked potential results, behavioral and electrophysiologic results on a battery of dichotic speech tests, performance on a battery of neuropsychological tests, and the evaluation of hearing aid performance in both unilateral and bilateral modes. Their subject, AK, had a bilateral sensorineural hearing loss with the right ear being slightly worse than the left in the low frequencies, but better than the left ear in the mid to high frequencies. Although the hearing loss was fairly symmetrical, word recognition scores were asymmetrical, yielding results of 96% in the right ear and 76% in the left ear (Chmiel et al., 1997). However, using monaural stimulation, absolute latencies and amplitudes were symmetrical for the auditory brainstem response, middle latency response, and late vertex responses (Chmiel et al., 1997). Dichotic speech testing was administered to determine AK’s binaural processing abilities. Chmiel et al. used three dichotic tests: the Dichotic Sentence Identification Test (DSI), the Cued Listening Test, and dichotic PB word tests. The DSI test consisted of two presentation conditions: monotic and dichotic presentations. The monaural condition included single sentence presentations and two sentences in sequenced presentations. Dichotic presentations were measured under four conditions: precued, postcued, focused attention, and divided attention. Cued tasks included a presentation of the words “listen right” or “listen left” before each trial (precued) and immediately following each trial (postcued). In the focused attention mode, the subject was asked to respond only to one cued ear, while during the divided attention condition, they were asked to respond to both ears. Monaural performance from the left and right ears was the same, yielding results of 100% for the single sentence task. When presented monaurally with two sentences in sequence, performance dropped to 90% in the right ear and 75% in the left ear (Chmiel et al., 1997). In a divided attention mode, where pairs of sentences were presented dichotically, the right ear scored 90%, while the left ear showed a significant decrease to 15%. AK was asked to focus on one cued ear during the focused attention mode. During this trial, the right ear score increased to 100%, while the left ear score decreased to 10%. The left ear performance remained at 10% for both the postcued and precued conditions. The only drop in right ear performance was seen during the precued condition where it dropped to approximately 70% (Chmiel et al., 1997).

The cued listening task, devised by Jerger and Jordan (1992), was presented to AK through soundfield (Chmiel et al., 1997). A narrative was presented through each speaker to her right and left ears; however, there was a 60 second time delay between speakers. She was precued to "listen right" or "listen left" in blocks of five trials. A third loudspeaker, directly above AK in the sound booth, presented multitalker babble. AK was scored on correct word identification in relation to the signal-babble ratio (SBR). At a SBR of +10 dB, little difference was seen between ears. However, as the SBR became unfavorable (for example, SBRs of -5 dB), the left side performance was poorer than right side performance (Chmiel et al., 1997).

To further investigate AK's left ear disadvantage, a dichotic PB word test procedure, devised by Jerger, Alford, Lew, Rivera, and Chmiel in 1995, was used (Chmiel et al., 1997). The P_{300} event related potential was used with a verbal and nonverbal "oddball" paradigm. AK showed a left ear disadvantage in identifying words for the verbal condition and a right ear disadvantage for the non-verbal condition. P_{300} waveform amplitudes were consistent with these findings (Chmiel et al., 1997).

Chmiel et al. also evaluated AK on a set of neuropsychological tests. These tests measured AK's general intelligence, reasoning ability, language comprehension, visual reasoning ability, memory, psychomotor skills, and personality. AK showed significant impairment on the haptic naming test, which consisted of naming objects out of view with her left hand, and the traffic reaction time test which measured the time between seeing a visual stimuli and stepping on the brake. All other tests of neuropsychological abilities were within normal limits (Chmiel et al., 1997). These findings indicated normal psychomotor skills and personality.

In the same study, an evaluation of hearing aid performance was carried out on subject AK. She was tested under the following conditions: 1) unaided, 2) aided in the right ear only, 3) aided in the left ear only, and 4) aided bilaterally. AK also was tested using an assistive listening device comparing right ear vs. left ear use (Chmiel et al., 1997). Hearing aid performance results were consistent with previous tests, showing the right ear alone with the highest percent correct, the left ear alone with the lowest percent correct, and bilateral amplification falling between the two (Chmiel et al., 1997). Correct identification while using an assistive listening device was near normal when used on the right ear but poor with left ear use.

Chmiel et al. (1997) noted that subject AK is like many elderly hearing aid users in the fact that she showed more satisfaction when wearing one hearing aid rather than two. Chmiel et al. concluded that AK exhibits the phenomenon of binaural interference described by Jerger et al. (1993). Chmiel et al. discussed their reasoning for AK's preference for using one hearing aid versus two. They suggested, "1. A greater peripheral deficit on the left ear leading to imbalance in, or asynchrony of, binaural input, 2. A cognitive deficit limiting successful use of binaural input, or 3. An auditory processing deficit limiting successful use of binaural input (Chmiel et al., 1997, p.7)."

They argued the difficulty in placing blame purely on the left ear deficit. This was due to the ability to reverse ear advantage in verbal vs. nonverbal tasks during dichotic listening tests. A cognitive deficit might have been considered if a memory problem had been determined, or dichotic stimulation to both ears could have caused a sensory overload for cognitive processing, making it easier for the signal to be processed monaurally rather than binaurally. If this was the case, when AK was tested under a focused condition where only one ear was attending, a deficit should not have been noted (Chmiel et al., 1997). AK's overall results on the neuropsychological evaluation were within normal limits, making it difficult to use cognitive deficit as a strong explanation.

Chmiel et al. (1997) proposed that the strongest explanation was an auditory processing deficit impacting binaural input. Based on the results of the dichotic tests, when the dichotic task was verbal, the left ear performed worse. However, when the task was nonverbal, the right ear performed worse (Chmiel et al., 1997). These results showed similarities to those who have demyelination of the corpus callosal fibers (Goldstein & Shelly, 1974). Taking into consideration the important role that the corpus callosum plays in binaural processing, Chmiel et al. concluded, "AK's difficulty with binaural amplification may be explained by age-related progressive effects of the demyelinated corpus callosum causing a deficit in interhemispheric auditory transfer in a manner similar to research presented by Jerger et al., 1995" (Chmiel et al., p. 8, 1997).

More recently, research by Allen, Schwab, Cranford, and Carpenter (2000) investigated the phenomenon of binaural interference in normal hearing and hearing impaired adults. This study sought to determine if binaural interference occurred in normal hearing individuals and in hearing impaired individuals, regardless of amplification status and age. Subjects had no significant medical involvement, such as head trauma, stroke, or mental illness (Allen et al., 2000). Four groups of twelve participants were examined (48 total): young normal (YN) hearing adults, older normal (ON) hearing adults, older unaided hearing-impaired adults (OHI), and older aided (OA) hearing-impaired adults. The OA group consisted of six adults fit unilaterally and six fit bilaterally. The mean SRT differed among the four groups; however, this difference was expected since hearing thresholds differed among groups (Allen et al., 2000).

In the Allen et al. (2000) study, WRSs on the CID-W22 word lists were evaluated in monaural left, monaural right, and binaural conditions under insert earphones. Statistical evaluations, using 4x3 repeated-measures ANOVA and post hoc analysis using Tukey HSD tests, found significant differences between right vs. left monaural WRS and left monaural vs. binaural WRS. To determine which listening condition allowed for optimal word recognition performance, each individual's best monaural WRS was compared to his/her binaural WRS. The majority (56%) of subjects in YN, OHI, and OA groups performed best in the binaural condition. However, in the ON group, 58% of the subjects performed better in the monaural unaided condition (Allen et al., 2000). The authors noted that if the performance of the YN group were used to define a standard range for differences between monaural and binaural scores, then among the older groups 7 subjects demonstrated binaural interference and 10 subjects showed binaural advantage. After statistical analysis, the degree of these differences was found to be statistically significant for 3 subjects. Two of these subjects showed binaural interference and one showed significant binaural advantage (Allen et al., 2000).

The two subjects who demonstrated binaural interference were from the older aided hearing impaired (OA) group and the older normal hearing (ON) group. The subject from the OA group, AM, was an 85 year old man who wore bilateral hearing aids. The subject from the ON group, JE, was a 73-year-old female who had no significant difference between her left and right monaural WRS scores (Allen et al., 2000). Subject JE was of particular interest because she did not demonstrate evidence of hearing loss or prolonged auditory deprivation, which had been believed to be a key contributor to the phenomenon of binaural interference (Jerger et al., 1993). This finding raised questions as to whether other factors besides an impaired peripheral system can contribute to binaural interference (Allen et al., 2000). Allen et al. concluded, "Based on the results of the present study, it may be possible that 9 to 10 percent of elderly individuals may exhibit binaural interference, regardless of hearing status (pg. 499)."

Allen et al. suggested that further research needed to be conducted to investigate the presence of binaural interference in normal hearing adults of all ages in contrast to only young normal hearing adults. They also stated the need to evaluate WRSs binaurally as well as monaurally prior to hearing aid fittings (Allen et al., 2000).

Recently, an unpublished study by Allen, Sigurdson, and Downs investigated binaural interference in normal hearing adults (Allen, R., personal communication, June 20, 2007). Subjects' ages ranged from 20-80 + years and they were grouped by decade of life. There were 12 subjects per group (Allen, personal communication, June 20, 2004).

The CID W-22 word lists, PAL PB 50 word lists, and Sentence-in-Noise (SIN) sentence lists were used for word recognition and sentence recognition testing. Fifty-one (64.5%) out of 79 subjects showed the same or poorer binaural word scores for the CID W-22. For the CID W-22 word lists, three individuals showed statistically significant binaural interference (a 30 year old (p=.05), a 50 year old (p= .00), and a 70 year old (p=.02)). For the PAL PB 50 word lists two individuals showed statistically significant binaural interference (a 20 year old (p=.05) and a 60 year old (p=.00)), and two showed statistically significant binaural advantage (two 50 year olds (p=.05; p=.03)) (Allen, personal communication, June 20, 2008). Allen concluded that nearly half of the adult subjects (aged 20-80+) performed poorer in the binaural condition on word recognition tasks. Sentence performance yielded better binaural than monaural scores on the SIN test. Fifty-four subjects (68.4%) demonstrated a binaural advantage, 24 (30.4%) demonstrated a monaural advantage, and one subject (1.2%) demonstrated binaural indifference.

A case study of binaural interference in a child was documented by Schoephflin, (2007). The patient, KB, was first seen at the age of 1.6 years at which time he had a soundfield threshold of 75 to 90 dB HL. He was fit with a body aid to his right ear and aided testing showed soundfield thresholds of 25 to 40 dB HL. Retesting at the age of 4.6 years showed a severe sensorineural hearing loss bilaterally. Word recognition performance was evaluated using the full Phonetically-Balanced Kindergarten (PBK) word lists presented at 25 dB SL re: SRT. The resulting scores were 88% in the right ear and 40% in the left ear. Based on Thornton and Raffin (1978), these scores indicated a statistically significant interaural difference. These results, according to Schoepflin, presented evidence of auditory deprivation in the left ear, due to a three-year period of unaided auditory stimulation. Subsequently, the left ear was aided with a body aid. Three months after bilateral amplification, the patient's mother and teachers reported an unfavorable change in KB's behavior. Schoepflin (1997) reevaluated KB's pure tone thresholds, SRTs, and word recognition testing, nine months after the bilateral amplification fitting. Results were consistent with those at the age of 4.6 years. Soundfield aided word recognition testing yielded scores of 90% right, 36% left, and 59% binaural.

Based on the word recognition results and the reports of academic and behavioral changes following bilateral amplification, Schoepflin recommended removal of KB's left hearing aid and implementation of an intensive home treatment program which included auditory training and speech reading training. The auditory training was conducted with unilateral left hearing aid use and then bilateral amplification. The period of bilateral amplification use was increased gradually, with the goal being full time, daily use. It was reported that KB was able to wear bilateral amplification successfully for approximately two hours a day, but long term success could not be documented because KB stopped showing up for his follow-up visits.

Schoepflin discussed the need for binaural testing in the auditory test battery, especially in children. She stressed the need to recognize those who maybe are at risk for binaural interference, such as those with asymmetric word recognition scores. If auditory deprivation is one of the causes of binaural interference, then one could possibly reverse these effects by providing auditory training to the poorer ear (Schoepflin, 2007).

Walden and Walden (2005) compared unilateral and bilateral aided speech recognition in background noise in 28 subjects that were fit with amplification. Of the 28 subjects, 23 were experienced bilateral hearing aid users, with an average of 6.4 years of hearing aid experience. The remaining five subjects were new hearing aids users. The mean age of the subjects was 75.1 years. Mean audiometric thresholds showed subjects as having bilateral, symmetric mild sloping to severe sensorineural hearing loss. Subjects were fitted with custom hearing aids (canal or completely-in-the-canal), and if the hearing aids had directional microphones these were disabled during the study (Walden & Walden, 2005). Subjects were tested using the QuickSIN test presented in soundfield (Etymotic Research, 2001) and Dichotic Digits Test presented under insert earphones (Musiek, 1983).

The Dichotic Digit Test (DDT) was used to assess binaural interference/separation. This test consisted of two conditions (free recall and directed recall). On the free recall task the subjects were asked to repeat all numbers heard, regardless of ear (stimuli consisted of two or three digit pairs presented to both ears simultaneously). In contrast, in the directed recall condition, the subjects had to attend to one or the other ear and repeated the digits heard in that ear only (stimuli consisted of one digit presented to each ear). The DDT is scored by percent correct for each condition (left directed recall, right directed recall, and bilateral free recall). Stimuli were presented at 70 dB HL and presentation order of test conditions was randomized. These results were later compared to the QuickSIN results. QuickSIN testing revealed less SNR loss (better performance) for the right ear when compared to the left ear. Bilateral aided performance revealed a greater SNR (poorer performance) loss than either of the unilateral aided conditions. When the bilateral aided performance was compared to that of the poorer unilateral aided performance, no significant difference in SNR loss was noted; however bilateral performance scores were significantly poorer than the best unilateral performance. Due to the directed recall data for the one and two pair digits sets demonstrating ceiling effects, only the three pair digits set was analyzed for the DDT. No significant difference was observed between the right and left ear directed recall results for the three pair digit sets. When the data was reconfigured to compare the QuickSIN results of the better performing ear to the poorer performing ear, subjects showed a better directed recall on the DDT in their better performing ear on the QuickSIN score. Walden and Walden discussed possible bilateral amplification effects on speech recognition. The first effect could be that there is no interaction between ears, if the bilateral performance is equal to that of the better performing ear. Secondly, if binaural integration occurs, the results from speech recognition with bilateral amplification would be better than speech recognition results under unilateral amplification from either ear. Lastly, with binaural interference, results from bilateral amplification would be poorer than unilateral amplification performance. Results of Walden and Walden (2005) showed that the majority of the subjects were vulnerable to binaural interference. That is, their bilateral aided performance was poorer than their unilateral aided performance. Walden and Walden cited a study by Jerger, Carhart, and

Dirks (1961), which investigated word recognition in noise in middle-aged and elderly subjects, and suggested there was a relationship between binaural interference and age. In summary, the authors concluded that speech recognition performance when presented in background noise might be better when listening unilaterally and bilaterally. When listening to speech in background noise, listeners may receive a distorted signal or a proportion of an auditory signal. Under these conditions, the auditory system may still be able to discriminate using auditory closure. Walden and Walden's QuickSIN testing used presentation of sentences and noise from the same loudspeaker and with hearing aids set to omnidirectional microphone setting. Further research is needed to determine whether binaural interference is exhibited when there is a spatial separation for noise and speech and/or when directional microphones are in use (Walden & Walden, 2005).

Theories Behind Binaural Interference

Evidence Supporting Peripheral Involvement

Arkebauer, Mencher, & McCall (1971) believed a deficiency in the peripheral auditory system could be associated with the occurrence of binaural interference. As previously stated, the authors concluded in their study that, "the poorer ear signal was interfering with the better ear signal causing a decrease in speech recognition scores (pg. 209)." The subjects in this research project had bilateral asymmetrical sensorineural hearing losses. Based on this research, an asymmetrical degraded auditory signal may have been an underlying cause of binaural interference. Subsequent studies looked into the effects of auditory deprivation with asymmetric sensorineural hearing losses (Gelfand

& Silman, 1993; Rothpletz, Tharpe, & Grantham, 2004; Silverman, Silman, Emmer, Schoepflin, & Lutolf, 2006).

Hattori (1993) investigated whether an auditory deprivation/dominant ear effect associated with non- altering unilateral amplification (i.e., amplification is worn on a specific ear and is not moved to the other ear for any length of time) was present in children. Subjects included 35 children with congenital, bilateral symmetric sensorineural hearing loss. Degree of hearing loss was moderately severe to profound. Subjects were fit unilaterally or bilaterally at ten years of age or younger (Hattori, 1993). Two groups were formed consisting of 17 children who were fit with non-alternating unilateral amplification and 18 children who were fit with alternating unilateral or bilateral amplification. Subjects were tested approximately 4 years after being amplified (initial test) and again approximately 14 years later (retest). The test battery included pure-tone threshold testing, speech reception thresholds, and supra-threshold nonsense syllable recognition (NSR) presented through headphones. Results indicated no significant difference in performance for the bilateral or alternating unilateral aided groups. Overall scores increased over time for NSR testing for the bilateral and unilateral groups. The unilateral group showed a greater increase in performance in the aided ear (19.3%) compared to the unaided ear (7.3%). Hattori concluded that unaided effects were primarily attributed to maturation and aided effects were due to auditory stimulation from amplification, auditory training, and maturation.

In 1993, Gelfand and Silman researched auditory deprivation in children. They sought to determine implications of fitting children unilaterally versus bilaterally. This study was a retrospective study of 20 children with bilateral moderate sensorineural hearing loss. Ten of the children were fit unilaterally and the other ten were fit bilaterally with hearing aids. These children had initial pure tone and speech recognition testing performed when they were fit with their hearing aids and were retested at least four years later. Results from the retest revealed no significant shift in pure tone thresholds for both groups. Speech recognition scores showed no significant changes for either ear in the bilateral group or the aided ear of the unilateral group. Change was noted in the unaided ears of the unilaterally fit group. Speech recognition scores decreased by 18.6% in the unaided ears of the group that was fitted unilaterally (Gelfand & Silman, 1993). These results brought further awareness to the existence of auditory deprivation in children as a result of lack of auditory stimulation to the unaided ear.

Rothpletz, Tharpe, and Grantham (2003) studied the effect of asymmetrical speech degradation on binaural speech recognition in children and adults. In order to control for extraneous variables, this study looked at binaural speech perception performance in children and adults with normal hearing sensitivity using stimuli that were degraded in a way to simulate the effects of cochlear hearing loss. Twenty-eight children and 14 adults with normal hearing sensitivity participated. The children were split into younger and older groups.

Speech perception testing was performed using sentence materials from the Hearing-in-Noise Test for Children (HINT-C) (Nilsson, 1996). These sentences were degraded by altering the signal digitally in the MATLAB programming environment (Rothpletz et al., 2003). Digitized six-talker babble served as the competing noise stimuli. Participants were tested on sentence recognition in the following simulated conditions: (a) monaural mild loss; (b) binaural mild loss; (c) binaural asymmetric hearing loss. Participants were asked to repeat each sentence and a speech-to-babble ratio (SBR) was calculated for 50% word identification. Rothpletz et al. (2003) used an interfacing computer to establish a signal-to-babble threshold (SBT), which was dependent on the average SBR presentation for sentences 5-13. Lower SBRs indicated better speech perception performance.

The mean SBR were averaged for the three listening situations and were: 9.98 dB for the younger child group, 5.12 dB for the older child group and 1.59 dB for the adult group. Adults significantly outperformed both child groups, and the older child group significantly outperformed the younger child group. All groups performed better in the binaural-mild condition than in the monaural-mild condition with all groups showing a binaural advantage. Adults did show evidence of binaural interference when monaural-mild and binaural-asymmetric conditions were compared. An equal number of children showed a binaural advantage to those who showed binaural interference, when the individual scores for binaural asymmetric conditions were compared to monaural conditions. In the adult group, binaural interference was statistically significant in a majority of the participants when comparing the binaural mild to the binaural asymmetric conditions.

Rothpletz et al. stated that the expectation was to find binaural interference to be observed more in children than in adult participants. They attribute their findings to, “the children’s poor performance in the monaural condition.”(p. 277). The children needed a relatively large SBR in the monaural simulated hearing loss conditions, therefore adding a severely degraded signal in the opposite ear showed little interference effects. The authors stated that, “a larger sample size, different stimulus parameters, or different speech materials may have increased the detection of the binaural interference effect.” (p. 278). However, due to the evidence that many of the children demonstrated a binaural-asymmetric advantage, children of a larger sample size may not demonstrate binaural interference.

Silverman, Silman, Emmer, Schoepflin, and Lutolf (2006) investigated auditory deprivation in adults with asymmetric, sensorineural hearing impairment. The authors’ goals were to prospectively examine pure-tone air conduction thresholds, speech recognition thresholds, and supra-threshold word recognition scores over time. The subjects consisted of 21 unilaterally aided and 18 unaided adults with asymmetric sensorineural hearing loss. There was a >20 dB asymmetry in the pure tone air conduction thresholds between the better and worse ears. The mean age of the subjects was 54.4 years of age. Audiometric testing was administered yearly and after the initial test, the aided group was fit with unilateral amplification to the poorer ear. There were no significant changes in the WRSs and speech recognition thresholds for the better ears of either group. However, there was a decline in W-22 WRS in the poorer ears of the control (unaided) group (Silverman et al., 2006). Silverman et al. noted that this decline could suggest that auditory deprivation occurs in the poorer ears of unaided adults with asymmetric sensorineural hearing loss.

Relative to research by Arkebauer et al. (1973), individuals with asymmetric hearing loss may show effects of auditory deprivation. Individuals demonstrating auditory deprivation could experience binaural interference, due to the poorer auditory signal interfering with the better auditory signal. Research has shown binaural interference in adults (Arkebauer et al., Jerger et al., Chmiel et al.), but binaural interference has not been systematically evaluated in children. Studies have shown auditory deprivation effects in children with hearing loss (Gelfand and Silman, 1993; & Hattori, 1993). Therefore, based on the previously stated theory of Arkebauer et al., children with asymmetrical hearing loss may show evidence of binaural interference. Binaural interference may be seen especially in those children who demonstrate auditory deprivation, since the asymmetric degraded signal could possibly be an underlying source of binaural interference.

Evidence Against Peripheral Involvement

Binaural interference in normal hearing adults. Despite research showing supportive evidence (Arkebauer et al., 1973) for peripheral involvement, later research (Allen et al., 2000; Chmiel et al., 1997; & Jerger et al., 1993) provides evidence to rule out peripheral involvement in some individuals. Allen et al. (2000) investigated binaural interference in normal hearing and hearing impaired individuals. Of the 48 subjects tested, two individuals showed statistically significant binaural interference, based on the Raffin & Thornton scales of binominal distribution (Raffin & Thornton, 1980). One of the subjects was hearing impaired, however the other subject had normal hearing. If binaural interference is due to peripheral involvement, then an individual with normal hearing should not experience this phenomenon. This finding provides evidence that the occurrence of binaural interference may not be solely linked to peripheral involvement.

Cortical and midbrain involvement. Jerger et al. (1993) used electrophysiologic measures to show the presence of binaural interference through the use of topographic brain maps, auditory brainstem responses, and middle latency responses. Evidence for binaural interference was observed in the topographic brain maps and middle latency responses, but not in the auditory brainstem response. The authors noted the uncertainty in knowing the exact mechanism for the binaural interference phenomenon, which may be due to a peripheral or central involvement. Jerger et al. discussed that peripheral involvement was most likely not the case. They concluded that even with an asymmetric degraded signal, the binaural results should be better or the same as the best monaural results.

Influence from the corpus callosum. Jerger, Alford, Lew, Rivera, and Chmiel (1995), were the first to publish evidence of the role of the corpus callosum as an underlying mechanism of binaural interference. Jerger et al. concluded, "Marked interaural imbalance in the processing of verbal materials may be the basis for the binaural interference". (p. 497). Chmiel et al. (1997) later researched the unsuccessful use of bilateral amplification by an elderly person. A 90-year-old subject, AK, underwent intensive testing in the attempt to gain insight into the underlying mechanism attributing to binaural interference. Chmiel et al. discussed that one of the possible mechanisms that could be contributing to binaural interference was an auditory processing deficit. They compared AK's dichotic test results to subjects who had undergone commissural sectioning. AK showed a right ear advantage on verbal tasks; however the performance reversed on non-verbal tasks showing a left ear advantage. Goldstein and Shelly (1974) studied the importance of the role for the corpus callosum on mediating verbal responses to left-ear inputs, and noted that age related changes to the corpus callosum can affect interhemispheric transfer. Chmiel et al. highlighted research by Doraiswamy, Figiel, Husian, McDonald, Shah S, Boyko O, and Krishnan (1991) in documenting age-related changes in the corpus callosum. With aging, there is a lack of inter-hemispheric transfer of auditory information through the corpus callosum (Chmiel et al., 1997). Chmiel et al. (1997) concluded, "AK's preferences for unilateral amplification were related to the age-related progressive atrophy or demyelination of corpus callosal fibers, resulting in delay or other loss of the efficiency of interhemispheric transfer of auditory information in a manner similar to that recently suggested by Jerger et al. (1995)." (p. 8).

In summary, past research has shown the presence of binaural interference in normal hearing, as well as, hearing impaired adults. Past research also suggests that peripheral involvement and demyelination of the corpus callosum may be contributing factors to binaural interference in older, hearing impaired adults (Chmiel et al., 1997). Based on the findings of Allen et al. (2000), in the absence of hearing loss, (i.e., normal peripheral hearing sensitivity), the presence of binaural interference in younger adults may be attributed to involvement of one or more structures of the central auditory nervous system, including the corpus callosum.

Overview of Central Auditory Processing Disorder in Children

A central auditory processing disorder as described by ASHA (2005) refers to:

> …the difficulties in the processing of auditory information in the central nervous system. Such auditory processing abilities include: sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, auditory performance in competing acoustic signals, and auditory performance with degraded acoustic signals (ASHA, 2005, p. 1).

Bellis and Ferre (1999) have suggested central auditory assessment tools for current clinical use and presented four case studies that used these tools to better understand the nature of auditory difficulties. These authors believe central auditory processing disorders (CAPD) need to be assessed through a multidimensional approach. They noted that with the appropriate tools, dysfunction of specific brain regions could be found and used to better assess a child's learning difficulties. They described central auditory assessment tools and commented that although the following were not the only available tools, CAP test batteries should include at least the following: dichotic listening tasks, monaural low-redundancy speech tasks, tasks of temporal patterning, and binaural interaction tasks (Bellis & Ferre, 1999). These were recommended by the authors for an appropriate CAP test battery.

Dichotic listening tasks include stimuli presented binaurally with the stimulus to each ear being different. Subjects are asked to repeat either all of the words heard or to focus on a target ear and repeat only what is heard in that ear. Research has shown these tasks to be sensitive to dysfunction in the interhemispheric pathways, brainstem and cortical areas (Jerger & Jerger, 1975; & Musiek, F.E., Kurdziel, S., Kibbe, K., Gollegly, K.M., Baran, J.A., & Rintelmann, W.F., 1989). Dichotic tests could include but are not limited to the : Dichotic Digits Test (Musiek, 1983a), Dichotic Rhyme test (Musiek et al., 1989), Competing Sentences (Willeford & Burleigh, 1994), and the Staggered Spondaic Word test (Katz, 1962).

Monaural low-redundancy speech tests include distorted monosyllabic words in which the extrinsic redundancy of the signal has been reduced (Bellis & Ferre, 1999). These tests evaluate auditory closure and can show sensitivity to brainstem and cortical dysfunction. Included tests are: low pass filtered speech, time-compressed speech, and time compressed speech with reverberation (Bellis & Ferre, 1999).

Temporal patterning tests assess the listener's ability to perceive a difference between tonal stimuli. Such tests include pitch pattern sequence (Pinheiro & Ptacek, 1971) and duration patterns (Pinheiro & Musiek, 1985). Temporal pattern tests are sensitive to cortical and interhemispheric disruptions (Musiek, F.E., Pinheiro, M.L., & Wilson, D.H., 1980).

Lastly, binaural interaction tasks were suggested for use (Bellis & Ferre, 1999). On these tasks, a portion of the target message is presented to each ear of the subject. The subject is to fuse the two messages together to detect or identify the target message. Binaural interaction tests have been shown to be sensitive to brainstem pathologies (Musiek, 1983b). Such tests include: Rapidly Alternating Speech Perception (Willeford & Bilger, 1978), consonant-vowel-consonant (CVC) binaural fusion, and high/low pass binaural fusion (Bellis & Ferre, 1999).

Bellis and Ferre (1999) presented four case studies to illustrate a comprehensive central auditory evaluation. Each subject was tested in a sound treated room and underwent preliminary standard audiometric and immittance testing. A case history was performed prior to testing and similar complaints were seen among the four cases.

The first case was a 9 year, 10-month old girl with apparent deficits in listening comprehension, auditory word memory, and auditory sequencing. She had normal cognitive abilities, but showed difficulties in reading, spelling, and written language. She also had a history of ear infections and had patent pressure equalization tubes during testing preliminary testing revealed normal hearing and excellent word recognition scores in quiet. The subject showed abnormal performance on the following tasks: bilateral low-pass filtered speech testing, bilateral Dichotic Digits, and competing sentences. Bellis and Ferre (1999) concluded that this subject had a deficit in auditory closure and could possibly have dysfunction in the auditory cortex. Management included classroom modifications to improve the signal to noise ratio, an assistive listening device, and personal counseling related to compensatory strategies.

The next case involved a 9 year, 3-month old boy with difficulties related to listening comprehension and academic performance. This subject had a mild cognitive deficit and was in a self-contained classroom. He showed difficulties with fine and gross motor abilities, visual-auditory association, and carrying out motor responses to verbal commands (Bellis & Ferre, 1999). This subject struggled in all academic areas as well as nonacademic areas, such as art, music, and sports. Although he had normal hearing and middle ear function, he showed deficits on temporal patterning tasks, dichotic speech tasks, and monaural low-redundancy speech tasks. Bellis & Ferre concluded that this subject had a deficit in the interhemispheric transfer of information via the corpus callosum. Management included preteaching of new information, assistance from a note taker, and lastly, the separation of auditory and visual cues (the subject will hear the task first and then visually see the tasks, by silent visual or tactile demonstration) (Bellis & Ferre, 1999).

The third case involved a 9 year, 2-month old boy who had difficulty in understanding verbally presented information, especially in the presence of background noise, and difficulty sequencing verbally presented information. This subject had prior speech therapy and his mother had concerns about his communication skills. He had normal cognitive function, normal hearing, and normal middle ear function. Deficits were found on the frequency pattern and dichotic digits tests (left-ear deficit), (which could be an indicator of right hemisphere involvement (Bellis & Ferre, 1999).

The final case described by Bellis & Ferre (1999) was a 10 year, 9 month old boy referred after neuropsychological testing. The subject’s parents reported classroom listening difficulties and inattentiveness. The subject showed difficulty in language, note taking, and reading. Neuropsychological reports noted that the child’s difficulties might be due to a CAP disorder or attention deficit disorder (ADD). Similar to the other cases, the subject had normal hearing, excellent word recognition, and normal middle ear function. This subject performed within normal limits on all CAP tasks. The authors concluded that due to age-appropriate CAP abilities, the subject might have ADD and he was referred to a pediatric neurologist for an ADD evaluation (Bellis & Ferre, 1999).

Bellis & Ferre discussed the importance of treating each case individually because not all children with similar complaints have the same types of deficits. Furthermore, a child with complaints similar to those for CAPD, might not have CAPD, and might need additional referrals. In addition to Bellis & Ferre, other scientists and clinicians have tried to reach a consensus on the diagnosis of central auditory processing disorders in children.

Jerger and Musiek (2000) gathered senior scientists and clinicians to reach this consensus. The authors stated a preference for the term “auditory processing disorder” (APD) rather than CAPD, due to there being possible involvement at both peripheral and central sites. The main purpose of their consensus meeting was to present recommendations toward a differential diagnosis of APD to identify auditory-specific perceptual deficits (Jerger & Musiek, 2000). Scientists and clinicians focused on four areas: screening for APD, differential diagnosis of APD, a minimal test battery, and directions of future research.

For the purpose of screening for APD, clinicians have used checklists and questionnaires to identify children with APD. Screening tests, such as the SCAN: Test for Auditory Processing Disorders in Adults (SCAN: A) (Keith, 1995) or SCAN: Test for Auditory Processing Disorders in Children: Revised (SCAN: C) (Keith, 2000), have also been used in the identification of APD. The original SCAN-A, (Keith, 1995), was revised and the SCAN:C Auditory Processing Disorders in Children-Revised test was developed (Keith, 2000). Keith (2000) developed normative data collected on 650 children ages 5 years, 0 months, to 11 years, 11 months for the SCAN: C. Keith noted an improvement in children's performance with increasing age and found no gender effects. The SCAN: C has been widely used clinically as a screening tool in the identification of auditory processing disorder. Jerger and Musiek (2000) raise caution in the use of screening tests for the diagnosis of APD. They stress that screenings should serve as a tool for identification of children at high-risk for an auditory processing disorder and should not be used for differential diagnosis. The consensus team recommended that a dichotic digit test consisting of two digits in each ear, using a free-recall response mode, and a gap-detection test (temporal processing) be considered for an appropriate screening protocol. It was suggested that research needs to be performed to provide a screening test battery for children under the age of six, and the involved group suggested a questionnaire (Jerger & Musiek, 2000). Before developing a differential diagnosis, the authors expressed the importance of knowing whether non-auditory disorders are often present in children with APD. The authors described that auditory processing can be expressed in different ways, a pure auditory processing disorder or an auditory processing disorder accompanied with disorders in other areas (multisensory) (Jerger & Musiek, 2000).

The presence of another deficit also can make diagnosis of APD difficult. Other common deficits include attention deficit hyperactive disorder (ADHD), language impairments, learning disabilities, reading disabilities, autism, and reduced intellectual functioning. Jerger and Musiek (2000) discussed the importance of task variables. Such variables include cognitive demands (memory, attention), floor or ceiling effects, learning or practice behavior, linguistic demands, and response mode. Suggestions on how to minimize these variables were discussed by the authors and the following recommendations included but were not limited to: 1) comparing different multi-sensory modalities (auditory vs. visual tasks); 2) using test materials that are not linguistically demanding; 3) minimizing memory load; and 4) seeking validation from individuals who helped in developing the differential diagnosis test battery. The consensus team proposed a minimal APD test battery for the diagnosis of APD in children. According to the consensus group, testing should be carried out in the following manners: behavioral, electrophysiologic and electroacoustic tests, and neuroimaging studies (Jerger & Musiek, 2000). Involved scientists and clinicians proposed that a behavioral battery supplemented by electrophysiologic testing would provide the best test battery among clinics. According to the consensus team, behavioral tasks should include, but are not limited to: measures of detection, measures of suprathreshold discrimination, and measures of identification. These tests could be presented monotically, diotically, and dichotically. The committee came to a consensus on the minimal test battery necessary for diagnosing APD. The test battery included pure tone audiometry, word recognition performance-intensity function, and temporal processing tasks (duration pattern sequence test and temporal gap detection) (Jerger & Musiek, 2000). Immittance testing, otoacoustic emissions, and auditory brainstem response were recommended following behavioral testing in some cases. The need for future research in many different areas of APD was noted. Some research topics included: the prevalence of APD in children, an appropriate age to begin APD screening, and the relationship between APD test outcomes and management strategies.

When comparing recommendations by Bellis and Ferre (1999) to the outcomes of the consensus group, similarities can be observed. Bellis and Ferre were in agreement on the importance of creating a well-accepted test battery for the diagnosis of APD. Both groups included dichotic tasks and temporal tasks as part of their minimal test battery. Bellis and Ferre (1999) presented a need for binaural interaction tasks, such as the MLD or binaural fusion tests. Although specific tests for an APD test battery may vary between clinics, both groups emphasized a minimal test battery that is multidimensional with consideration of task variables (for example, ceiling effects, linguistic demands, cognitive demands, etc.) (Bellis & Ferre, 1999; Jerger & Musiek, 2000).

Different test batteries and theoretical models for APD (i.e., Bellis/Ferre and Buffalo models) have been developed, and research has been performed to determine the applicability of these models. Jutras, Loubert, Marcoux, Dumont, and Baril (2007) sought to determine the applicability of two central auditory processing disorder models. Two models were of interest, the Bellis/Ferre model and the Buffalo model. Jutras et al., (2007) described the Buffalo model as including four major deficit categories: decoding, tolerance-fading memory, integration, and organization. Decoding consisted of the processing of auditory information at a rapid pace and a breakdown in decoding could lead to slower responses by individuals. Tolerance fading memory involved short term auditory memory problems and reduced tolerance to noise. Integration involved the processing of auditory information along with other types of information (e.g. visual information). Organization involved the ability to appropriately sequence auditory information (Jutras et al., 2007). In contrast, the Bellis/Ferre model is comprised of three primary and two secondary deficit categories. Jutras et al. (2007) described the primary categories as breakdowns in communication between the right and left hemisphere and were the following: auditory decoding deficit, prosodic deficit, and integration deficit. The secondary categories of the Bellis/Ferre model were labeled as language or attention deficits and were: associative deficit and output-organization (Jutras et al., 2007).

In order to examine both models, Jutras et al. (2007) developed a retrospective study to examine which model best classified children found to have APD. Out of 178 records, 48 records of children diagnosed with central auditory processing disorder, were reviewed. Since Jutras et al. had applicability data on the Buffalo model (i.e., the model used in the initial diagnosis of APD); the authors evaluated the Bellis/Ferre model for comparison to the Buffalo model. After reviewing the subjects' charts, Jutras et al., classified the individual subjects into the different categories in the Bellis/Ferre model. The authors noted that a majority of the children were classified under the decoding deficit in the Buffalo model. However, in the Bellis/Ferre model 60% of the subjects were unclassified. Jutra et al. argued that the Bellis/Ferre model does not lend itself to identifying a specific deficit category. Furthermore, they raised caution to the diagnosis of CAPD based on only one test, as seen in the Buffalo model (Jutra et al., 2007). In conclusion, the authors recommended the need for further research to fine tune both the Buffalo and Bellis/Ferre models, which the authors determined to be "inadequate for clinical use" (Jutra et al., 2007, p. 105).

When developing a multidimensional test battery, it is first important to have an understanding of the different auditory processes. The following sections present the areas of auditory processing included in the present study: binaural interaction, temporal processing, and sentence-in-noise testing.

Binaural Interaction

Binaural interaction refers to the combination of two individual auditory signals received from each ear (Musiek & Baran, 1986). Functions dependent on binaural interaction are localization of auditory stimuli, binaural release from masking (BMLD), detection of a signal in noise, and binaural fusion (Bellis, 2003). Musiek and Baran (1986) discussed the importance of brainstem involvement for binaural interaction tasks, specifically at the level of the superior olivary complex (SOC). It is at the SOC that the auditory signal from each ear converges, and the stimuli arrival time provides information for sound localization (Musiek & Baran, 1986). Binaural interaction tasks include, but are not limited to, rapidly alternating speech perception, binaural fusion, and the masking level difference tests.

Masking level difference is defined as the difference between binaural thresholds for a homophasic (the signal and the noise are in phase, SoNo) and antiphasic (the signal and/or noise are 180 degrees out of phase at the two ears; for example SoNπ or SπNo) (Wilson, R., Zizz, C., & Sperry, J., 1994). Masking level difference tests can use either tonal or speech stimuli to determine either a tonal MLD or a speech MLD.

Roush and Tait (1984) studied binaural fusion, masking level difference, and auditory brainstem responses in children with language-learning disabilities. The experimental group consisted of 18 normal hearing children from 6 to 12 years of age who had abnormal performance on an auditory-language test battery. The control group consisted of 18 normal hearing children with normal auditory-language skills. Each subject was administered a binaural fusion test and a masking level difference test. Auditory brainstem responses were also measured. The binaural fusion test consisted of three listening situations: dichotic (low pass band was delivered to the left ear and high pass band was delivered to the right ear), diotic (both the low and high pass bands were delivered simultaneously to each ear), and the dichotic II condition (the reverse of the dichotic condition, each ear was given the other stimuli) (Roush & Tait, 1984). Subjects were instructed to repeat what they heard after each stimulus presentation. Binaural fusion results demonstrated that both groups had relatively higher scores in the diotic condition, and the control group outperformed the experimental group on all three tests.

The masking level difference was evaluated using a 500 Hz tonal and a narrowband noise stimulus under a homophasic reference condition and an antiphasic condition (SπNo) (Roush & Tait, 1984). Each subject was instructed to raise his/her hand when he/she heard the tone among the noise. The tone level was increased in 2 dB steps. This procedure was performed until a threshold response level was recorded for the homophasic and antiphasic conditions. These conditions were counterbalanced between subjects. The difference between the tonal threshold obtained in the homophasic (SoNo) and antiphasic (SπNo) conditions was defined as the subjects' MLD. Roush and Tait (1984), stated within normal limits on the masking level difference test for both groups, however the normative values used to determine normal performance was not reported.

Auditory brainstem responses (ABR) were also obtained. For each ear, absolute latencies were measured for waves I, III, V, and the interpeak latencies of I-III, III-V, and

I-V (Roush & Tait). ABR results were within normal limits for both groups and there was no significant difference between the two groups.

Overall results indicated a difference in performance between normal and experimental groups for the binaural fusion test, demonstrating sensitivity of the binaural fusion test to the identification of auditory processing disorders. However, due to both groups showing normal MLD and ABR results, the authors advised that although the binaural fusion test can be a useful CAPD test, it should not be considered, “a test specific to sub-cortical processing integrity” (Roush & Tait, 1984, p. 40).

In 1990, Hall and Grose studied the masking level difference (MLD) in children. They used a tonal masking level difference procedure developed by Hirsh (1948) and investigated children ranging in age from 3.9 to 9.5 years and an adult control group. The study included 26 children and 10 adults. The authors used a three alternative forced-choice adaptive tracking procedure. The first measure included a 300 Hz wide noise band masker centered on 500 Hz, and a pure tone signal of 500 Hz presented in phase (So) or 180^o out of phase (Sπ). For the second measurement, a 40 Hz wide narrowband noise centered on 500 Hz was used as the signal and the masker. MLDs were established using an interaural amplitude difference cue and interaural time difference cue. Hall and Grose (1990) explained that, “For the interaural amplitude difference cue, the signal was presented in phase with the masker in one ear and 180^o out of phase with the masking in the other, and for the interaural time difference cue, the Sπ signal has the same waveform as the masking with a 500 μs delay with respect to the masker” (p. 82).

Results for the pure tone signal added to a 300 Hz wide noise masker revealed the MLD was smaller in children than adults and increased in magnitude up to 5-6 years of age (Hall & Grose, 1990). The authors discussed how maturational effects on peripheral/brainstem auditory function might account for maturational changes of the MLD in children (Hall & Grose, 1990). The MLD for the 40 Hz wide band noise yielded smaller MLDs for children than adults. However these MLDs were smaller than those obtained with the 300 Hz-wide noise masker. The authors attempted to explain this finding by the fact that the 40 Hz signal had the same pitch and timbre for the signal and the masker, and a young listener may not be able to distinguish between the signal and the noise (Hall & Grose, 1990).

Wilson, Moncrieff, Townsend, and Pillion (2003) studied the performance of adults on a tonal MLD task for the development of a 500 Hz MLD protocol for clinic use. Three experiments were performed which consisted of a 300 ms 500 Hz tonal stimulus within a narrow band noise (200-800 Hz band centered around 500 Hz). The first experiment consisted of 57 stimuli presentations, comprised of a SoNo, SπNo, and a control condition of noise without tonal signals. Adults in experiment one showed a mean (SπNo) MLD threshold of 13.9 dB with a standard deviation of 3.4 dB. The authors stated that 90% of the listeners had MLDs $\geq$ 10 dB. The second experiment consisted of similar stimuli as experiment one, but with 37 stimuli presentations. Results indicated a mean (SπNo) MLD threshold of 13.0 dB, and 90% of the listeners had MLDs $\geq$10.6 dB. The third experiment differed from the previous experiments by the reduction of the interstimulus intervals being reduced from 5 to 4 s and the addition of a SoNπ condition.

The authors found similar mean (SπNo) MLD threshold of 12.8 dB, with 90% of the listeners having MLDs $\geq$ 10 dB. A mean (SoNp) MLD threshold of 10 dB was reported. Wilson et al. (2003) concluded that, "collectively, 95% of the young adult listeners with normal hearing studied in the three experiments had SπNo MLDs $\geq$ 10 dB" (p. 7). The final tonal MLD protocol developed for clinic use included 10 SoNo conditions, 12 SπNo conditions, and 11 no tone conditions.

Aithal, Yonovitz, Aithal, and Dold (2006) studied the tonal masking level difference in children. Their study included 62 normal hearing children, aged 7 to 13 years. There were 40 males and 22 females that participated. Participants had no history of ear disease. Two conditions were administered. In the first condition, the masking noise was an interaurally in phase (No) 160 Hz wide noise band centered at 500 Hz and a 500 Hz pure tone signal, which was generated digitally, and presented either interaurally in-phase (So) or 180 degrees out of phase (Sπ). In a second test condition, the 500 Hz pure tone signal was interaurally in phase (So) and the noise was either interaurally in phase (No) or 180 degrees out of phase (Nπ). The test was administered using an automated, simple up-down intensity adaptive procedure. The mean MLD for the SπNo condition was 11.21 dB and the MLD for the second SoNπ condition was 7.83 dB. The majority of the children demonstrated an MLD between 7 dB and 8 dB for the SoNπ condition and 9 dB and 10 dB for the SπNo condition. There was a significant difference in performance between the conditions. Gender and age effects were not significant. Aithal et al. suggested that an MLD smaller than 7.9 dB for the SπNo condition and smaller than 4.3 dB for the SoNπ condition should be considered abnormal (i.e., two standard deviations below the mean) for normal hearing children.

In addition to the tonal masking level difference test, research has been conducted using a speech stimulus (speech MLD). Most speech MLD research has been conducted with adults and only limited research has been conducted in the development of normative data for the speech MLD in children.

Speech MLDs were first investigated by Licklider (1948), who explored the influence of interaural phase relations upon the masking of speech in the presence of white noise. Licklider presented speech and white noise to a listener and adjusted the phase of the stimuli between the two ears to improve intelligibility. Licklider discovered intelligibility to be highest, approximately 25% higher, when the signal and noise were presented 180 degrees out of phase at both ears, than when the signal and noise were both in phase. He concluded that interaural phase could have a direct influence upon the masking of speech (Licklider, 1948).

In 1978, Sweetow and Reddell studied the use of masking level differences in the identification of children with perceptual problems. They sought to find an auditory processing test that would measure auditory function and could be completed by children with severe language disorders. They believed that the masking level difference test met these criteria. The purpose of their study was to determine if the masking level difference test could differentiate between children with suspected auditory perceptual dysfunction and children with normal auditory processing.

Two groups of children, aged 4 to 12 years, participated in the study. All children had normal hearing sensitivity. There were 24 children in the experimental group (suspected auditory perceptual dysfunction) and 14 children in the normal group. An additional group of 11 normal hearing adults was used to determine whether there were differences between the children with normal auditory processing skills and adults with normal auditory processing skills. Testing included MLDs for spondees and for a 500 Hz pure tone using the SoNo (homophasic) and SπNo (antiphasic) conditions. Spondee pictures were used for younger children.

The mean results for speech MLDs were: 8 dB for the adult group, 6.85 dB for the control sample of children, and 6.25 dB for the children suspected of auditory perceptual problems. There were no statistically significant differences among the three groups. Using a cutoff value of 4 dB or less to determine abnormal performance, 25% of the suspected children would have been identified, and 14% of the normal children would have been identified. The mean results for tonal MLDs were 9 dB for the adult group, 9.78 dB for the normal children, and 5.83 dB for the children with suspected auditory perceptual problems. The mean differences between the normal children and those with suspected auditory perceptual problems were statistically significant beyond the .01 level. Using a cut-off value of 7 dB or less, 79% of the suspected children were identified and 14% of the normal children were identified (Sweetow & Reddell, 1978).

Sweetow and Reddell concluded that the speech MLD was not as useful of a diagnostic tool as the tonal MLD. In trying to explain the poorer speech MLD performance, they stated that the monitored live voice technique used may have impacted the results. Regardless, the authors expressed that the tonal MLD test would be most desired since it has no linguistic component (Sweetow & Reddell, 1978).

Nozza, Wagner, and Chandell (1988) studied the binaural release from masking for detection of the speech sound /ba/. The authors sought to determine if there was a developmental change in the BMLD for infants, preschool children, and adults. They estimated binaural masked thresholds under two interaural phase conditions (NoSo, noise and signal in phase; and NoSπ, noise in phase and signal 180 degrees out of phase) and determined the BMLD by calculating the difference between the two thresholds (Nozza et al., 1988). Infant responses were obtained through the use of an established visual reinforcement procedure (Nozza & Wilson, 1984) while preschoolers' responses were obtained through play audiometry. Adults responded by pressing a button.

Nozza et al., found BLMD thresholds of 5.0 dB, 8.3 dB, and 10.8 dB (pg. 215) for the infants, preschoolers, and adults respectively. Among other findings, the BMLD of infants was significantly different than the BMLD of the preschoolers and adults. The authors suggested, "a developmental change in binaural analysis postnatally but probably not after 4 years of age" (Nozza et al., 1988, pf. 216). Based on this, children over the age of four may perform similar to adults on speech MLD tasks. Alternatively, performance may relate to the type of speech material and task used.

More recently, Wilson, Zizz, and Sperry (1994) investigated masking level differences for spondaic words embedded in a 2000 msec burst of broadband noise. They reported prior findings by Levitt and Rabiner (1967) that a larger MLD was found for the following two test conditions: low-frequency dominated speech signals (spondaic words) rather than high frequency dominated speech signals (monosyllabic words) and for speech detection tasks instead of speech recognition tasks (Wilson et al., 1994). The purpose of this experiment was to “describe the development and evaluation of the MLD paradigm for spondaic words in 2000-msec bursts of broadband noise” (Wilson et al., 1994). Two experiments were designed. The first was to obtain normative homophasic (S_oN_o) and antiphasic ($S\pi N_o$) thresholds in a 2000 msec bursts of broadband noise for young listeners. The second experiment compared spondaic words embedded in continuous noise versus a noise burst (Wilson et al., 1994). The ten spondaic words that would produce the largest MLD (Wilson et al., 1982) were digitized from CID W-1 analog tape recordings (Wilson et al., 1994). In experiment one, S_oN_o and $S\pi N_o$ thresholds were established for the 10 selected spondaic words embedded in 2000 msec broadband noise bursts for 24 normal adult hearing subjects (Wilson et al., 1994). The mean MLD was 9.5 dB. In experiment two, better performance was observed for the noise burst than for the continuous noise condition. Wilson et al. noted that the bursts of noise alerted the subject to the listening intervals, which reduced the uncertainty associated with the listening task. The compact disc trials were conducted with 60 normal hearing adult subjects at noise levels of 65 and 85 dB SPL, and 90% of the listeners had MLD greater than or equal to 5.5 dB. Wilson et al. concluded that a MLD of less than 5.5 dB should be considered abnormal for adult listeners with normal hearing (Wilson et al., 1994). They noted that additional research is needed for older individuals, and those with neurologic impairments or who have peripheral hearing loss (Wilson et al., 1994).

There is limited research related to the speech MLD for children. Hall and Grose reported that the tonal MLD for children matched the MLD for adults at the ages of 5-6 years. Therefore, one could speculate that at 5-6 years of age, the speech MLD of a child would match that of an adult (i.e., 5.5 dB, as reported by Wilson et al., 1994). Future research needs to be conducted to establish normative data for speech MLDs in children. Auditory processing not only relies on binaural interaction, but also the time-related aspects of acoustic processing, known as temporal processing (Chermak & Lee, 2005).

Temporal Processing

Temporal processing relies on time related characteristics of acoustic processing (Chermak and Lee, 2005). The skills related to temporal processing include, but are not limited to, the following: temporal discrimination, temporal masking, temporal integration, temporal ordering, and pitch perception (ASHA, 2005). Studies have investigated these skills in children and adults. ASHA (1996) describes temporal processing deficits seen in children diagnosed with (central) auditory processing disorder. These deficits included: “difficulty understanding speech in the presence of background noise, difficulties in auditory performance with competing signals, difficulties in auditory performance with degraded acoustic signals, and difficulty following verbal directions” (ASHA, 1996). For the purpose of the present study, the task of pitch perception was focused upon. The pitch pattern sequence test (Musiek, 1994) assesses an individual’s ability to discriminate between two different frequencies. While performing this listening task, individuals are asked to identify whether the audible tone was high in pitch or low in pitch. In addition, listeners must report the sequence (e.g., HHL, LLH, etc.) When identifying the tones as high and low, some individuals reverse the terms (i.e., report high for low or low for high).

Musiek, Pinheiro, and Wilson (1980) explored auditory pattern perception in split-brain subjects. Testing was performed on 3 right-handed subjects who had undergone a complete sectioning of their corpus callosum. All subjects had normal hearing and were tested in a monaural condition with stimuli presented at 40 dB re: SRT. Two types of stimuli were presented: 1) frequency patterns (high, low), and 2) intensity patterns (loud, soft). Subjects were first asked to give a verbal response to the three sequenced stimuli they perceived. The next task required the subjects to offer a hummed response of the stimuli they perceived (Musiek et al., 1980).

All three subjects had great difficulty completing the verbal response task. On the hummed task, subjects 2 and 3 (subject 1 was not tested on the hummed response) performed within the normal range and just below the normal range, respectively. Musiek et al. explained that the left hemisphere needs the acoustical information on the tones from the right hemisphere in order to develop the proper verbal response (Musiek et al., 1980). Musiek et al. further explained the ability of the subjects to hum the tonal responses. The authors noted that the right hemisphere may be processing the tonal sequence independently, or the response may be processed at a sub-cortical level due to the hummed response being less complex than a verbal response (Musiek et al., 1980).

In 1994, Musiek developed a compact disc version of the frequency and duration pattern tests. Frequency patterns consisted of three 150-msec tones with two 200 msec intertone intervals. The low frequency (L) tone was 880 Hz and the high frequency (H) tone was 1122 Hz. Six possible combinations were included: LLH, LHL, LHH, HLH, HLL, and HHL (Musiek, 1994). Duration patterns consisted of three 1000 Hz tones with two 300 msec intertone intervals. Duration pattern tests consisted of tones that were 250 msecs for short (S) durations and 500 msecs for long (L) durations. Six possible patterns were derived: LLS, LSL, LSS, SLS, SLL, and SSL (Musiek, 1994). For both tests, 60 normal hearing subjects were asked to verbally state the tone combinations. Musiek compared presentation levels of 40 dB SPL and 70 dB SPL and found no effect of presentation level on performance. The mean scores for the 60 adult subjects were approximately 90% correct on both tasks (Musiek, 1994). Similar frequency pattern testing has been used for pediatric populations.

In 2004, Stollman, van Velzen, Simkens, Snik, and van den Broek studied the development of auditory processing in 6-12 year old children. Twenty children with normal cognitive and language development were tested over a six-year period (age range including 6, 7, 8, 10, and 12 years). A control group of 20 normal hearing adults were also tested for comparison. The goal of this study was to better describe the auditory processing development in children and compare their performance to that of adults (Stollman et al., 2004). Subjects had to have normal hearing during all stages of testing and were recruited from a previous study by Stollman et al. (2004), in which the children's cognitive and language development skills were tested. The auditory processing test battery consisted of the following tests: speech-in-noise, filtered speech, binaural fusion, frequency pattern test, duration pattern test, auditory word discrimination, auditory synthesis, auditory closure, and number recall. All subjects were administered the tests in the same order. The speech tests used CVC monosyllables from standard Dutch speech audiometry materials (Stollman et al., 2004).

Results of the Stollman et al. (2004) study were compared using the Kruskal-Wallis ANOVA and the results of the 10-12 year olds were compared to the adults. Overall results showed a significant difference among performance across the ages of children (Stollman et al., 2004). The 12 year olds' and adults' performance on the frequency and duration pattern tests, binaural fusion test, and filtered speech tests yielded similar results. With the exception of the binaural fusion task, performances of the 10 year olds were similar to that of the adult subjects. Stollman et al. (2004) noted, that starting from age six, test performance became better with increasing age. When comparing this study to research by Keith (1995, 2000), Stollman et al. confirmed Keith's statements that the auditory system is typically mature by age 12. No significant gender effects were found. However, Stollman et al. reported ear effects for the binaural fusion test. The monaural right-ear scores were significantly worse than the binaural scores for the 10-12 year old groups. Stollman et al. concluded that maturational effects play a strong role in auditory processing until 12-13 years of age. They further commented on the usefulness of the duration pattern and frequency pattern tests, but raised caution that conducting these tests on younger children (6-9 year olds) may produce high variability in test results (Stollman et al., 2004).

Speech-In-Noise Testing to Evaluate Auditory Closure

Auditory closure is the ability to achieve auditory recognition when a portion of the auditory signal is missing or distorted, and is thought to be due to the redundancy within the CANS (Bellis, 2003). Extrinsic redundancy refers to the characteristics of the auditory signal received from our environments. These characteristics rely on our knowledge of vocabulary, syntax, semantics, and phonetic aspects of speech. Intrinsic redundancy refers to the repeated representation of the auditory signal throughout the CANS. Its breakdown within the CANS can lead to deficits in auditory closure (Bellis, 2003). More specifically, research by Musiek and Geurkink (1982) identified an ipsilateral deficit on filtered or compressed speech tests to be associated with a brainstem lesion at the levels of the pons. This provides an example of how a breakdown in the CANS can have an impact on an individual's auditory closure ability.

The method used to assess auditory closure in the present study was by testing word recognition performance in noise. Word recognition testing assesses an individual's ability to identify words in quiet and noisy environments. Word recognition skills have been investigated in children and adults (Papso & Blood, 1989; Dubno, Lee, Matthews, & Mills, 1997; Stuart, 2005). Papso and Blood (1989), studied word recognition skills in background noise in children and adults. A total of 60 subjects were evaluated which included 30 children and 30 adults. Ages of the children ranged from 4 years, 0 months to 5 years, 10 months. Adult ages ranged from 19 and 28 years. Subjects were tested using modified Word Intelligibility by Picture Identification (WIPI) word lists 1, 2, and 3. The test was modified to include pink noise and multitalker noise 6 dB less intense than the original WIPI lists, to yield a score of at least 70% using 4-6 year old children (Papso & Blood, 1989). Testing was performed in a sound treated booth in soundfield. The subjects were instructed to point to the picture that represented the word presented through the loudspeaker. Results showed no significant difference between children and adults under quiet listening conditions. There were significant differences between the scores in the pink noise and multitalker noise conditions for children, but not adults. The researchers suggested that in the presence of multiple talkers (i.e. multitalker condition), children have greater difficulty with word recognition than when listening in “non speech-like” noise (Papso & Blood, 1989).

Geffner, Lucker, and Koch (1996) conducted an evaluation of auditory discrimination in children with and without attention deficit disorder (ADD). Participants were 27 children, who were diagnosed with ADD and aged between 6 and 15 years of age. For comparison, 15 children within the same age group, whom were not diagnosed with ADD, also participated in the study. Subjects were evaluated in a sound treated booth under insert earphones. Speech identification scores were obtained using recorded Northwestern University Auditory Test No. 6 (NU-6) word lists and the Goldman-Fristoe-Woodcock (GFW) Auditory Selective Attention Test. This test allows for presentations in quiet, fan noise, cafeteria noise, and voice. Both groups of children were able to complete the NU-6 (verbal response) test and GFW (picture pointing response) test under the quiet condition without difficulty (Geffner et al., 1996). When tests were presented in the presence of a competing message, both tasks were more difficult for both groups. The NU-6 word recognition scores in noise were significantly poorer for the ADD versus the non-ADD group. Geffner et al. attributed these differences to decreased figure-ground identification in children with ADD, and suggested that they are unable to suppress the noise and focus on the target word being presented. The authors also stressed the lack of “processing energy” children with ADD had to discriminate the target word. They proposed that the majority of the children’s “processing energy” was given to filtering the unwanted noise versus identifying the target word (Geffner et al., 1996). The authors concluded that both the NU-6 test and GFW Auditory Selective Attention test can provide information concerning word recognition in ADD children. However, the NU-6 test can also be a sensitive test for identifying non-ADD children who demonstrate difficulty in understanding speech in background noise (Geffner et al., 1996).

In addition to word recognition in noise, there are other speech-in-noise tests that use sentences in noise to determine an individual’s auditory closure abilities. Recently, Bamford-Kowal-Bench sentence test in Auditec-4 talker babble (BKB-SIN test), was developed Etymotic Research (Etymotic Research, 2005). This test provides norms for children ages, 5-6, 7-10, and 11-14 (Etymotic Research, 2005). Sentence equivalent list pairs were developed (Etymotic Research, 2005). In 2007, Wilson, McArdle and Smith evaluated the BKB-SIN, Hearing-in-noise-test (HINT) (Nilsson, Soli, & Sullivan, 1994), Quick Speech-in-Noise test (QuickSIN) (Killion, M., Revit, L., & Banerjee, S., 2004), and Words in Noise (WIN) (Wilson, 2003; Wilson & Burks, 2005) materials on listeners with normal hearing and listeners with hearing loss. Participants included 24 listeners with normal hearing aged 18 to 30 years and 72 listeners with sensorineural hearing loss aged 53 to 87. Testing was performed under supra aural headphones. To avoid ear effects, the order for testing the left and right ears was alternated between the subjects. Comparisons among the four tests revealed that the BKB-SIN and HINT sentences provided more semantic context than that of the QuickSIN sentences (Wilson et. al, 2007). Both groups of listeners had better performance on the BKB-SIN and HINT materials than on the QuickSIN and WIN material. However, the QuickSIN and WIN tests showed a greater separation between the normal hearing and hearing impaired groups. The authors suggested that the QuickSIN would be the test of choice for a sentence speech-in-noise test. They also pointed out that the WIN test uses monosyllabic words, and the same words are spoken by the same speaker for both the quiet and noise conditions. They recommended the BKB-SIN and HINT tests for studies involving young children or individuals with substantial hearing loss (Wilson et. al., 2007)

Stuart (2005) studied the development of auditory temporal resolution in school-age children through testing word recognition performance in continuous and interrupted noise. Stuart hypothesized that children’s word recognition performance would be poorer than adult’s performance. Stuart’s investigation sought to determine at what age word recognition abilities in children (under quiet and competing noise conditions) were similar to adults.

Participants consisted of 5 groups of 16 children and one group of 16 young adults. Ages were grouped in the following ranges: 6:0 to 7:11 (yr: mo), 8:0 to 9:11, 10:0 to 11:11, 12:0 to 13:11, and 14:0 to 15:11. Subjects were tested using the NU-CHIPs monosyllabic words in quiet and in competing backgrounds of continuous and interrupted noise (Stuart, 2005). NU-CHIPs speech stimuli were presented at 30 dB sensation level relative to the subjects’ speech recognition thresholds. Presentation was in quiet and with competing noise at S/N ratios of 10, 0, -10, and –20 dB (Stuart, 2005). As predicted, children exhibited poorer word recognition performance than adults. Under the quiet condition, a child reached adult-like performance at the age of 7, and for competing noise adult-like performance was reached at 11 years of age (Stuart, 2005). The author suggested, “changes in performance in the interrupted noise, as with continuous noise, in school-age children from 6 to 10 yr of age can be attributed to central maturation and not factors in peripheral development” (Stuart, 2005, p. 85).

Overall, previously stated research provided evidence for the usefulness of speech in noise tests in children. For speech-in-noise testing, the BKB-SIN and HINT tests have been recommended for the testing of young children and individuals with substantial hearing loss (Wilson et al., 2007). Developmentally, Stuart (2005) reported adult-like word recognition performance at 7 years of age, under quiet conditions with word recognition performance in competing noise reaching adult-like maturation at 11 years of age (Stuart, 2005).

In conclusion, the previously cited studies have offered evidence of binaural interference in elderly hearing impaired aided adults (Chmiel et al, 1993; Jerger et al., 1993; Allen et al., 2000), elderly normal hearing adults (Allen et al., 2000), and young normal hearing adults (Allen et al., 2000). Binaural interference was demonstrated in word recognition scores and speech-in-noise tests by comparing performance under the following conditions: 1) left ear, 2) right ear, and 3) binaurally. Individuals with binaural interference showed a decrease in binaural performance when compared to their best monaural performance. Arkebauer et al. (1971) believed a deficiency in the peripheral auditory system could be associated with the occurrence of binaural interference. Despite research showing supportive evidence for peripheral involvement, later research provided evidence to rule out peripheral involvement (Allen et al., 2000). Allen et al. investigated binaural interference in normal hearing and hearing impaired adults and noted evidence of binaural interference in a normal hearing individual. Jerger et al. (1993) noted the uncertainty in knowing the exact mechanism for the binaural interference phenomenon, and that it may be due to peripheral or central involvement. Chmiel et al. believed that binaural interference shown in her subject was due to demyelination of fibers of the corpus callosum resulting in a decrease in interhemispheric transfer. Based on the findings of Allen et al. (2000), in the absence of hearing loss, (i.e., normal peripheral hearing sensitivity), the presence of binaural interference in younger adults may be attributed to involvement of one or more structures of the central auditory nervous system, including the corpus callosum.

Although several studies have shown evidence of binaural interference and provided possible underlying mechanisms, all studies have tested adults. Other than one case study, there have been no formal studies of binaural interference in children. Therefore, the purpose of this experiment was to investigate whether binaural interference occurs in normal hearing children.

CHAPTER II: Methods

Rationale of the Study

The previously discussed research has shown evidence of binaural interference, the phenomenon that occurs when individuals perform worse when a stimulus is presented binaurally than when presented monaurally (Jerger, 1993). The current research on binaural interference has focused on the adult population. There is very limited research investigating the presence of binaural interference in children. This is a needed area of study due to growing interest and research related to auditory processing in children and the fitting of bilateral hearing aids.

The proposed research investigated binaural interference in normal hearing school aged children. Testing included the assessment of word recognition, speech-in-noise identification, masking level differences, and pitch pattern sequencing. To investigate the possible presence of binaural interference, comparisons of the participant's right, left, and binaural performances were measured for word recognition scores, and speech-in-noise tests. For word recognition testing, the Northwestern University Children's Perception of Speech (NU-CHIPS) 50-word lists were used because it was age appropriate for all age groups within this study. The BKB-SIN test was used for speech-in-noise testing and was chosen because it was age appropriate for the population in the present study, and is a difficult enough task to avoid ceiling effects.

Based on research provided by Jerger et al. (1993) and Chmiel et al. (1997), the brainstem and corpus callosum are possible underlying contributors to binaural interference. The masking level difference and pitch pattern sequence tests may provide further information about possible underlying mechanisms of binaural interference. Lynn, Gilroy, Taylor, and Leiser (1981) and (Roush & Tait, 1984) indicated that the mechanism important for performance in masking level difference is at the low brainstem level. In addition to being a test sensitive to lower brainstem, little research has been conducted on speech and tonal MLDs in children. More research is needed in this area to determine normative data for these tests, as well as additional information concerning the robustness of the tonal MLD to the speech MLD. Sweetow and Reddell (1978) found that tonal MLDs appear to be more sensitive than the speech MLD to central auditory dysfunction in children. Pitch pattern sequence testing not only evaluates temporal aspects; it is also sensitive to dysfunction of the corpus callosum (Musiek et al., 1980). The pitch pattern sequence test could provide useful information on interhemispheric transfer in children. One could speculate that a child demonstrating binaural interference could have abnormal performance on this test. This could support the theory by Chmiel et al., 1997, that associates demyelination of the corpus callosum could be a contributor to the presence of binaural interference. In addition, more research is needed in the establishment of normative data in children for the pitch pattern sequence test. Normative data is needed using a formal protocol for both verbal and non-verbal response modes.

Past research has shown the presence of binaural interference in hearing impaired as well as normal hearing adults (Allen et al., 2000). If binaural interference exists in adults with normal peripheral sensitivity, then one could speculate the occurrence of binaural interference in children with normal hearing. Once binaural interference is investigated in normal hearing children, it will serve as a basis for future research of binaural interference in hearing impaired children and children with central auditory processing disorder. It can be speculated that findings of binaural interference in children with hearing impairment could warrant the need for additional counseling for the parents concerning appropriate hearing aid use and auditory training.

The importance of research in binaural interference is that it can provide additional information in the area of central auditory processing disorder. Minimal research has been conducted in the area of binaural interference as a CAPD deficit. New information about binaural interference in children could support the added use of diotic testing in the central auditory processing test battery. If binaural interference testing is added to the CAPD test battery, additional information should be added in the counseling of parents of children in which binaural interference is found.

Plan of Study and Experimental Questions

This study investigated the phenomenon of binaural interference in normal hearing children. Prior to the study it was hypothesized that:

1) A small percentage of normal hearing children would show evidence of binaural interference on word recognition scores and/or sentence in noise tests.
2) For those children who show evidence of binaural interference there will be evidence of either sub-cortical involvement from the brainstem (as indicated by poor performance on the MLD), or cortical involvement involving the corpus callosum (as indicated by poor performance on pitch pattern testing).
3) For children ages 7 years, 0 months to 12 years, 11 months, the tonal masking level difference will be larger than speech masking level difference.

Participants

A total of 96 normal hearing children, aged 7 years, 0 months to 12 years, 11 months, were participants. Children were grouped according to age so there were 16 participants in each of the 6 age groups. Children were recruited from the Announce email list at East Carolina University, by public announcement, and East Carolina University faculty.

Participants met the following criteria: normal hearing sensitivity based on a 15 dB HL hearing screening at 500, 1000, 2000 and 4000 Hz (participants had to pass all frequencies in both ears to be eligible); and normal middle ear function (compensated static acoustic admittance >0.2 mmho; ear canal volume < 1.0 cm^3; and tympanometric width <160 daPa) (Margolis & Goycoolea, 1993); by parental report, participants were enrolled in regular classrooms; spoke English as a first language; had no known or suspected cognitive or memory deficits; had no history of speech, language, or learning problems; and had no history of remedial services.

There was one participant with mild ADHD (based on parental report). This participant was allowed in the study and had taken his ADHD medication prior to testing. The inclusion of this participant was based on the ASHA recommendations for (central) auditory processing disorders (2005), that if children presented with attention deficit disorder (ADD) or attention deficit hyperactive disorder (ADHD), by parental report, their attention deficit must be medication controlled during testing.

Equipment

Participants were tested at either of two facilities: 1) East Carolina University, Department of Communication Sciences and Disorders, Greenville North Carolina or; 2) Coastal Ear, Nose, and Throat in New Bern, North Carolina. At East Carolina University, otoscopy was conducted using a Welch Allyn lighted otoscope. A Grason-Stadler Tympstar Middle Ear Analyzer (Serial #: 2001-0501) was used for tympanometry measures. A Grason-Stadler 61 (GSI 61) Clinical Audiometer (Serial #: AA062531) was used for pure tone screenings and to deliver recorded materials. The audiometer was calibrated using a Bruel & Kjear sound level meter (Model 2231). Recorded stimuli were routed through the speech circuit of the GSI 61 to the EAR Tone 3A insert earphones (Right serial #: 66398, Left serial #: 66397). A Phillips Audio Compact Disc Recorder CDR 765 (serial # 17358148) was used to route recorded stimuli through the audiometer. Participants were seated in an Industrial Acoustics Company (IAC) sound treated suite, which was in compliance with ANSI standards for maximum permissible ambient noise levels for audiometric test rooms (ANSI, 1991).

At Coastal Ear, Nose and Throat, otoscopy was conducted using a Welch Allyn lighted otoscope. Participants were seated in a Tranacoustic sound treated suite, which was in compliance with ANSI standards for maximum permissible ambient noise levels for audiometric test rooms (ANSI, 1991). A GSI 61 Clinical Audiometer (Serial #: 2001-0212) was used for pure tone screenings and to deliver recorded materials. The audiometer was calibrated using a Bruel & Kjear sound level meter (Model 2231). A Maraniz compact disc/DVD player (model #: PMD910, serial # MZ000326000602) was used to route recorded stimuli through the audiometer. Recorded stimuli were routed through the speech circuit of the GSI 61 to the EAR Tone 3A insert earphones (Right serial #: 12380, Left serial #: 12379). A Madison Zodiac 901 (Serial#: 94809) was used for tympanometric measures.

The following recorded materials were used at both facilities: BKB-SIN CD1: Standard test version 1.03, Tracks 2, 3-20, Auditec of St. Louis disc: NU-CHIPS Track 2 and 3, Auditec Quality Recordings of Auditory Tests: Spondee Word List, Track 2 and 3; Pitch Pattern Sequence Test for Children, Tracks 7-10, and a 500 Hz Tonal MLD and Speech MLD disc (Wilson et al., 2003).

For the purpose of an additional practice for the pitch pattern sequence test, a practice test was developed by Dr. Andrew Stuart (Stuart, A., personal communication, February, 2009). The pitch pattern practice compact disk was custom made. Five tracks of synthetic speech and pure tone stimuli were generated. Synthetic speech tokens were generated by AT & T Labs, Inc. – Research *Text-To-Speech* application (http://www.research.att.com/~ttsweb/tts/demo.php). Text-To-Speech is computer software that converts text into audible speech. The speech output audio formats were simple WAV files. Speech tokens were generated in a female voice (i.e., "Crystal") in US English. Pure tone stimuli were synthesized in Peak 4.13 (BIAS, Inc., Petaluma, CA) on an Power Mac G5 (Dual 2.3 GHz Power PC). A high (1430 Hz) and low (880 Hz) tone was generated. Each tone was 500 ms in duration with a 10 ms rise/fall time. In addition a 10s 1000 Hz tone was generated for calibration purposes. A demonstration track for training purposes consisted of an introductory "low" or "high" speech token followed by five respective pure tones with 500 ms inter-stimulus intervals. Each demonstration was alternated and repeated twice. Four practice tracks were also generated. They consisted of 10 tones (i.e., five low and high each) high and low tones mixed in random order. The tone sequence was preceded by the speech token “ready”. Research Randomizer (http://www.randomizer.org/) generated the randomization. The five track sequences were saved as WAV files in Peak 4.13. These files were then imported into iTunes (Apple Version 8.0) for generation of a compact disc to be used for play back.

Procedures

Informed consent and minor assent. All informed consents and minor assents were obtained prior to the test session. Parental guardians of the participants reviewed the informed consent document and had the opportunity to ask questions before signing. Once the legal guardian gave consent, the child read the minor assent form and was allowed time to ask questions. If the child demonstrated understanding of the project and wanted to participate in the study, his/her signature was obtained on the assent form. Once both consent and assent forms were signed, the Health Insurance Portability and Accountability Act (HIPPA) document was explained and a signature was required before any further testing was performed. All participants were literate and none were involved in any remedial reading classes.

Otoscopy. Otoscopy was performed on all participants prior to testing. Participants were seated and visual inspection was performed using a Welch Allyn lighted otoscope to ensure that all ears were negative for ear drainage, structural deficits, ear canal abnormalities (i.e., obstruction, impacted cerumen, foreign objects, blood or secretion, or atresia), otitis externa, or a perforated tympanic membrane (American Speech, Language & Hearing Association, Panel on Audiologic Assessment, 1997).

Tympanometry. Each participant was seated and a soft probe tip was placed into his/her ear canals (right and left ears). Middle ear function was assessed using the Grason Stadler Tympstar Middle Ear Analyzer and results for compensated static acoustic admittance, ear canal volume, and tympanometric width were compared to normative data by Margolis and Goycoolea (1993). For children aged 3-10 years, the normative data is as follows: compensated static acoustic admittance >0.2 mmho; ear canal volume < 1.0 cm3; and tympanometric width <160 daPa. Since there are no known normative data specifically for 11 year old children, the previous noted normative data was used for this age group.

Pure tone screenings. All participants were screened in a sound treated suite using pure tones of 15 dB HL at 500, 1000, 2000, and 4000 Hz in each ear (Northern & Downs, 2002). Testing was performed with insert earphones. Each participant was asked to raise his/her hand every time a tone was heard. Participants had to hear all frequencies tested to meet the study's inclusion criteria.

Speech recognition thresholds. Speech recognition thresholds (SRTs) were obtained using the spondaic words (spondees) and 2 dB step procedure specified by ASHA (1988) under insert earphones. Spondee words were presented using the Auditec Quality Recordings of Auditory Tests, Tracks 2 and 3. Calibration was performed using a 1000 Hz calibration tone (Track 1) to set the level of the recorded speech tests on the audiometer VU meter to "0". Speech recognition thresholds were obtained monaurally right, monaurally left, and binaurally with Ear 3A insert earphones. The SRTs were used to validate pure tone thresholds and to provide a reference point for stimuli intensity during word recognition testing.

Word recognition testing. Word recognition scores were obtained using the Northwestern University Children's Perception of Speech (NU-CHIPS), from the Auditec of St. Louis compact disc, Tracks 2 and 3. Calibration was performed using a 1000 Hz calibration tone (Track 1) to set the level of the recorded speech tests on the audiometer

VU meter to “0”. Testing was performed under 3A insert earphones. Participants were asked to repeat the words heard aloud. Participants were tested monaurally right, monaurally left, and binaurally. Ear order was randomized among participants. A percent correct score was calculated for each of the three listening conditions. Stimuli were presented at 30 dB SL relative to speech recognition thresholds for monaural right, monaural left, and binaural conditions.

BKB SIN test. The BKB SIN Test was administered using the BKB SIN Test CD 1: Standard BKB-SIN, Tracks 3-20, developed by Etymotic Research (Etymotic research, 2005). Testing was performed under insert earphones. Calibration was performed using the 1 kHz calibration tone on Track 2, and an adjustment was made so the audiometer VU meter read “0”. Stimuli were presented monaurally right, monaurally left and binaurally through insert earphones and ear order was randomized between participants. The recommended presentation level for BKB-SIN testing is 50 to 70 dB HL for normal hearing children. For the purpose of this study, the stimulus was presented at 50 dB HL. The following standard test instructions were used:

“You will hear a man talking to you through the earphones. He is going to say “Ready” and then he’ll say a sentence. Repeat the sentence the man says. You will hear other talkers in the background. Don’t pay any attention to them; just repeat what the man says. The background talkers will get louder, and then it will be hard for you to hear the man’s voice. When that happens, it is OK to guess; repeat anything you think you heard the man say” (Etymotic Research, 2005).

For the purpose of this study, the number of correct key words identified for each list was counted and divided by the total key word count (31 key words) to obtain a percent correct score. The average of the two lists within each list pair was then calculated for an overall average percent correct score for the monaural right, monaural left, and binaural conditions and ear order was randomized.

500 Hz tonal masking level difference test. Masking level difference (MLD) testing was performed under insert earphones. Stimuli were used from a compact disc containing the 500 Hz tonal masking level difference test for the SoNo and SπNo conditions, Track 4 (Wilson, 2007). Calibration was performed using the 1 kHz calibration tone on Track 1, and an adjustment was made so the audiometer VU meter read “0”. The test contained 10 SoNo (homophasic) stimuli, 12 SπNo (antiphasic) stimuli, and 11 burst with no tone (NT) that served as catch trials. As recommended, the participant was reinstructed if he/she identified a beep during these catch trials and testing was discontinued if more than two false responses were given. Channels A and B of the audiometer were set to 50 dB HL for presentation of stimuli.

Participants heard the following standard instructions: “You will hear a series of noise bursts that sound like “Shhhhhhhhhhhh”. Each noise burst is 3 seconds long. During some of the noise bursts there is a beeping tone. I want you to tell me, “yes” if you heard a beeping tone during the noise burst, or “no” if you did not hear a beeping tone during the noise burst. Sometimes the beeping tone will be loud and at other times the beeping tone will be soft. Regardless of how loud you think the beeping tone is, let me know that you heard it. Remember, not all noise bursts have beeping tones. Are there any questions?" (Wilson, R., personal communication, June 2007).

Participant SoNo and SπNo thresholds were calculated using the following calculations: SoNo calculations used the following formula: (dB S/N) = 2 dB S/N – (2 x # correct). SπNo calculations used the following formula: (dB S/N) = -6 dB S/N – (2 x # correct). To calculate the participants' MLD, the SπNo threshold was subtracted from SoNo threshold (SoNo – SπNo).

Speech masking level difference test. The speech masking level difference test was performed under insert earphones. Stimuli used were from a compact disc containing the speech masking level difference test for the SoNo and SπNo conditions, Tracks 2 and 3 (Wilson, 2007). Calibration of the auditory signal was performed, and the VU meter was adjusted to read "0" for the External A and External B outputs. The participant was given a printed card with the ten spondaic test words. The recording presented the spondaic words to the participant at sixteen signal to noise ratios from 0 dB S/N to –30 dB S/N in 2 dB steps, with the noise increasing in 2 dB steps after each set of four spondee words. Words were presented at 50 dB HL.

Participants were given the following standard instructions: "You will hear the words on the list mixed with the noise. At first, the words will be louder than the noise, but as testing continues the words will become softer and softer and the noise will become louder than the words. The words may seem to disappear but keep guessing" (Culbertson, D., personal communication, May 2007).

As recommended, the SoNo condition was administered first followed by the SπSo condition. For each condition, testing was stopped after the participant missed two test blocks. The thresholds for each condition were calculated using the following equation: Threshold = (presentation level in dB HL) + 1 – (correct responses/2). The speech masking level difference thresholds was calculated using the following equation: MLD = SoNo threshold – SπNo threshold.

Pitch pattern sequence test. Frequency pattern testing was conducted using the Auditec Quality Recordings of Auditory Tests compact disc, Tracks 7-10 under 3A insert earphones. Calibration was performed using the 1 kHz calibration tone on Track 1, and an adjustment was made so the audiometer VU meter read "0". Stimuli were presented monaurally right at 50 dB HL. The participants were presented two practice sets. The first practice, which was developed for this study, consisted of "high" and "low" tone examples, and four single tone practice sets. Participants were instructed to listen to the examples and state whether the single tone was "high" or "low" in pitch. The second practice set consisted of ten presentations of two tone pairs. Participants were instructed to repeat the pattern heard. For the test session, participants were instructed that they would hear sets of three consecutive tones that varied in pitch. Participants were asked to report each tone as "high" (1122 Hz) or "low" (880 Hz). The test consisted of 60 test patterns. The test patterns were split into two sets of thirty trials each. During the first set of test patterns the participants were asked to verbally state the pattern. During the second set of test patterns the participants were asked to point to the appropriate picture on a test sheet. The pictures on the test sheet displayed a "high" bar and a "low" bar.

Scheduled breaks. There were scheduled breaks every 15 minutes (approximately every two tests administered). The participants were required to take all scheduled breaks. Additional breaks were allowed at the participant's request.

Statistical Measures

Sample size. It is a possibility that binaural interference is very rare in normal hearing children. It is hypothesized that the percent of normal hearing children with binaural interference is less than 10%. Then sample size calculations show a sample of 29 or more is needed for power of .8 at the $\alpha = .05$ significance level, when the true population percent is between 0.2% and 0.8%. Although this sample size was taken into consideration, a larger sample size was needed for the development of normative data. Therefore a population size of 96 normal hearing children without auditory processing disorders was used for this study.

Data analysis. The Statistical Package for the Social Sciences (SPSS) was used for data analysis. Descriptive statistics were used to calculate group means and standard deviations. A paired-sample *t*-test was used to determine mean differences for the SRT, WRS, PPFT, and BKB-SIN data. A one-way analysis of variance (ANOVA) was performed on the SRT, WRS, MLD, and PPFT data. Tukey's Honestly Significant Difference (Tukey's HSD) post hoc analysis was used for group comparisons on the SRT, WRS, MLD, and PPFT data. An arcsin transformation was used, since a large number of participants scored the maximum possible score (100%) on the NU-CHIPS and Pitch Pattern Testing. The WRS, VPPS, and MPPS were transformed using the arcsin transformation, recommended by Rao, 1998. A frequency analysis was used to determine the 90th percentile score for speech MLDs. Raffin and Thornton (1980), confidence levels for differences between speech-discrimination scores, were used to determine the confidence level of the difference scores for word recognition results and BKB-SIN results. These are single particiapantt results, and the significance was determined for each individual difference score (for all 96 participants).

CHAPTER III: RESULTS

Speech Recognition Threshold

Speech recognition thresholds (SRTs) were obtained monaurally right, monaurally left, and binaurally. Spondee words were used as the stimuli. Ear order was randomized for each participant.

Individual data. Individual SRTs for the monaural right, monaural left, and binaural conditions can be found in Appendix B. Of the 96 participants, 75 participants had the lowest or best SRTs in the binaural condition, and 32 participants performed better in the monaural right condition than the monaural left condition.

Group data. A paired-sample *t*-test was used to determine if any age group showed a significant right or left ear advantage. The mean right SRTs were subtracted from the mean left SRTs to determine a mean difference for each age group. Mean differences ranged from -.13 dB to .88 dB. A left ear advantage was noted by a negative mean difference and a right ear advantage showed a positive mean difference. No group showed a significant right or left ear advantage. Raw group data is presented in Table 1. For each age group, the mean SRTs for the right ears, left ears, and binaural thresholds were calculated (Figure 1). A paired-sample *t*-test was performed to determine the mean binaural difference for each group. The mean best monaural SRTs were compared to the mean binaural SRTs to compute the mean binaural difference. All age groups showed a significant binaural advantage ($p < .05$) (Table 2). The mean binaural

Table 1

Mean SRT Differences and Standard Deviations of the dB Differences between the Monaural Right and Monaural Left Conditions.

Age	Mean Difference (dB HL)	SD	*P*-value
7	.063	2.32	.916
8	.625	1.75	.173
9	.875	1.84	.069
10	-.688	2.15	.221
11	.875	2.42	.168
12	-.125	2.68	.855

Note: Differences were calculated by subtracting the monaural left SRTs from the monaural right SRTs. Positive mean differences represent right ear advantages and negative mean differences represent left ear advantages.

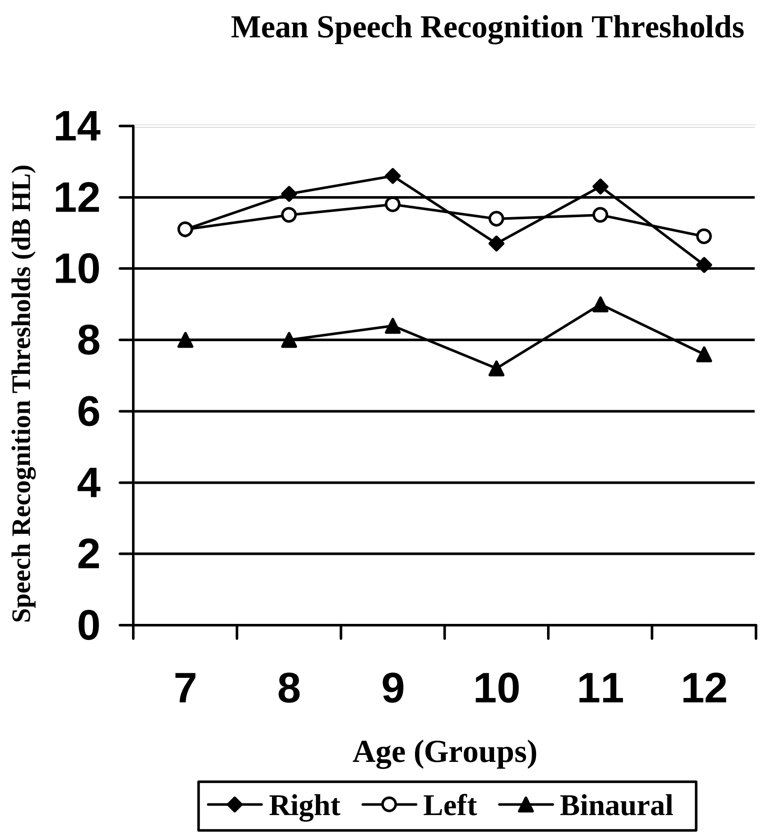

Figure 1. Mean Speech Recognition Thresholds for each age group (7, 8, 9, 10, 11, and 12 year olds) for each listening condition (monaural right, monaural left, and binaural).

Table 2

Group Differences in Mean Best Monaural SRTs and Binaural SRTs in dB HL.

Age	Mean Difference (dB HL)	SD	*P*-value
7	2.31	3.42	.016
8	3.13	2.06	.000
9	3.13	2.42	.000
10	3.13	2.31	.000
11	2.00	2.53	.006
12	2.25	1.77	.000

Note: Mean differences were calculated by subtracting the mean binaural SRTs from the monaural SRTs for each age group. A positive mean difference represents a binaural advantage. SD (standard deviation of the differences).

advantage ranged from 2 dB, for the 11 year olds, to 3.13 dB for the 8, 9, and 10 year olds. A one-way analysis of variance (ANOVA) with a Tukey's Honestly Significant Difference (Tukey's HSD) post hoc analysis was calculated for group comparisons (Appendix C). There was no significant difference in performance (monaurally right, monaurally left, and binaurally) among any of the age groups. In other words, even though the 8, 9, and 10 year olds had a greater mean binaural advantage, it was not significantly greater than the mean advantage of the other groups.

Word Recognition

Word recognition scores, for 50-word NU-CHIPS tests were obtained for three conditions: monaural right, monaural left, and binaural.

Individual data. For all 96 participants, mean word recognition scores were 97%, 96%, and 98% for the right, left, and binaural conditions, respectively. Individual scores ranged from 84% to 100% for the monaural right condition, 84% to 100% for the monaural left condition, and 86% to 100% for the binaural condition. Individual scores can be seen in Appendix D. No significant differences were found between male and female participants.

Group comparisons for monaural right and monaural left conditions. A paired-sample *t*-test was calculated to determine if a right ear advantage was noted. There were no significant differences between the groups' mean WRS for the right and left ears among the 7, 8, 9, 10, and 11 year olds. However, the 12 year old group did show a significant right ear advantage ($p = .013$). A one-way ANOVA with a Tukey's HSD was performed for group comparisons. Group comparisons showed a significant mean difference (.05 significance level), between the 7 and 10 year olds (p = .012), 7 and 11 year olds (p = .018), and 7 and 12 year olds (p= .001) for the monaural right and monaural left conditions. The mean differences in word recognition scores, for the monaural conditions, were 3.3 dB, 3.1 dB, and 3.8 dB poorer for the 7 year olds than the 10, 11, and 12 year olds, respectively. In the binaural condition, there was no significant difference in word recognition performance between groups. Group data can be seen in Appendix E.

Group comparisons of best monaural WRS to binaural WRS. To determine the presence/absence of binaural interference, a comparison of each participant's best monaural score was compared to the binaural score (Figure 2). Individual best monaural scores ranged from 92% to 100%, while binaural WRS ranged from 86% to 100%. A paired-sample t-test was computed to compare group mean differences between the best monaural and binaural scores. There were no significant differences among the mean best monaural and binaural WRS for each age group. Therefore no significant binaural interference or binaural advantage was noted for any age group.

Difference scores. Individual difference scores between the best monaural word recognition score and binaural word recognition score were calculated. Of the 96 participants, 35 participants demonstrated a binaural advantage, 36 participants demonstrated binaural indifference, and 25 participants demonstrated monaural advantage (Table 3). One participant demonstrated statistically significant binaural interference (p = .05) (Raffin & Thornton, 1980). No individual demonstrated a

Mean Best Monaural WRS Compared to Mean Binaural WRS

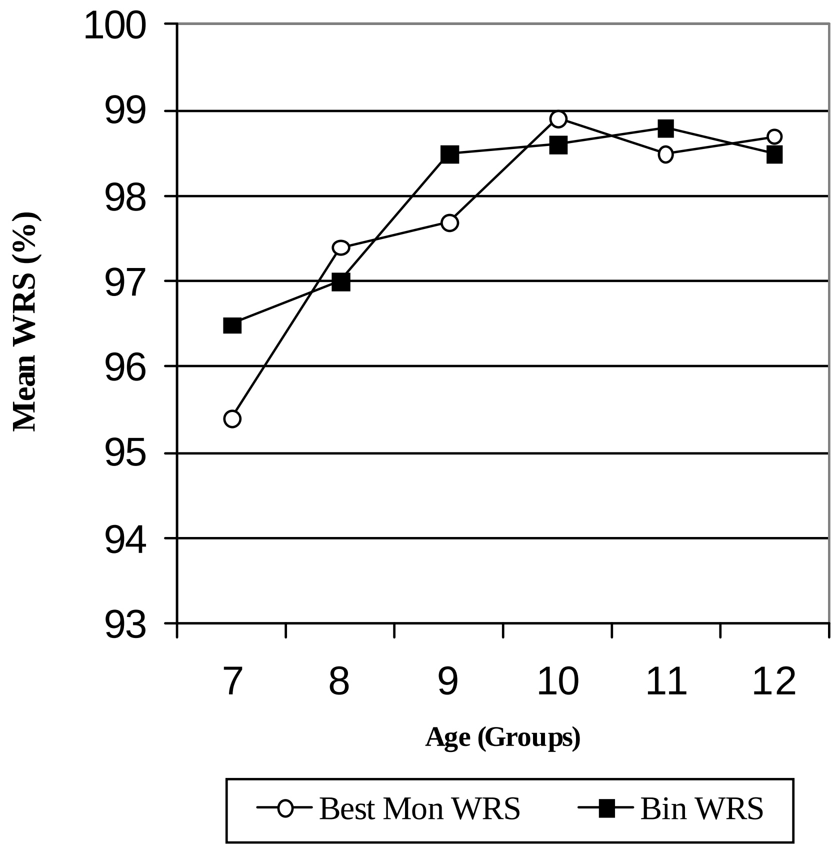

Figure 2: There were no significant differences among the mean WRS for each age group. Therefore no significant binaural interference or binaural advantage was noted for any age group.

Table 3

Individual Difference Scores for Word Recognition Testing

% Diff						
6	••	•			•	
4	•	•	•••		•	•
2	•••••	•••	••••••	••••••	••••	••
0	•••••	••••••••	•••	••••••	••••	•••••••••
-2	••	•	••	•••	•••	•••
-4	•	••	••	••	••	
-6						•
	7	8	9	10	11	12

Age (Groups)

Note: For each age group, the plotted symbol represents an individual that demonstrated the difference between their best monaural word recognition score and binaural word recognition score. A difference score of 0 represents binaural indifference, a positive number represents binaural advantage and a negative number represents binaural interference.

significant binaural advantage ($p < .05$) (Raffin & Thorton, 1980). Individual raw data can be found in Appendix F.

Arcsin transformation. A large number of participants scored the maximum possible score (100%) on the NU-CHIPS. In cases such as this, an arcsin transformation is recommended (Rao, 1998). The arcsin transformation was calculated and the Paired-sample *t*-test and one-way ANOVA with a Tukey's HSD was performed. The results of the tests on the arsin transformed data were the same as the results on the untransformed data. Statistically significant differences were not found in either case.

Masking Level Difference

The masking level difference tests were presented in the binaural condition. Two different stimuli were used for testing. The speech stimuli consisted of spondee words while the tonal stimuli consisted of a pure tone centered at 500 Hz. Stimuli were used from a compact disc containing the 500 Hz tonal masking level difference test for the SoNo and SπNo conditions, Track 4, and the speech masking level difference test for the SoNo and SπNo conditions, Tracks 2 and 3 (Wilson, 2007).

Individual tonal MLD. Individual MLDs ranged from 8 dB to 18 dB, which resulted in a mean MLD for all 96 participants of 12.81 dB and a standard deviation of 2.24 dB. Individual thresholds can be found in Appendix G. No significant gender differences were noted.

Individual speech MLD. Individual MLDs ranged from 4 dB to 14 dB, which resulted in a mean MLD for all 96 participants of 7.3 dB, with a standard deviation of

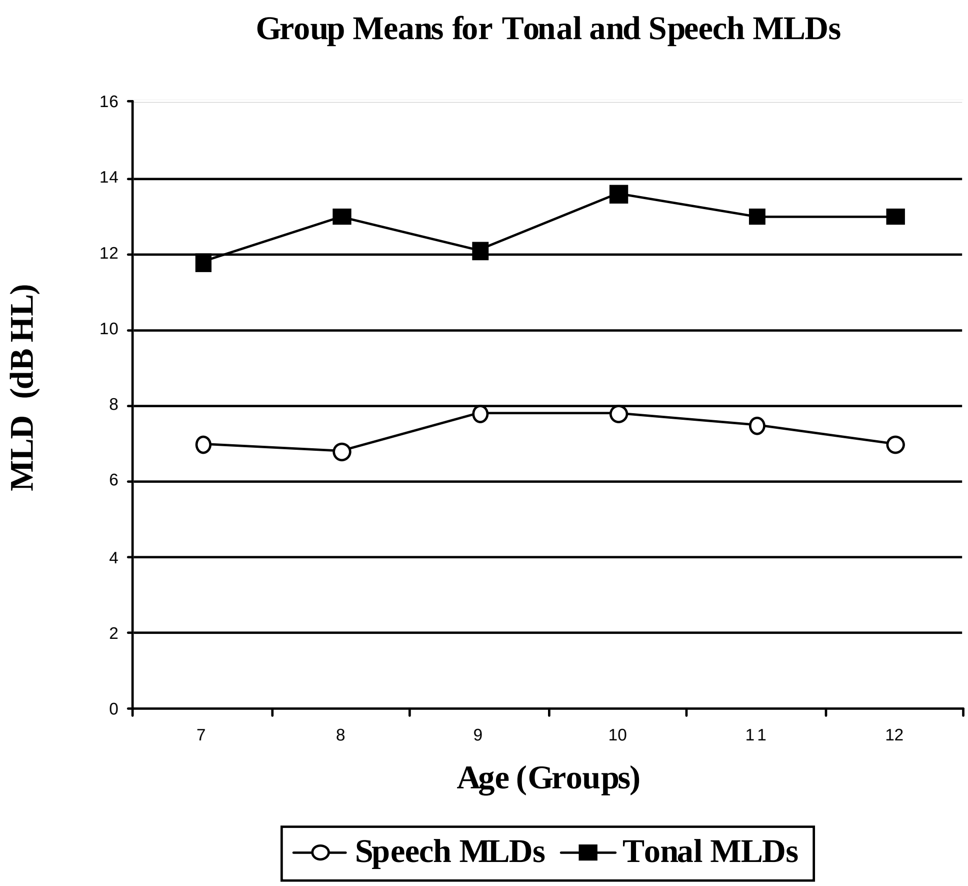

Figure 3. Means for tonal and speech masking level difference tests for each age group (7, 8, 9, 10, 11, and 12 year olds).

1.66 dB. Individual thresholds can be found in Appendix G. No significant gender differences were noted.

Group comparisons for tonal MLDs. The mean tonal MLD for the age groups were: 11.75 dB (7 year olds), 13 dB (8 year olds), 12.12 dB (9 year olds), 13.62 dB (10 year olds), 13.07 dB (11 year olds), and 12.93 (12 year olds) (Figure 3). A one-way ANOVA with Tukey's HSD test was calculated for group comparisons. There were no significant differences ($p < .05$) in tonal MLD performance between age groups.

Group comparisons for speech MLDs. The mean tonal MLD for the age groups were: 7 dB (7 year olds), 6.8 dB (8 year olds), 7.8 dB (9 year olds), 7.8 dB (10 year olds), 7.5 dB (11 year olds), and 7 dB (12 year olds) (Figure 3). A one-way ANOVA with Tukey's HSD test was calculated for group comparisons. There were no significant differences ($p > .05$) in speech MLD performance between age groups. The 90th percentile score for speech MLDs for all 96 participants was 5.5 dB.

Pitch Pattern Sequence Test

Pitch pattern testing was presented monaurally right and data was recorded under two response conditions. The conditions consisted of a motor response (MPPS) or a verbal response (VPPS). Frequency pattern testing was conducted using the Auditec Quality Recordings of Auditory Tests compact disc, Tracks 7-10.

Individual data for VPPS. Individual scores for the 96 participants on the VPPS ranged from 20% to 100%. The overall mean score of all the 96 participants on the VPPS test was 92% with a standard deviation of 12%. Individual scores can be found in Appendix H. No significant gender differences were noted.

Individual data for MPPS. Individual scores on the MPPS for the 96 participants ranged from 37% to 100%. The overall mean score of all the 96 participants on the MPPS test was 95% with a standard deviation of 9%. Individual scores can be found in Appendix H. No significant gender differences were noted.

Group data for VPPS. The mean score and standard deviation on the VPPS for each age group were: 7 year olds (81.5%, 21.1), 8 year olds (90.1%, 7.9), 9 year olds (90.4%, 13), 10 year olds (97.8, 2.9), 11 year olds (96.1%, 3.9), and 12 year olds (96%, 5.8) (Table 5). A one-way ANOVA with a Tukey's HSD test was calculated for group comparisons. There were significant differences ($p < .05$) in VPPS performance between the 7 and 9 year olds ($p = .032$), the 7 and 10 year olds ($p = .001$), 7 and 11 year olds ($p = .004$), and the 7 and 12 year olds ($p = .005$). Group data can be found in Appendix I. A linear regression analysis was performed and showed a significant relationship ($p = .000$) between age and VPPS performance. VPPS scores tended to increase as age increased.

Group data for MPPS. The mean score and standard deviation on the MPPS for each age group were: 7 year olds (87.1%, 17.6), 8 year olds (93.7%, 7.9), 9 year olds (96.3%, 4.4), 10 year olds (96.7%, 5.1), 11 year olds (98.1, 2.8), and 12 year olds (98.1%, 3.4) (Table 4). A one-way ANOVA with a Tukey's HSD test was calculated for group comparisons. The 7 year olds' performance was significantly different ($p <.05$) from the 9 year olds ($p = .035$), 10 year olds ($p = .025$), 11 year olds ($p = .006$) and 12 year olds ($p = .006$). Group data can be found in Appendix I. A linear regression analysis showed a significant

Table 4

VPPS and MPPS Mean Scores and Standard Deviations

Test	Age Group	Mean Score	SD	1 SD below the mean	2 SD below the mean
VPPS	7	81.5%	21.1	60.4%	39.3%
	8	90.1%	7.9	82.2%	74.3%
	9*	93%	8.7	84.3%	75.6%
	10	97.8%	2.9	94.9%	92%
	11	96.1%	3.9	92.2%	88.3%
	12	96%	2.8	90.2%	84.4%
MPPS	7	87.1%	17.6	69.5%	51.9%
	8	93.7%	7.9	85.8%	77.9%
	9	96%	4.4	91.9%	87.5%
	10	96.7%	5.1	91.6%	86.5%
	11	98.1%	2.8	95.3%	92.5%
	12	98.1%	3.4	94.6%	91.2%

Note: There were significant differences ($p < .05$) in VPPS performance between the 7 and 9 year olds ($p = .032$), the 7 and 10 year olds ($p = .001$), 7 and 11 year olds ($p = .004$), and the 7 and 12 year olds ($p = .005$). For the MPPS performance, scores for the 7 year olds were significantly different ($p <.05$) from the 9 year olds ($p = .035$), 10 year olds ($p = .025$), 11 year olds ($p = .006$) and the 12 year olds ($p = .006$). * Indicates that the outlier data was removed.

relationship (p = .000) between age and MPPS performance. MPPS test scores tended to increase as age increased.

A paired-sample *t*-test was conducted to determine if there was a significant difference in performance between the VPPS and MPPS tests. There was a significant difference in MPPS performance over VPPS performance for the 7 year olds (p = .004), 8 year olds (p = .023), and 11 year olds (p = .037). The 9 year olds (p = .091), 10 year olds (p = .252) and 12 year olds (p = .060) did not show significant differences in performance between the tests (Figure 4).

Arcsin transformation. A large number of participants scored the maximum possible score (100%) on the MPPS and VPPS. In cases such as this, an arcsin transformation is recommended (Rao, 1998). The arcsin transformation was calculated and the paired-sample *t*-test and one-way ANOVA with a Tukey's HSD was performed. The results of the tests on the arcsin transformed data were the same as the results on the untransformed data.

BKB-SIN

The Bamford-Kowal-Bench Sentence in Auditec-4 talker babble was administered using the BKB Sin Test CD 1: Standard BKB-SIN, Tracks 3-20, developed by Etymotic Research (Etymotic research, 2005). Lists were presented in list pairs in the monaural right, monaural left, and binaural conditions. Ear order was counter balanced across participants. Results were an overall percent correct, as explained in the methods section.

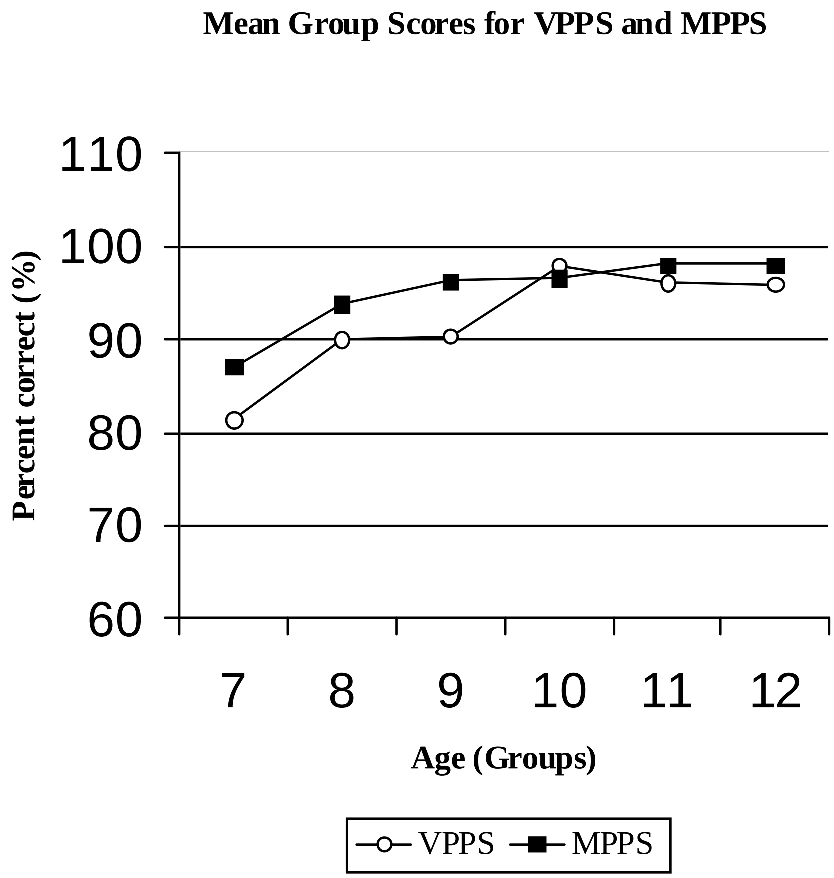

Figure 4: There was a significant difference in MPPS performance over VPPS performance for the 7 year olds (p = .004), 8 year olds (p = .023), and 11 year olds (p = .037). The 9 year olds (p = .057), 10 year olds (p = .252) and 12 year olds (p = .060) did not show a significant difference in performance between the tests.

Individual BKB-SIN performances (percent scores). The individual BKB-SIN scores for the 96 participants ranged from 59.7%-82% (monaural right), 56%-82% (monaural left), and 68%-84% (binaural). The mean score for each condition were 69.8% (monaural right), 70.5% (monaural left), and 76.4% (binaural). No statistical significant gender effects were noted. Individual scores can be found in Appendix J.

Comparison of monaural performance (percent correct scores). A paired-sample *t*-test was calculated to determine if there was an ear advantage. For each individual age group, there was no significant difference between the monaural right and monaural left conditions.

Best monaural score compared to binaural score (percent correct scores). A paired-sample *t*-test was calculated to determine if a binaural difference occurred for any age group. The 7, 8, 9, 10 and 11 year olds showed a significant binaural advantage ($p < .01$). Although the 12 year olds showed a binaural advantage, it was not significant ($p = .595$). These results are shown in Figure 5. Individual data showed 73 participants had a binaural advantage, 15 participants had binaural interference, and 8 participants had binaural indifference. Although there was binaural interference in 15 participants, these scores were not statistically significant ($p > .05$) (Raffin & Thornton, 1980). (Appendix K).

Mean Best Monaural BKB Compared to Mean Best Binaural BKB

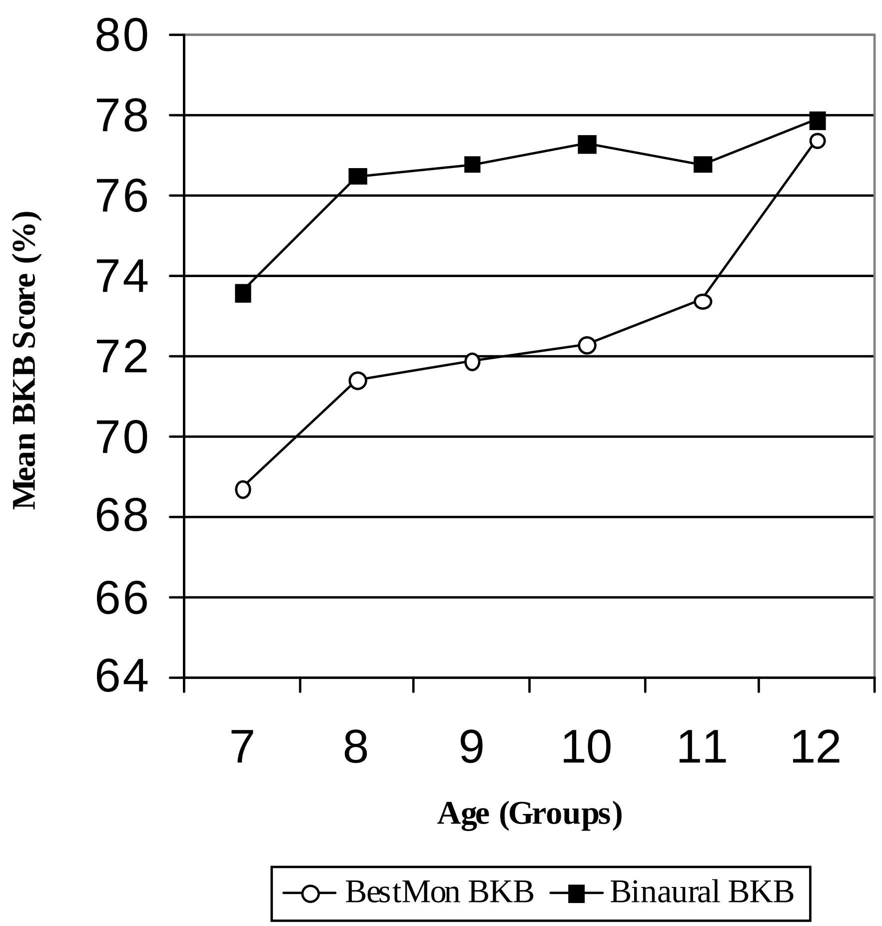

Figure 5: The 7, 8, 9, 10 and 11 year olds showed a significant binaural advantage ($p < .01$). Although the 12 year olds showed a binaural advantage, it was not significant ($p = .595$).

CHAPTER IV: DISCUSSION

Major Findings

The current study tested 96 children on five auditory tasks: speech recognition thresholds, word recognition testing, speech-in-noise testing, masking level difference test (MLD), and pitch pattern sequence test (PPT). All age groups showed a significant binaural advantage for speech recognition thresholds. Word recognition testing revealed 35 participants demonstrated a binaural advantage, 36 participants demonstrated binaural indifference, and 25 participants demonstrated a monaural advantage. Only one participant (P92) showed statistically significant binaural interference (p=.05). Speech-in-noise testing revealed 72 participants demonstrating a binaural advantage, 12 participants showing binaural indifference, and 12 participants with a monaural advantage. No statistically significant binaural interference was found for speech-in-noise testing. The mean masking level differences were 7.3 dB for speech stimuli and 12.81 dB for tonal stimuli. Pitch pattern sequence testing showed improved performance with increasing age for both the verbal and motor responses. Overall, children showed better performance on the motor response PPT than the verbal PPT.

Initially, it was hypothesized that a small percentage of normal hearing children would show evidence of binaural interference on word recognition scores and/or sentence-in-noise tests. If binaural interference was observed, it was hypothesized that there would be an association of cortical or sub-cortical involvement, as indicated by abnormal performance on the pitch pattern sequence test and/or masking level difference tests. The presence of binaural interference was considered significant at the .05

confidence level using confidence levels for differences between speech-discrimination scores (Raffin & Thornton, 1980).

Speech Recognition Thresholds

Speech recognition thresholds (SRTs) had to be established so that word recognition testing could be conducted at an appropriate sensation level. Speech recognition thresholds were obtained in the monaural right, monaural left, and binaural conditions. Although no significant ear advantage was noted, all age groups showed significantly better binaural performance over monaural performance (better performance indicated by a lower speech recognition threshold). In the current study, binaural scores were approximately 2-3 dB lower (better) than monaural scores. Previous studies have shown that when stimuli are presented diotically, an increase of 3 dB was noted in binaural loudness (Dermody & Bryne, 1975). One could expect that this increase in loudness, or binaural summation, would produce better speech recognition thresholds for the binaural condition.

Binaural Interference Findings

Binaural interference was investigated through word recognition and sentence testing. For word recognition testing, only 1 of 96 participants (Participant #92) showed significant binaural interference in the word recognition scores. This participant was in the 12 year old group. P92 had a right monaural word recognition score of 100%, a left monaural word recognition score of 98%, and a binaural score of 94%. The difference of 6% was statistically significant (Raffin & Thornton, 1980) at $p = .05$. On the sentence-in-noise task, P92 did not show evidence of binaural interference. P92's performances on the pitch pattern sequence test and masking level difference tests were reviewed to determine if there was any evidence for cortical or sub-cortical association. Based on the hypothesis, one could expect an abnormal score on either of these tasks. P92 performed within normal limits on both the pitch pattern sequence tests and the masking level difference tests. Although P92 performed within normal limits on these tasks, this cannot determine whether binaural interference is or is not a breakdown in the cortical or sub-cortical levels, due to its presence in only one participant. Additionally, the PPT and MLD tests may not be the most sensitive measures to confirm a cortical or sub-cortical deficit. A larger variety and number of cortical and sub-cortical tests would need to be carried out on a large population of individuals who demonstrate binaural interference in order to make such a conclusion.

This study sought to determine if normal hearing children demonstrated statistically significant binaural interference. In general, one would expect children to perform better in the binaural condition on word recognition tasks. In the present study, however, only 35 participants (36.4%) demonstrated a binaural advantage and 36 participants (37.5%) demonstrated binaural indifference. Twenty-five participants (26%) demonstrated a monaural advantage with only one participant (P92) showing statistical significance (p=.05). These findings are important because it provides evidence that approximately 26% of children should perform better in the monaural condition on similar word recognition tasks. Similar findings were reported in adults by Allen et al., (Allen, R., personal communication, June 2008), who reported that 35.5% of adults performed better in the monaural condition than the binaural condition for word recognition testing. Since most audiologists typically test word recognition in each ear independently, they may not be able to identify children with binaural interference. The addition of binaural word recognition testing would provide the audiologist with critical information relative to binaural performance.

Sentence-in-noise testing was also used for the investigation of binaural interference. Sentence-in-noise testing provided more of a real world situation compared to monosyllabic word recognition scores. The scoring protocol for the BKB-SIN was modified to establish an overall percent correct for each condition. When best monaural versus binaural performance was compared using confidence levels for differences between speech-discrimination scores (Raffin & Thornton, 1980), no participant showed significant binaural interference. Again, one would predict that children would perform better in the binaural condition than the monaural condition, however in this study 72 (75%) participants showed a binaural advantage, 12 participants (12.5%) showed binaural indifference, and 12 participants (12.5%) had a monaural advantage. A larger number of individuals showing a binaural advantage in the current study were comparable to research by Allen et. al., (Allen R., personal communication, June 2008), who found 54 adult participants (68.4%) showed a binaural advantage, 24 (30.4%) participants showed a monaural advantage, and one participant (1.2%) showed binaural indifference.

As stated previously, in the current study one participant (P92) was found to have binaural interference at a statistically significant level ($p = .05$). It is important to note that the difference in P92's best monaural and binaural word scores was only 6%. When an individual demonstrates binaural interference, either in word recognition scores or sentence scores, it is important to determine if this statistical significance is also clinically significant and some type of clinical intervention is warranted. P92's scores of 100% and 94% would typically be considered as scores within the normal performance range for speech recognition testing and would not be considered clinically significant. In contrast, a monaural score of 80% compared to a binaural score of 64% is not statistically significant ($p = .077$), but this 16% difference in scores may be considered clinically significant by some audiologists to the extent that they might alter amplification recommendations or counseling strategies. In considering amplification recommendations, it behooves the audiologist to test for binaural interference in both the aided and unaided conditions. These test results would indictate whether the initial fitting strategy may be to fit binaurally, or monaurally with the ultimate goal of making a binaural fitting.

It is also important to determine the test- retest reliability of individual scores. If binaural interference is seen in the initial test session, retesting at periodic intervals would be advised as it has yet to be determined if binaural interference is a stable or transient phenomenon. Intervention strategies would certainly be different if the binaural interference was only present on one occasion versus multiple test sessions.

Our original hypothesis predicted that a small percentage of normal hearing children would show binaural interference. This hypothesis was based upon earlier evidence that showed a few normal hearing adults displayed binaural interference on word recognition tests (Allen R., personal communication, June 20, 2007). The present study found only one participant who showed binaural interference for word recognition scores at a statistically significant level, which yielded a 1% occurrence of binaural interference in this population. Based on chance probability, about five participants should have shown binaural interference at the .05 confidence level and about one participant at the .01 confidence level if, in fact, there were no participants with binaural interference. Since our participant (P92) showed binaural interference at the .05 level, our original hypothesis was not supported. Furthermore, the data tend to support the theories that binaural interference is more likely to be found in individuals with impaired peripheral and/or central auditory systems (Arekebauer et al., 1971; Chmiel et al., 1997; Hattori, 1993; Jerger et al., 1995; Jerger et al., 2003; and Rothpletz et al., 2004). If breakdowns in these systems were associated with aging in other reported cases, one would not expect to see binaural interference in this pediatric population.

Normative Data

The original purpose of including masking level difference tests and pitch pattern sequence tests in this study's protocol was to determine if there was an association with the presence of binaural interference and abnormal performance on either the PPT or MLD tests. Since our hypothesis was not supported these associations could not be established. However, the data collected on these tests provided useful information in the development of normative data for children's performance on the tonal and speech MLD tests and pitch pattern tests.

Tonal masking level difference test. For the masking level difference test, limited data has been published regarding normative values for the speech and tonal masking level differences in children. The mean tonal MLD threshold (for the $S\pi No$ condition) for each group was: 11.75 dB (7 year olds), 13 dB (8 year olds), 12.12 dB (9 year olds), 13.62 dB (10 year olds), 13.07 dB (11 year olds), and 12.93 (12 year olds). Group comparisons did not show significant differences among the age groups. These findings were in agreement with research by Aithal et al. (2006), Hall and Grose (1990), and Roush and Tait (2004), who found no age effects on mean tonal MLDs in children over the age of seven. In contrast, Hall and Grose (1990), believed there was an age effect up to 5- 6 years of age, but since this study investigated children over the age of 7, one would not expect to see an age effect.

The overall mean tonal MLD for all 96 participants was 12.82 dB with a standard deviation of 2.24 dB. Previous research has reported normative values as 2 standard deviations below the mean for the overall population (Aithal et al., 2006; Wilson et al., 2003). Therefore a tonal MLD threshold less than 8.33 dB (2 standard deviations below the mean) would be considered abnormal. The normative data in this study was similar to findings by Aithal et al., 2006. Aithal et al. considered an MLD smaller than 7.9 dB (2 standard deviations below the mean) for the SπNo condition to be considered abnormal for normal hearing children. A comparable 500 Hz pure tone was used as the signal for both studies. In this study the noise was a 200-800 Hz band noise (Wilson et al., 2003) compared to a 160 Hz band noise used in the study by Aithal et al., 2006. Despite this difference in the noise signals, MLDs appear to be similar or comparable.

Speech masking level difference test. Currently, there is no known published normative data for the speech masking level difference in normal hearing children (ages 7-12 years) for the SπNo condition used in this study. The mean speech MLD for each age group was: 7 dB (7 year olds), 6.8 dB (8 year olds), 7.8 dB (9 year olds), 7.8 dB (11 year olds), and 7 dB (12 year olds). No age effects were found. For determining a normative value for the speech MLD, research by Wilson et al. stated "a 90^{th} percentile score was recommended to define the normal range, due to the bimodal distribution of the MLDs" (Wilson et al, 1994, p.241). After further analysis of the speech MLD data in the present study, it appeared that the overall distribution showed signs of a bimodal distribution. Therefore, the 90^{th} percentile score for speech MLDs was determined based on recommendations of Wilson et al., 1994. For all 96 participants in the present study, the 90^{th} percentile score for the speech MLD was 5.5 dB. Therefore, a speech MLD less than 5.5 dB would be considered abnormal for normal hearing children aged 7-12 years. This normative value is comparable to research by Wilson et al. (1994) which considered a speech MLD threshold less than 5.5 dB to be considered abnormal in normal hearing adults. Hall and Gross (1990) found that above the age of 5-6 years, children's performance matched that of adults for the tonal MLD. Based on these findings one could speculate that above 5-6 years of age, the speech MLD would match those of adults.

When comparing the tonal and speech MLD performance in normal hearing children, this study found that the speech MLD produced significantly lower MLDs than the tonal MLDs. These findings are supported by previous research (Sweetow & Reddell, 1978; Wilson et al., 1994; Wilson et al., 2003). Research by Sweetow & Reddell (1978) found the speech MLD was not as useful of a diagnostic tool as the tonal MLD, since the tonal MLD test was more sensitive in identifying children with suspected perceptual dysfunction. There has been limited research published that compares children's abilities on both the tonal and speech MLDs, especially in pediatric populations suspected of central auditory processing disorder to support or disprove Sweetow & Reddell (1978). Currently, the speech MLD test may be more widely used clinically due to its availability. Until recently, special equipment or functions through an audiometer were required to perform the tonal MLD. Now, the tonal MLD test is available on a compact disc for purchase. Therefore, the tonal MLD may become more widely used in the clinic. When testing children, audiologists may find it easier to condition a child to a speech task rather than a tonal task. Variability has been seen in children's performance for a tonal task. Such variability was seen in the performance of the younger age groups for the pitch pattern sequence test.

Pitch pattern sequence test (verbal response). The mean VPPS scores and standard deviations for each age group were: 7 year olds (81.5%, 21.1), 8 year olds (90.1%, 7.9), 9 year olds (93%, 8.7), 10 year olds (97.8%, 2.9), 11 year olds (96.1%, 3.9), and 12 year olds (96%, 5.8). Normative data for the VPPS were created by using a cutoff of two standard deviations below the mean. Normative values were the following: 7 year olds (39.3%), 8 year olds (74.3%), 9 year olds (75.6%), 10 year olds (92%), 11 year olds (88.3%), and 12 year olds (90.4%). Group comparisons showed a significant difference in performance between the 7 year olds and the 10, 11, and 12 year olds.

Pitch pattern sequence test (motor response). The mean scores and standard deviations for each age group were: 7 year olds (87.1%, 17.6), 8 year olds (93.7%, 7.9), 9 year olds (96.3%, 4.4), 10 year olds (96.7%, 5.1), 11 year olds (98.1, 2.8), and 12 year olds (98.1%, 3.4). Normative data for the MPPS were created using a cutoff of two standard deviations below the mean. Normative values were the following: 7 year olds (51.9%), 8 year olds (77.9%), 9 year olds (87.5%), 10 year olds (86.5%), 11 year olds (92.5%), and 12 year olds (91.2%). Group comparisons showed a significant difference in performance between the 7 year olds and the 9, 10, 11, and 12 year olds.

When looking at the data for the VPPS and MPPS, it is important to look at both the means and the standard deviations for each group. There is larger variability seen among the standard deviations than the mean scores for each group, with the greatest variability observed in the 7 year olds. This variability is consistent with normative data published by Keith (2000), for the SCAN-C. When there is greater score variability, as in the 7 year olds, the range for normal performance is much broader making it more unlikely that a given child's score would be outside the normal range. As previously noted, this greater score variability has been previously observed but its cause is unknown.

Compared to "clinic normative data" by Bellis, 2003, the present study produced higher (or better) scores for each age group on both the VPPS and MPPS. A possible explanation for this could be the use of an additional practice set that was created for this study. This additional practice provided an opportunity to ensure that the child understood the task prior to administering the test. In the Bellis (2003) "clinic normative data", the exact response mode used was not clearly stated. In the present study, all children were tested with a verbal and non-verbal response mode, which allowed for the creation of specific normative data sets for each condition.

Significant improvement in MPPS performance over VPPS performance was seen for the 7, 8, and 11 year olds. Although not at the significance level of .05, all groups with the exception of the 10 year olds, performed better on the MPPS test than the VPPS test. A possible explanation for these findings could be that the motor response does not contain a linguistic component. Musiek (1980) suggested that the verbal response is reliant on both hemispheres, the acoustical information of the tones from the right hemisphere, and the development of the verbal response from the left hemisphere. Therefore, a hummed or motor response may be solely reliant on the right hemisphere alone, or at a sub-cortical level (Musiek, 1980). Thus, the hummed and motor responses may be less complex than the verbal task. Based on this statement, an explanation can be provided for the improved performance in the MPPS task over the VPPS task seen in this study. One could predict that, as the auditory system matures, there would be a smaller difference in performance between these two tasks. In the current study, a smaller difference was seen in the older children (10, 11, & 12 year olds) who supposedly have more mature auditory systems. A greater difference between the two tasks was seen in the younger age groups (7, 8, and 9 year olds).

Participant Selection

Sample size. This study included a large sample size of children. In order to recruit the large population, testing was performed at two different locations. Administration of the test protocol was carried out by the same researcher. Both testing sites had comparable equipment, and test procedures and protocols remained the same. In addition to the 96 participants, three participants were not included in this study. Two of three participants were excluded due to hearing thresholds that exceeded 15 dB HL in either ear, therefore not meeting the inclusion criteria for this study. The third participant met the inclusion criteria, however, was unable to perform the majority of the protocol and testing was stopped without penalty.

Fatigue. When testing any population for the amount of time needed in this study, the possibility of fatigue must be acknowledged and managed. Based on personal observation, fatigue appeared to be more of an issue for the younger children (7-8 year olds) than the older children (11-12 year olds). Testing took place during the week and weekends. Therefore, the children tested after school may have had more fatigue than those tested on the weekends. Overall test time was approximately 1.5 to 2 hours. In an attempt to control for fatigue, there were scheduled breaks every 15 minutes (approximately every two tests administered), as well as any additional breaks if the child requested one. Additionally, tests and ear order were counterbalanced to ensure that any one test was not always administered first or last. If fatigue was an issue, one might expect to see large variability in the data sets. The variability of results seen in the present study is consistent with expected outcomes.

Gender. The current study included 45 male participants and 51 female participants, therefore each group was not gender balanced. There was a greater response to recruitment from parents of female participants compared to male participants. No groups contained only females or only males. No significant gender effects were seen among the tests administered.

Test Stimuli

The test protocol used in this study modeled previous research by Jerger et al., (1993) and Allen et al., (2000). Both studies compared monaural versus binaural word recognition abilities, to investigate the phenomenon of binaural interference. It was important that the appropriate stimuli be used to determine word recognition abilities in children. Northwestern University Children's Perception of Speech (NU-CHIPS) 50 item word lists provided age appropriate stimuli for the evaluation of word recognition abilities. A presentation of 30 dB SL re: SRT was used based on research by Stuart (2005), which allowed for a comfortable and uniform presentation level. Although the NU-CHIPS provided an age appropriate stimuli, a limitation was seen through ceiling effects. A large number of participants scored the maximum (100%) for both monaural and binaural conditions. A word recognition test with more challenging stimuli would limit ceiling effects and be more beneficial for the investigation of binaural interference. However, for the current study, such age appropriate lists were not available for pediatric populations.

Sentence-in-noise testing. For sentence-in-noise testing, the BKB-SIN test provided an age appropriate test that was difficult enough in nature to prevent ceiling effects. Wilson et al. (2007) compared several different sentence-in-noise tests for children, and recommended the BKB-SIN test for studies involving young children. Although our hypothesis of the occurrence of binaural interference was not supported, sentence testing is believed to be a useful tool in the investigation of binaural interference. The BKB-SIN test protocol was modified for this study. Based on the original protocol in the BKB-SIN manual, testing is performed in the binaural condition. However, for the current study it was administered in the monaural right, monaural left, and binaural conditions. This allowed for the investigation of binaural interference using a stimulus that was more real world than the monosyllabic words used for word recognition testing.

Pitch pattern sequence testing. The pitch pattern sequence test was used as a test of auditory cortical function. If individuals showed significant binaural interference, one might expect the possibility of an abnormal performance on the pitch pattern sequence test. This assumption is based on research of Chmiel et al., 1997, who suggested that binaural interference could be related to a breakdown or demyelination of the corpus callosum (Chmiel et al., 1997). Caution was taken when using this assumption for the current study since the demyelination of the corpus callosum was believed to be an age effect. The pitch pattern sequence test has been considered a useful tool in evaluating interhemispheric transfer in children (Bellis, 2003). Bellis (2003) recommends that if children are unable to complete the pitch pattern sequence test using a verbal response, testing should be repeated using a non-verbal response (hummed response). This ability to correctly identify the tones in a hummed response over a verbal response was thought to bring awareness “to the interhemispheric integration of auditory information” (Bellis, 2003, p. 251). For the current study, all participants were tested under verbal and non-verbal response conditions. The first condition was a verbal response and the second condition a motor response (pointing to the appropriate picture). The purpose of this protocol allowed for normative data to be generated for both conditions. Previous published "clinical normative data" by Bellis (2003) did not clearly state a formal protocol used for the generation of this data. In addition to the pitch pattern sequence test being an indicator of cortical function, the use of this test for the current study provided normative data for this pediatric population.

The tonal and speech masking level difference tests were chosen due to the importance of brainstem (sub-cortical) involvement for binaural interaction tasks (Musiek & Baran, 1986). If binaural interference was seen in this population, this study sought to determine if there was an association between binaural interference and poor performance on a sub-cortical task. Since our original hypothesis was not supported, this association could not be established. This study allowed for the generation of normative data for both the tonal & speech MLD tests. Currently, there is little research available that has published normative MLD for children. The speech and tonal MLD protocols and stimuli used were obtained from Richard Wilson Ph.D., VA Medical Center, Mountain Home, Tennessee. Both the speech and tonal MLD tests are now commercially available, however only adult normative data is reported. The data collected for this study provided useful normative data for children 7 – 12 years of age utilizing speech and tonal MLD protocols by Wilson et al., 1994 & 2003.

Outliers

After statistical analyses were performed, two significant outliers were noted for the pitch pattern sequence test. One participant was in the 7 year old group and the other in the 9 year old group. Statistical analyses were performed with and without these participants in the data sets. Overall, the 7 year old group showed great variability in performance on the pitch pattern testing, which was previously highlighted by Stollman et al., (2004). Stollman et al., (2004) raised caution that conducting these tests on younger children (6-9 year olds) may produce high variability among test results. For the 7 year old participant data, no significant difference was seen with the removal of this participant and this participant remained in the data set. The 9 year old participant's performance on the pitch pattern sequence test was below normative data suggested by Bellis (2003). Removal of this participant showed a significant difference in the standard deviation for the 9 year old group. The 9 year old outlier was removed from the data set for the normative data established for the pitch pattern sequence test.

Implications for Future Research

Although our original hypothesis was not supported, future research is needed in the areas of binaural interference and masking level difference testing. In the area of binaural interference, results of this study tend to support the theory that binaural interference is a result of a breakdown in the peripheral and/or central auditory system. The next direction in research would be to conduct binaural interference testing with a large sample of children with binaural and/or monaural hearing loss. This research could provide evidence of whether binaural interference occurs in children with hearing loss. Clinically, this information would be useful in the fitting of hearing aids in pediatric patients. If a child is known to have binaural interference as evidenced by aided testing, it may be beneficial to begin with a unilateral rather than a bilateral fitting. Since binaural hearing has additional advantages to speech understanding such as sound localization, binaural squelch, and binaural fusion (Ross, 2006), the use of binaural hearing aids should be a long term goal. Schoepflin (2007) discussed using auditory training with unilateral amplification and then bilateral amplification. The period of bilateral amplification was increased gradually, with the goal being full time, daily use (Schoepflin, 2007).

The second pediatric population of interest for binaural interference would be children diagnosed with central auditory processing disorders (CAPD). Research in this area could provide evidence that binaural interference is a result of a breakdown within the central auditory system. Caution should be raised for testing of CAPD children due to the heterogeneous nature of this disordered group. Different protocols have been used clinically in diagnosing a child with CAPD. The child generally does not have to have a deficit in all areas of the central auditory processing test battery to be diagnosed as having CAPD. Therefore, for future recruiting, it would be important to have as much as a homogenous population as possible. For example, all participants would have deficits in binaural interaction and temporal processing tasks. Although not impossible, the recruitment of such a population may be difficult and time consuming. If binaural interference was found in the CAPD population, it would provide evidence supporting the need for binaural interference testing as part of the standard CAPD test battery. In addition to adding binaural interference testing to the CAPD test battery, it would be important to develop and discuss appropriate counseling techniques and recommendations for the child and his/her parent or guardian (i.e., auditory training).

This study was able to generate normative data for the tonal and speech masking level difference tests in children aged 7-12 years of age. Future research is needed to establish normative values in younger and older populations. It is important to know the age where the MLD threshold in children, for speech and tonal stimuli, is comparable to adult MLDs. This would provide more insight into the maturation of the developing auditory system.

In conclusion, although our original hypothesis was not supported in this study, it provided a foundation for future research in other populations. The identification of binaural interference in any population will provide the audiologist with valuable information regarding the fitting of hearing aids and counseling strategies in children. In addition, this study has provided useful normative data for the pitch pattern sequence tests and the speech and tonal masking level differences in children.

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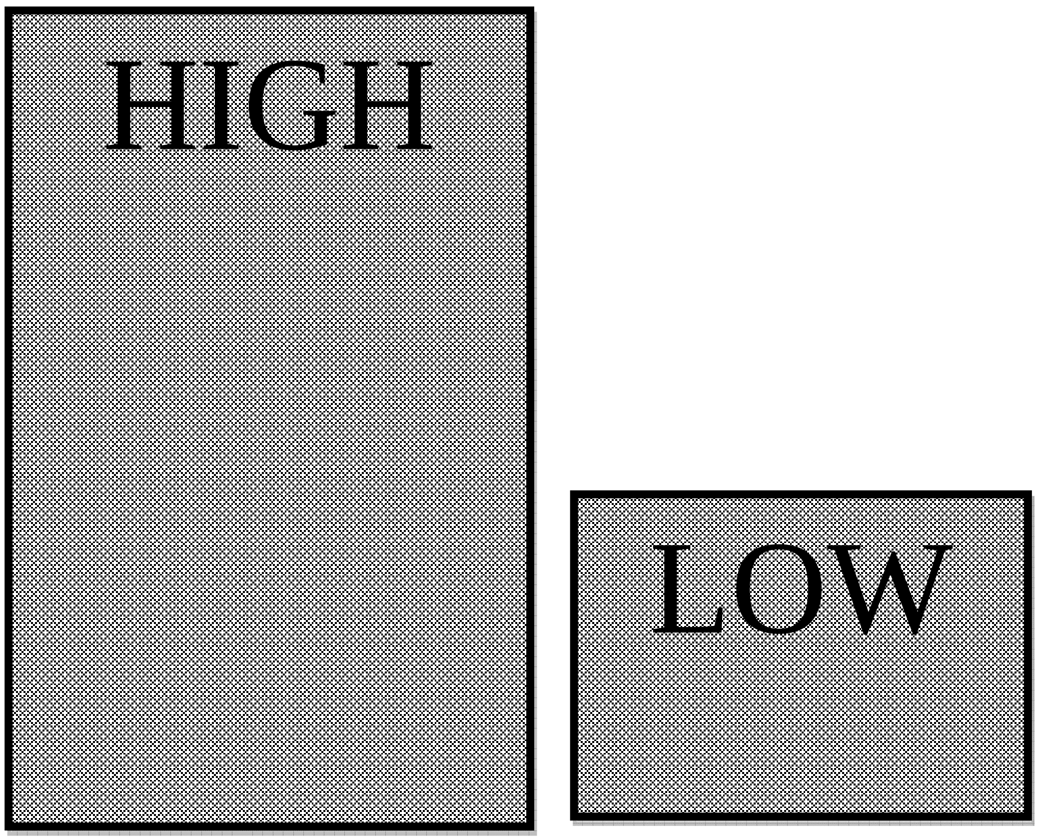
Appendix A:

Motor Pitch pattern sequence Test Motor Response Picture



Motor Pitch pattern sequence Test Motor Response Picture

Appendix B:

Individual SRTs for Monaural Right, Monaural Left, and Binaural Conditions

Individual SRTs for Monaural Right, Monaural Left, and Binaural Conditions

Participant #	Right SRT	Left SRT	Binaural SRT
1	4.0	8.0	8.0
2	12.0	12.0	6.0
3	16.0	14.0	8.0
4	14.0	14.0	10.0
5	14.0	12.0	6.0
6	10.0	5.0	10.0
7	12.0	14.0	8.0
8	8.0	12.0	10.0
9	10.0	12.0	8.0
10	10.0	10.0	6.0
11	12.0	10.0	6.0
12	8.0	8.0	6.0
13	12.0	10.0	10.0
14	12.0	12.0	10.0
15	12.0	12.0	8.0
16	12.0	12.0	8.0
17	10.0	14.0	6.0
18	14.0	14.0	8.0
19	10.0	8.0	6.0
20	16.0	16.0	14.0
21	12.0	10.0	10.0
22	10.0	8.0	8.0
23	10.0	12.0	8.0
24	12.0	10.0	8.0
25	14.0	12.0	6.0
26	12.0	10.0	6.0
27	12.0	12.0	8.0
28	12.0	10.0	8.0
29	12.0	12.0	10.0
30	12.0	12.0	10.0
31	14.0	12.0	6.0
32	12.0	12.0	6.0
33	12.0	16.0	10.0
34	16.0	16.0	12.0
35	10.0	10.0	10.0
36	12.0	12.0	10.0
37	14.0	10.0	8.0

38	12.0	12.0	8.0
39	12.0	12.0	8.0
40	12.0	10.0	8.0
41	12.0	10.0	8.0
42	14.0	14.0	6.0
43	12.0	10.0	4.0
44	12.0	10.0	4.0
45	16.0	14.0	8.0
46	12.0	10.0	10.0
47	14.0	14.0	12.0
48	10.0	8.0	8.0
49	18.0	18.0	12.0
50	12.0	8.0	8.0
51	10.0	8.0	6.0
52	12.0	12.0	8.0
53	10.0	10.0	4.0
54	12.0	12.0	10.0
56	10.0	10.0	8.0
55	12.0	14.0	6.0
57	5.0	10.0	5.0
58	12.0	14.0	8.0
59	12.0	14.0	10.0
60	12.0	12.0	6.0
61	6.0	6.0	4.0
62	10.0	12.0	10.0
63	10.0	14.0	8.0
64	8.0	8.0	2.0
65	12.0	8.0	10.0
66	18.0	18.0	16.0
67	12.0	10.0	8.0
68	10.0	8.0	8.0
69	10.0	10.0	10.0
70	10.0	12.0	8.0
71	12.0	14.0	6.0
72	12.0	14.0	12.0
73	14.0	12.0	8.0
74	14.0	12.0	10.0
75	12.0	12.0	10.0
76	12.0	6.0	8.0
77	14.0	14.0	8.0
78	16.0	12.0	10.0
79	10.0	10.0	4.0

80	10.0	12.0	8.0
81	12.0	12.0	6.0
82	10.0	8.0	8.0
83	10.0	16.0	8.0
84	10.0	8.0	8.0
85	12.0	12.0	8.0
86	10.0	10.0	8.0
87	10.0	12.0	10.0
88	10.0	12.0	8.0
89	10.0	12.0	8.0
90	8.0	6.0	6.0
91	10.0	10.0	6.0
92	18.0	12.0	8.0
93	8.0	10.0	6.0
94	12.0	10.0	8.0
95	12.0	14.0	8.0
96	10.0	10.0	8.0

Appendix C:

Tukey HSD Results for Speech Recognition Thresholds

Tukey HSD Results for Speech Recognition Thresholds

Dependent Variable	(A) Age	(B)Age	Mean Difference (A-B)	SD	Sign.
RSRT	7	8	-1.00	.833	.835
		9	-1.50	.833	.470
		10	.438	.833	.995
		11	-1.25	.833	.665
		12	.375	.833	.998
	8	9	-.500	.833	.991
		10	1.48	.833	.519
		11	-.250	.833	1.00
		12	1.38	.833	.567
	9	10	1.94	.833	.194
		11	.250	.833	1.00
		12	1.88	.833	.225
	10	11	-1.69	.833	.336
		12	-.063	.833	1.00
	11	12	1.63	.833	.379
LSRT	7	8	-.438	.912	.997
		9	-.688	.912	.974
		10	-.313	.912	.999
		11	-.438	.912	.997
		12	.188	.912	1.00
	8	9	-.250	.912	1.00
		10	.125	.912	1.00
		11	000	.912	1.00
		12	.625	.912	.983
	9	10	.375	.912	.998
		11	.250	.912	1.00
		12	.875	.912	.930
	10	11	-.125	.912	1.00
		12	.500	.912	.994
	11	12	.625	.912	.983
BSRT	7	8	.000	.765	1.00
		9	-.375	.765	.996
		10	.812	.765	.895
		11	-1.00	.765	.781
		12	.375	.765	.996
	8	9	-.375	.765	.996
		10	.812	.765	.895
		11	-1.00	.765	.781
		12	.375	.765	.996
	9	10	1.87	.765	.632
		11	-.625	.765	.964
		12	.750	.765	.923
	10	11	-1.813	.765	.179
		12	-.438	.765	.993
	11	12	1.375	.765	.473

Appendix D:

Individual WRS for Monaural Right, Monaural Left, and Binaural Conditions

Individual WRS for Monaural Right, Monaural Left, and Binaural Conditions

Participant #	Right WRS	Left WRS	Binaural WRS
1	94.0	96.0	100.0
2	92.0	90.0	98.0
3	98.0	98.0	98.0
4	100.0	96.0	100.0
5	98.0	94.0	100.0
6	100.0	96.0	96.0
7	92.0	90.0	94.0
8	96.0	96.0	96.0
9	98.0	98.0	100.0
10	94.0	96.0	96.0
11	94.0	94.0	94.0
12	92.0	92.0	90.0
13	84.0	92.0	98.0
14	92.0	88.0	90.0
15	96.0	94.0	98.0
16	94.0	92.0	96.0
17	96.0	94.0	96.0
18	98.0	98.0	100.0
19	94.0	96.0	96.0
20	100.0	100.0	100.0
21	98.0	92.0	96.0
22	100.0	98.0	96.0
23	98.0	96.0	98.0
24	98.0	90.0	94.0
25	96.0	96.0	100.0
26	100.0	100.0	100.0
27	100.0	100.0	100.0
28	96.0	96.0	96.0
29	96.0	98.0	100.0
30	98.0	96.0	98.0
31	90.0	92.0	86.0
32	94.0	86.0	96.0
33	96.0	96.0	100.0
34	96.0	98.0	100.0
35	94.0	98.0	94.0
36	98.0	96.0	100.0
37	100.0	98.0	98.0
38	98.0	96.0	98.0

39	94.0	96.0	100.0
40	94.0	94.0	92.0
41	98.0	98.0	100.0
42	98.0	98.0	100.0
43	100.0	100.0	100.0
44	98.0	96.0	94.0
45	96.0	84.0	100.0
46	96.0	98.0	100.0
47	98.0	98.0	100.0
48	100.0	98.0	100.0
49	100.0	100.0	100.0
50	98.0	98.0	100.0
51	94.0	100.0	98.0
52	100.0	96.0	100.0
53	100.0	98.0	100.0
54	98.0	96.0	100.0
56	98.0	96.0	96.0
55	100.0	98.0	100.0
57	100.0	100.0	100.0
58	96.0	94.0	98.0
59	100.0	100.0	96.0
60	98.0	98.0	100.0
61	94.0	98.0	100.0
62	92.0	96.0	92.0
63	100.0	100.0	100.0
64	98.0	100.0	98.0
65	100.0	96.0	100.0
66	100.0	100.0	96.0
67	98.0	100.0	100.0
68	98.0	100.0	100.0
69	96.0	96.0	100.0
70	98.0	96.0	96.0
71	100.0	98.0	96.0
72	98.0	96.0	96.0
73	98.0	96.0	100.0
74	100.0	98.0	98.0
75	96.0	98.0	100.0
76	96.0	98.0	100.0
77	92.0	90.0	98.0
78	100.0	100.0	100.0
79	96.0	100.0	100.0
80	98.0	96.0	100.0

81	100.0	98.0	100.0
82	98.0	96.0	98.0
83	100.0	96.0	100.0
84	94.0	96.0	100.0
85	100.0	98.0	98.0
86	100.0	98.0	100.0
87	100.0	100.0	100.0
88	98.0	100.0	100.0
89	96.0	96.0	98.0
90	100.0	98.0	100.0
91	100.0	98.0	98.0
92	100.0	98.0	94.0
93	98.0	94.0	98.0
94	94.0	92.0	94.0
95	100.0	100.0	98.0
96	98.0	98.0	100.0

Appendix E:

Tukey HSD Results for Word Recognition Scores

Tukey HSD Results for Word Recognition Scores

Dependent Variable	(B) Age	(B)Age	Mean Difference (A-B)	SD	Sign.
RWRS	7	8	-2.38	.952	.136
		9	-2.50	.952	.101
		10	**-3.25**	.952	.012
		11	**-3.13**	.952	.018
		12	**-3.88**	.952	.001
	8	9	-.125	.952	1.00
		10	-.875	.952	.941
		11	-.750	.952	.969
		12	-1.50	.952	.616
	9	10	-.750	.952	.969
		11	-.625	.952	.986
		12	-1.38	.952	.700
	10	11	.125	.952	1.00
		12	-.625	.952	.986
	11	12	-.750	.952	.969
LWRS	7	8	-1.63	1.04	.627
		9	-2.50	1.04	.168
		10	**-4.13**	1.04	.002
		11	**-3.50**	1.04	.014
		12	**-3.38**	1.04	.020
	8	9	-.875	1.04	.959
		10	-2.50	1.04	.168
		11	-1.88	1.04	.472
		12	-1.75	1.04	.549
	9	10	-1.63	1.04	.627
		11	-1.00	1.04	.929
		12	-.875	1.04	.959
	10	11	.625	1.04	.991
		12	.750	1.04	.979
	11	12	.125	1.04	1.00
BWRS	7	8	-.500	.943	.995
		9	-2.00	.943	.286
		10	-2.13	.943	.225
		11	-2.25	.943	.173
		12	-2.00	.943	.286
	8	9	-1.50	.943	.607
		10	-1.63	.943	.521
		11	-1.75	.943	.436
		12	-1.50	.943	.607
	9	10	-.125	.943	1.00
		11	-.250	.943	1.00
		12	.000	.943	1.00
	10	11	-.125	.943	1.00
		12	.125	.943	1.00
	11	12	.250	.943	1.00

Note: Significant differences (p<.05) are noted in bold print.

Appendix F:

Best Monaural WRS compared to Binaural WRS

Best Monaural WRS compared to Binaural WRS

Participant #	BestMon WRS	Binaural WRS	Difference Score	Confidence Level	Advantage
1	96.0	100.0	4	.123	Binaural
2	92.0	98.0	6	.187	Binaural
3	98.0	98.0	0	1.00	Binaural
4	100.0	100.0	0	1.00	Binaural
5	98.0	100.0	2	.317	Binaural
6	100.0	96.0	-4	.124	Monaural
7	92.0	94.0	2	.704	Binaural
8	96.0	96.0	0	1.00	Binaural
9	98.0	100.0	2	.317	Binaural
10	96.0	96.0	0	1.00	Binaural
11	94.0	94.0	0	1.00	Binaural
12	92.0	90.0	-2	.734	Monaural
13	92.0	98.0	6	.187	Binaural
14	92.0	90.0	-2	.734	Monaural
15	96.0	98.0	2	.596	Binaural
16	94.0	96.0	2	.675	Binaural
17	96.0	96.0	0	1.00	Binaural
18	98.0	100.0	2	.317	Binaural
19	96.0	96.0	0	1.00	Binaural
20	100.0	100.0	0	1.00	Binaural
21	98.0	96.0	-2	.596	Monaural
22	100.0	96.0	-4	.124	Monaural
23	98.0	98.0	0	1.00	Binaural
24	98.0	94.0	-4	.342	Monaural
25	96.0	100.0	4	.124	Binaural
26	100.0	100.0	0	1.00	Binaural
27	100.0	100.0	0	1.00	Binaural
28	96.0	96.0	0	1.00	Binaural
29	98.0	100.0	2	.318	Binaural
30	98.0	98.0	0	1.00	Binaural
31	92.0	86.0	-6	.352	Monaural
32	94.0	96.0	2	.674	Binaural
33	96.0	100.0	4	.124	Binaural
34	98.0	100.0	2	.317	Binaural
35	98.0	94.0	-4	.342	Monaural
36	98.0	100.0	2	.317	Binaural
37	100.0	98.0	-2	.317	Monaural

38	98.0	98.0	0	1.00	Binaural
39	96.0	100.0	4	.124	Binaural
40	94.0	92.0	-2	.704	Monaural
41	98.0	100.0	2	.317	Binaural
42	98.0	100.0	2	.317	Binaural
43	100.0	100.0	0	1.00	Binaural
44	98.0	94.0	-4	.342	Monaural
45	96.0	100.0	4	.124	Binaural
46	98.0	100.0	2	.317	Binaural
47	98.0	100.0	2	.317	Binaural
48	100.0	100.0	0	1.00	Binaural
49	100.0	100.0	0	1.00	Binaural
50	98.0	100.0	2	.317	Binaural
51	100.0	98.0	-2	.317	Monaural
52	100.0	100.0	0	1.00	Binaural
53	100.0	100.0	0	1.00	Binaural
54	98.0	100.0	2	.317	Binaural
56	98.0	96.0	-2	.596	Monaural
55	100.0	100.0	0	1.00	Binaural
57	100.0	100.0	0	1.00	Binaural
58	96.0	98.0	2	.596	Binaural
59	100.0	96.0	-4	.124	Monaural
60	98.0	100.0	2	.317	Binaural
61	98.0	100.0	2	.317	Binaural
62	96.0	92.0	-4	.424	Monaural
63	100.0	100.0	0	1.00	Binaural
64	100.0	98.0	-2	.317	Monaural
65	100.0	100.0	0	1.00	Binaural
66	100.0	96.0	-4	.124	Monaural
67	100.0	100.0	0	1.00	Binaural
68	100.0	100.0	0	1.00	Binaural
69	96.0	100.0	4	.124	Binaural
70	98.0	96.0	-2	.596	Monaural
71	100.0	96.0	-4	.124	Monaural
72	98.0	96.0	-2	.596	Monaural
73	98.0	100.0	2	.317	Binaural
74	100.0	98.0	-2	.317	Monaural
75	98.0	100.0	2	.317	Binaural
76	98.0	100.0	2	.317	Binaural
77	92.0	98.0	6	.187	Binaural
78	100.0	100.0	0	1.00	Binaural
79	100.0	100.0	0	1.00	Binaural

80	98.0	100.0	2	.317	Binaural
81	100.0	100.0	0	1.00	Binaural
82	98.0	98.0	0	1.00	Binaural
83	100.0	100.0	0	1.00	Binaural
84	96.0	100.0	4	.124	Binaural
85	100.0	98.0	-2	.317	Monaural
86	100.0	100.0	0	1.00	Binaural
87	100.0	100.0	0	1.00	Binaural
88	100.0	100.0	0	1.00	Binaural
89	96.0	98.0	2	.596	Binaural
90	100.0	100.0	0	1.00	Binaural
91	100.0	98.0	-2	.317	Monaural
92	100.0	94.0	-6	.050	Monaural
93	98.0	98.0	0	1.00	Binaural
94	94.0	94.0	0	1.00	Binaural
95	100.0	98.0	-2	.317	Monaural
96	98.0	100.0	2	.317	Binaural

Appendix G:

Individual Tonal and Speech Masking Level Difference Thresholds

Individual Tonal and Speech Masking Level Difference Thresholds

Participant #	Speech MLD	Tonal MLD
1	8.5	10.0
2	6.0	10.0
3	5.5	8.0
4	8.5	12.0
5	5.0	12.0
6	5.0	12.0
7	5.5	12.0
8	7.0	12.0
9	6.0	14.0
10	5.5	12.0
11	8.0	12.0
12	7.0	14.0
13	11.0	12.0
14	7.5	14.0
15	9.0	10.0
16	7.0	12.0
17	6.5	14.0
18	6.0	10.0
19	7.5	10.0
20	6.5	14.0
21	5.5	14.0
22	9.0	12.0
23	8.0	12.0
24	5.5	12.0
25	5.0	12.0
26	6.5	12.0
27	8.5	16.0
28	6.0	12.0
29	7.5	14.0
30	8.0	16.0
31	5.5	12.0
32	7.5	16.0
33	8.0	14.0
34	5.5	8.0
35	8.0	12.0
36	9.0	16.0
37	6.0	14.0
38	7.5	12.0

39	6.5	16.0
40	8.5	12.0
41	14.0	8.0
42	8.0	12.0
43	6.5	12.0
44	8.5	12.0
45	5.0	8.0
46	9.5	12.0
47	6.0	10.0
48	7.5	16.0
49	6.0	18.0
50	8.0	8.0
51	9.5	16.0
52	6.5	16.0
53	9.0	14.0
54	8.5	14.0
56	11.0	12.0
55	6.5	12.0
57	6.5	12.0
58	8.5	18.0
59	9.0	16.0
60	6.5	10.0
61	9.0	14.0
62	8.5	12.0
63	6.0	14.0
64	6.0	12.0
65	7.5	12.0
66	7.0	12.0
67	7.5	12.0
68	6.0	14.0
69	9.0	14.0
70	7.5	14.0
71	11.0	10.0
72	6.5	12.0
73	7.0	16.0
74	6.0	12.0
75	6.0	16.0
76	7.5	12.0
77	9.0	12.0
78	8.0	14.0
79	6.5	14.0
80	4.0	16.0

81	5.5	10.0
82	8.5	14.0
83	9.0	12.0
84	10.0	14.0
85	8.0	16.0
86	7.5	16.0
87	7.0	12.0
88	7.5	12.0
89	4.0	12.0
90	9.5	16.0
91	6.0	12.0
92	5.5	16.0
93	9.0	14.0
94	6.0	10.0
95	5.5	10.0
96	6.5	14.0

Appendix H:

Individual Pitch pattern sequence Test Scores for Verbal and Motor Responses

Individual Pitch pattern sequence Test Scores for Verbal and Motor Responses

Participant #	VPPS	MPPS
1	90.0	90.0
2	86.0	93.0
3	70.0	70.0
4	93.0	97.0
5	96.0	100.0
6	100.0	97.0
7	20.0	37.0
8	86.0	97.0
9	97.0	93.0
10	80.0	90.0
11	100.0	100.0
12	93.0	100.0
13	93.0	93.0
14	80.0	93.0
15	70.0	87.0
16	50.0	57.0
17	93.0	93.0
18	93.0	100.0
19	90.0	90.0
20	76.0	70.0
21	100.0	100.0
22	97.0	97.0
23	90.0	100.0
24	97.0	97.0
25	90.0	93.0
26	83.0	83.0
27	90.0	97.0
28	100.0	100.0
29	93.0	97.0
30	77.0	90.0
31	77.0	93.0
32	96.0	100.0
33	97.0	100.0
34	97.0	97.0
35	86.0	90.0
36	100.0	97.0
37	100.0	100.0
38	70.0	97.0

39	87.0	87.0
40	97.0	97.0
41	97.0	100.0
42	97.0	93.0
43	100.0	100.0
44	97.0	100.0
45	53.0	90.0
46	83.0	100.0
47	100.0	100.0
48	86.0	93.0
49	93.0	83.0
50	100.0	100.0
51	100.0	90.0
52	97.0	100.0
53	97.0	97.0
54	100.0	100.0
56	100.0	100.0
55	97.0	100.0
57	100.0	100.0
58	97.0	93.0
59	97.0	97.0
60	97.0	97.0
61	100.0	100.0
62	90.0	90.0
63	100.0	100.0
64	100.0	100.0
65	96.0	100.0
66	93.0	100.0
67	93.0	97.0
68	100.0	100.0
69	100.0	100.0
70	93.0	93.0
71	100.0	100.0
72	96.0	93.0
73	93.0	100.0
74	87.0	97.0
75	97.0	100.0
76	97.0	97.0
77	100.0	100.0
78	100.0	100.0
79	100.0	100.0
80	93.0	93.0

81	100.0	100.0
82	90.0	100.0
83	100.0	100.0
84	93.0	100.0
85	96.0	100.0
86	100.0	100.0
87	100.0	96.0
88	90.0	90.0
89	93.0	100.0
90	100.0	100.0
91	93.0	97.0
92	100.0	100.0
93	100.0	97.0
94	80.0	90.0
95	100.0	100.0
96	100.0	100.0

Appendix I:

Tukey HSD Results for Pitch pattern sequence Test (VPPS and MPPS)

Tukey HSD Results for Pitch pattern sequence Test (VPPS and MPPS)

Dependent Variable	(C) Age	(B)Age	Mean Difference (A-B)	SD	Sign.
VPPS	7	8	-8.63	3.91	.246
		9	-8.94	3.91	.212
		10	**-16.32**	3.91	.001
		11	**-14.63**	3.91	.004
		12	**-14.44**	3.91	.005
	8	9	-.313	3.91	1.00
		10	7.69	3.91	.371
		11	-6.00	3.91	.644
		12	-5.81	3.91	.675
	9	10	-7.38	3.91	.419
		11	-5.69	3.91	.695
		12	-5.5	3.91	.724
	10	11	1.69	3.91	.998
		12	1.88	3.91	.997
	11	12	.188	3.91	1.00
MPPS	7	8	-6.63	3.02	.252
		9	**-9.19**	3.02	.035
		10	**-9.57**	3.02	.025
		11	**-11.00**	3.02	.006
		12	**-11.00**	3.02	.006
	8	9	-2.56	3.02	.957
		10	-2.94	3.02	.926
		11	-4.38	3.02	.698
		12	-4.38	3.02	.698
	9	10	-.375	3.02	1.00
		11	-1.81	3.02	.991
		12	-1,81	3.02	.991
	10	11	-1.44	3.02	.997
		12	-1.44	3.02	.997
	11	12	0.00	3.02	1.00

Note: Significant differences ($p < .05$) noted in bold.

Appendix J:

Individual BKB-SIN Scores for Monaural Right, Monaural Left, and Binaural Conditions

Individual BKB-SIN Scores for Monaural Right, Monaural Left, and Binaural Conditions

Participant #	Right BKB	Left BKB	Binaural BKB
1	68.0	64.5	76.0
2	63.0	56.0	68.0
3	63.0	73.0	73.0
4	61.0	65.0	69.0
5	69.0	71.0	77.0
6	60.0	65.0	68.0
7	59.7	71.0	75.8
8	66.0	66.0	75.0
9	66.0	76.0	73.0
10	63.0	66.0	74.0
11	66.0	61.0	77.0
12	66.0	71.0	69.0
13	67.7	59.6	75.8
14	71.0	68.0	79.0
15	71.0	68.0	77.0
16	60.0	69.0	71.0
17	69.0	75.0	75.0
18	69.0	69.0	79.0
19	73.0	75.0	75.0
20	63.0	71.0	73.0
21	66.0	68.0	74.0
22	71.0	68.0	74.0
23	75.8	69.3	71.0
24	68.0	66.0	74.0
25	66.1	67.7	71.0
26	60.0	66.0	81.0
27	72.6	71.0	80.6
28	72.0	76.0	79.0
29	67.7	69.3	77.4
30	68.0	68.0	79.0
31	66.0	76.0	79.0
32	74.0	73.0	82.0
33	69.0	69.0	76.0
34	65.0	69.0	73.0
35	69.0	76.0	74.0
36	82.0	77.0	81.0
37	73.0	65.0	81.0
38	71.0	68.0	76.0

39	79.0	77.0	82.0
40	69.3	72.6	79.0
41	64.5	64.5	72.5
42	69.0	69.0	77.0
43	71.0	61.3	75.8
44	74.0	74.0	76.0
45	61.0	68.0	73.0
46	73.0	61.0	79.0
47	69.0	71.0	77.0
48	71.0	64.5	75.8
49	73.0	74.0	77.0
50	64.5	69.3	75.8
51	74.0	77.0	79.0
52	68.0	74.0	76.0
53	73.0	71.0	71.0
54	69.4	71.0	74.2
56	62.9	69.3	79.0
55	76.0	66.0	81.0
57	79.0	74.0	82.0
58	61.3	71.0	74.2
59	67.7	66.1	79.0
60	65.0	69.0	77.0
61	69.0	73.0	82.0
62	69.0	68.0	76.0
63	72.6	71.0	75.8
64	65.0	73.0	79.0
65	76.0	76.0	79.0
66	61.0	76.0	71.0
67	61.2	71.0	79.0
68	77.0	74.0	74.0
69	68.0	71.0	76.0
70	71.0	71.0	74.0
71	69.0	74.0	79.0
72	68.0	69.0	74.0
73	66.1	67.7	74.2
74	71.0	76.0	81.0
75	73.0	63.0	81.0
76	76.0	77.0	77.0
77	68.0	71.0	79.0
78	79.0	74.2	80.6
79	72.5	71.0	72.5
80	73.0	73.0	77.0

81	63.0	71.0	71.0
82	74.0	73.0	82.0
83	79.0	73.0	76.0
84	76.0	71.0	73.0
85	77.0	71.0	84.0
86	79.0	69.0	81.0
87	77.0	71.0	79.0
88	73.0	81.0	79.0
89	71.0	74.0	74.0
90	71.0	82.0	82.0
91	68.0	73.0	78.0
92	72.0	77.0	77.0
93	77.4	69.3	80.6
94	77.0	71.0	74.0
95	81.0	79.0	79.0
96	77.0	69.0	76.0

Appendix K:

Best Monaural BKB-SIN Compared to Binaural BKB-SIN

Best Monaural BKB-SIN compared to Binaural BKB-SIN

Participant #	BestMon BKB	Binaural BKB	Difference Score	Confidence Level	Advantage
1	68.0	76.0	8	0.3735	Binaural
2	63.0	68.0	5	0.6745	Binaural
3	73.0	73.0	0	1.000	Indifference
4	65.0	69.0	4	0.6745	Binaural
5	71.0	77.0	6	0.4965	Binaural
6	65.0	68.0	3	0.8337	Binaural
7	71.0	76.0	5	0.6599	Binaural
8	66.0	75.0	9	0.2713	Binaural
9	76.0	73.0	-3	0.8181	Monaural
10	66.0	74.0	8	0.1416	Binaural
11	66.0	77.0	10	0.1868	Binaural
12	71.0	69.0	-2	0.8337	Monaural
13	68.0	76.0	8	0.3735	Binaural
14	71.0	79.0	8	0.3524	Binaural
15	71.0	77.0	6	0.4965	Binaural
16	69.0	71.0	2	0.8337	Binaural
17	75.0	75.0	0	1.000	Indifference
18	69.0	79.0	10	0.2543	Binaural
19	75.0	75.0	0	1.000	Indifference
20	71.0	73.0	2	0.8181	Binaural
21	68.0	74.0	6	0.5093	Binaural
22	71.0	74.0	3	0.8181	Binaural
23	76.0	71.0	-5	0.6599	Monaural
24	68.0	74.0	6	0.5093	Binaural
25	68.0	71.0	3	0.6599	Binaural
26	66.0	81.0	15	0.0703	Binaural
27	73.0	81.0	8	0.3524	Binaural
28	76.0	79.0	3	0.6384	Binaural
29	69.0	77.0	8	0.3628	Binaural
30	68.0	79.0	11	0.177	Binaural
31	76.0	79.0	3	0.6384	Binaural
32	74.0	82.0	8	0.3421	Binaural
33	69.0	76.0	7	0.5093	Binaural
34	69.0	73.0	4	0.6599	Binaural
35	76.0	74.0	-2	0.8181	Monaural

36	82.0	81.0	1	1.000	Indifference
37	73.0	81.0	8	0.3421	Binaural
38	71.0	76.0	5	0.6599	Binaural
39	79.0	82.0	3	0.6241	Binaural
40	69.0	79.0	10	0.2543	Binaural
41	65.0	73.0	8	0.3953	Binaural
42	69.0	77.0	8	0.3628	Binaural
43	71.0	76.0	5	0.6599	Binaural
44	74.0	76.0	2	0.8181	Binaural
45	68.0	73.0	5	0.5093	Binaural
46	73.0	79.0	6	0.4839	Binaural
47	71.0	77.0	6	0.4965	Binaural
48	71.0	76.0	5	0.6599	Binaural
49	74.0	77.0	3	0.6455	Binaural
50	69.0	76.0	7	0.5093	Binaural
51	77.0	79.0	2	0.8026	Binaural
52	74.0	76.0	2	0.8181	Binaural
53	73.0	71.0	-2	0.8181	Monaural
54	71.0	74.0	3	0.8181	Binaural
56	76.0	81.0	5	0.3421	Binaural
55	69.0	79.0	10	0.2543	Binaural
57	79.0	82.0	3	0.8026	Binaural
58	71.0	74.0	3	0.8181	Binaural
59	68.0	79.0	11	0.177	Binaural
60	69.0	77.0	8	0.3628	Binaural
61	73.0	82.0	9	0.3421	Binaural
62	69.0	76.0	7	0.5093	Binaural
63	72.0	76.0	4	0.6599	Binaural
64	73.0	79.0	6	0.4839	Binaural
65	76.0	79.0	3	0.6384	Binaural
66	76.0	71.0	-5	0.5093	Monaural
67	71.0	79.0	8	0.3524	Binaural
68	77.0	74.0	-3	0.6455	Monaural
69	71.0	76.0	5	0.6599	Binaural
70	71.0	74.0	3	0.8181	Binaural
71	74.0	79.0	5	0.4839	Binaural
72	69.0	74.0	5	0.6599	Binaural
73	68.0	74.0	6	0.5093	Binaural
74	76.0	81.0	5	0.4715	Binaural
75	73.0	81.0	8	0.3421	Binaural
76	77.0	77.0	0	1.000	Indifference
77	71.0	79.0	8	0.3524	Binaural

78	79.0	81.0	2	1.000	Indifference
79	73.0	73.0	0	1.000	Indifference
80	73.0	77.0	4	0.6455	Binaural
81	71.0	71.0	0	1.000	Indifference
82	74.0	82.0	8	0.3421	Binaural
83	79.0	76.0	-3	0.6384	Monaural
84	76.0	73.0	-3	0.8181	Monaural
85	77.0	84.0	7	0.4473	Binaural
86	79.0	81.0	3	0.8026	Binaural
87	77.0	79.0	2	0.8026	Binaural
88	81.0	79.0	-2	0.8026	Monaural
89	74.0	74.0	0	1.000	Indifference
90	82.0	82.0	0	1.000	Indifference
91	79.0	78.0	1	1.000	Indifference
92	77.0	77.0	0	1.000	Indifference
93	77.0	81.0	4	0.8026	Binaural
94	77.0	74.0	-3	0.6455	Monaural
95	81.0	79.0	-2	0.8026	Monaural
96	77.0	76.0	-1	0.8181	Monaural

Appendix L

HIPAA Form

Research Participant Authorization to Use and Disclose Information for Research

UMCIRB#: 07-0650 **PI:** Rose Allen
Title: Binaural Interference in Normal Hearing Children

When taking part in research, health information is collected, used, and shared with others who are involved in the research. Federal laws require that researchers and health care providers protect your identifiable health information. Also, federal laws require that we get your permission to use collected health information for the research. This permission is called authorization.

In order to complete the research project in which you have decided to take part, we need to collect and use some of your health information. Specifically, this information includes:

Select the boxes that identify the types of health information:

[ ] Billing records
[ ] Mental Health records
[ ] Physician/clinic records
[X] Other: Audiological test results
[ ] Hospital/medical records (in and out patient)
[ ] Lab, pathology and/or radiology results
[ ] PHI previously collected for research purposes

The members of the research team will conduct the research study at [X] ECU [ ] PCMH [ ] ECU & PCMH [ ] Other

Select the boxes that identify who gets the information:

[X] Sponsor or other funding source to provide oversight for entire research project
[X] Research investigators to conduct and oversee the research project
[ ] Research team members to participate in the various research activities
[ ] FDA or other regulatory agencies to provide regulatory oversight
[ ] UMCIRB to provide continuing review of the research project
[ ] Institutional officials in connection with duties for monitoring investigatory activity
[ ] Researchers at other sites to participate in the research when more than one research site is involved
[ ] Other

Information about you will be used and released in such a way that will protect your identity as much as possible. The individual/agencies who may receive health information about you also agree to keep this information confidential. However, there is always a chance that you information could be shared in a way that it would no longer be protected. Therefore, although we take precautions to protect your information, confidentiality cannot be absolutely guaranteed.

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FROM 12-6-07
TO no expiration

UMCIRB Version date 08-04-03

Page 1 of 2

We are asking your permission to share your health information related to this study with the individuals/agencies listed above upon their request. You may or may not be eligible to begin participating in this study if you do not sign this Authorization form. You have the right to stop or limit the sharing your information. You have the right to limit who may receive this information. You may stop or limit how your protected health information is used for this research study by giving the investigator your request in writing. If you want us to stop using your information, you may be removed from the study. If you are removed from the study it will not affect your ability to receive standard medical care or any other benefits for which you are entitled to receive. Protected Health Information collected for the purpose of the research study collected prior to withdrawing your Authorization will continued to be used for the purposes of the research study.

We will share only the information listed above with the individuals/agencies listed above. If we need to share other information or if we need to send it to other individuals/agencies not listed above, we will ask you permission in writing again. At any time, you can ask us to tell you what information about you has been shared and with whom. However, you may not have access to your information until the study is over.

Research information continues to be looked at after the study is finished so it is difficult to say when use of your information will stop. Currently, there is not an expiration date for the use and disclosure of your information for this study.

If you have questions about the sharing of information related to this research study, call the principal investigator Robyn Drewes at phone number 919-440-4001 . Also, you may telephone the University and Medical Center Institutional Review Board at 252-744-2914. In additional, if you have concerns about confidentiality and privacy rights, you may phone the Privacy Officer at Pitt County Memorial Hospital at 252-847-6545 or at East Carolina University 252-744-2030.

Authorization

I authorize the principal investigator Robyn Drewes to share my research information with the individuals/agencies listed above. This information is to be used for research purposes. A signed copy of this Authorization will be given to you for your records.

Participant's Name (print) **Signature** **Date**

Authorized Representative Name (print)-----Relationship **Signature** **Date**

Person Obtaining Authorization **Signature** **Date**

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FROM 12-6-07
TO no expiration

Appendix M

Minor Assent and Informed Consent Forms

Minor Assent Document

Title of Research Study: Binaural Interference in Normal Hearing Children
Principal Investigator: Dr. Rose Allen; Sub-investigator: Robyn Drewes, B.S.
Telephone #: 919-440-4001

You should ask the study doctor or the study coordinator to explain any words or information that you do not understand.

What is the research study about? Most of the time we listen with both ears, this study will see how you listen to words and tones with your right ear, left ear, and both ears together.

Who will be in the research study? Children who are 7 years old -12 years old that have normal hearing can be in the study.

What will I be asked to do? You will be asked to sit quietly in a sound proof audiology booth and participate in a series of listening tests. You will be wearing a soft foam tip insert earphone in each ear. You will be asked to listen to a set of instructions for each listening test and perform the test according to the instructions (ex: repeat the word you hear or press the button when you hear a tone). You will receive breaks throughout the testing, but you may ask for additional breaks if you should need them.

Where will the research study take place? Research will be conducted in audiology lab H at the East Carolina University Health Sciences Building in Greenville, North Carolina or at Coastal, Ear, Nose, and Throat in New Bern, North Carolina.

How can I participate? You can participate by signing the minor assent form and having your parent or legal guardian sign a consent form. You must meet all the requirements set by the inclusion criteria in order to participate in this study.

What happens if I change my mind about participating?

Participating in this study is your choice. You may stop at any time during the study. No one will be upset with you if you decide not to participate.

Who can answer any questions that I might have later on?

You can talk to Robyn Drewes at 919-440-4001 if you have more questions at any time during the study. You can also call the university office at 744-2914 if you are concerned about how you have been treated in the study.

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) 12-5-08

If I put my name at the end of this form it means I agree to be in this study. I will be given a copy of this form to keep after I sign it and so will my parents.

Print your name ______________________________

Sign your name______________________________

Date ______________________________

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TO 12-5-08

CONSENT DOCUMENT

Title of Research Study: Binaural Interference in Normal Hearing Children
Principal Investigator: Dr. Rose Allen; Sub-investigator: Robyn Drewes, B.S.
Institution: East Carolina University
Address: School of Allied Health Sciences
Department of Communication Sciences and Disorders
Health Sciences Building
Greenville, NC 27858-4353 USA
Telephone #: 919-440-4001

INTRODUCTION

You are asked to participate in a research study being conducted by Robyn Drewes. This research study is an investigation of binaural interference, the phenomenon that occurs when individuals perform worse when an auditory stimulus is presented binaurally than when presented monaurally (Jerger, 1994).

PLAN AND PROCEDURES

You must meet the inclusion criteria in order to participate in the study. The following is the inclusion criteria:

1) normal hearing based on a 15 dB audiologic screening from 500 to 4000 Hz; 2) normal middle ear function; 3) no known diagnosis of central auditory processing disorder; 4) no current speech articulation or phonologic deficits; 5) no history of remedial services; 6) no known cognitive, memory, or learning deficits; and 7) English as a first language.

If you meet the inclusion criteria, you will be included as a participant in this research project. Testing will include the assessment of word recognition, masking level difference, speech-in-noise identification, and pitch pattern sequencing. To investigate the presence of binaural interference, comparisons of individual's right, left, and binaural performances will be measured for speech recognition thresholds, word recognition scores, and speech-in-noise tests. The test session should last approximately 2 hours. You will be provided with breaks throughout testing, and will be allowed to ask for a break whenever you need one.

POTENTIAL RISKS AND DISCOMFORTS

You will be required to wear insert earphones. These consist of soft foam tips that are inserted into the ear canals. Slight discomfort may exist, however not pain, for the amount of time that testing is taking place. You may become claustrophobic due to sitting in a small space. If this should happen, you may take a break or discontinue their

____
Participant's initials

participation in the study without penalty. There are no economical, social, or legal risks to the participants for this research project.

POTENTIAL BENEFITS

This research study allows the participants to receive a hearing test, central auditory processing assessment, and will be testing for binaural interference. This research project also investigates the phenomenon of binaural interference, a phenomenon that some people process sounds better monaurally than binaurally. The importance of research in binaural interference is that it can contribute to the fitting of children with hearing aids. If an individual has binaural interference, monaural amplification may provide more benefit than binaural amplification. This applies to FM systems as well. If children possess binaural interference, having the teacher's voice presented monaurally rather than binaurally may provide maximum benefit. A second approach to binaural hearing aid fittings, in the presence of binaural interference, is to provide extensive counseling while the user is adapting to the hearing aids. Speech discrimination testing at periodic intervals may reveal improved speech recognition performance as adaptation occurs (Silman, 1984). The data collected for this research study will be used to develop normative data for tonal and speech masking level difference in children.

SUBJECT PRIVACY AND CONFIDENTIALITY OF RECORDS

All participants will be assigned a number and all data entered is by the participant's number. All data will be locked in a file cabinet for three years at Dr. Rose Allen's office in the East Carolina University Health Sciences Building. No other individual except the primary and sub-investigator will have access to stored data. All data will be shredded and destroyed following three years after manuscript is in print. To further protect our participant's identity, only one location will display the participant's name, all other data will display their corresponding number.

COSTS OF PARTICIPATION

The cost to participate is the participant's time and travel expense.

VOLUNTARY PARTICIPATION

Participating in this study is voluntary. If you decide not to be in this study after it has already started, you may stop at any time without losing benefits that you should normally receive. You may stop at any time you choose without penalty.

APPROVED
FROM 7-1-08
TO 12-5-08

____
Participant's initials

PERSONS TO CONTACT WITH QUESTIONS

The investigators will be available to answer any questions concerning this research, now or in the future. You may contact the investigators, Robn Drewes or Dr. Rose Allen at phone numbers 919-440-4001 or 252-744-6083 (days). If you have questions about your rights as a research subject, you may call the Chair of the University and Medical Center Institutional Review Board at phone number 252-744-2914 (days), and/or the ECU Risk Management Office at 252-328-6858.

CONSENT TO PARTICIPATE

Title of research study: Binaural Interference in Normal Hearing Children

I have read all of the above information, asked questions and have received satisfactory answers in areas I did not understand. (A copy of this signed and dated consent form will be given to the person signing this form as the participant or as the participant authorized representative.)

Participant's Name (PRINT)	Signature	Date	Time

If applicable:

Guardian's Name (PRINT)	Signature	Date	Time

PERSON ADMINISTERING CONSENT: I have conducted the consent process and orally reviewed the contents of the consent document. I believe the participant understands the research.

Person Obtaining consent (PRINT)	Signature	Date

Principal Investigator's (PRINT)	Signature	Date

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TO 12-5-08

Version date:

Participant's initials

Appendix N

Internal Review Board Approval Forms

University and Medical Center Institutional Review Board
East Carolina University
Ed Warren Life Sciences Building • 600 Moye Boulevard • LSB 104 • Greenville, NC 27834
Office **252-744-2914** • Fax **252-744-2284** • **www.ecu.edu/irb**
Chair and Director of Biomedical IRB: L. Wiley Nifong, MD
Chair and Director of Behavioral and Social Science IRB: Susan L. McCammon, PhD

TO: Rose Allen, PhD, Dept. of CSDI, SAHS, ECU

FROM: UMCIRB

DATE: December 7, 2007

RE: Expedited Category Research Study

TITLE: "Binaural Interference in Normal Hearing Children"

UMCIRB #07-0650

This research study has undergone review and approval using expedited review on 12/6/07. This research study is eligible for review under an expedited category because it is a collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual. Dr. S. McCammon deemed this **ECU, Dept. of CSDI** sponsored study **no more than minimal risk** requiring a continuing review in **12 months**. Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The investigator must adhere to all reporting requirements for this study.

The above referenced research study has been given approval for the period of **12/6/07** to **12/5/08**. The approval includes the following items:

- Internal Processing Form
- Informed consent (Parental Permission)
- Minor Assent
- Letter of Support (Coastal Ear, Nose and Throat)
- Advertisement
- COI Disclosure Form (dated 9/28/07)
- Payment Protocol
- Equipment List

Dr. S. McCammon does not have a potential for conflict of interest on this study.

The UMCIRB applies 45 CFR 46, Subparts A-D, to all research reviewed by the UMCIRB regardless of the funding source. 21 CFR 50 and 21 CFR 56 are applied to all research studies under the Food and Drug Administration regulation. The UMCIRB follows applicable International Conference on Harmonisation Good Clinical Practice guidelines.

RECEIVED
DEC 3 1 2007
UMCIRB

UMCIRB #:

UNIVERSITY AND MEDICAL CENTER INSTITUTIONAL REVIEW BOARD
REVISION FORM

UMCIRB #: 07-0650 **Date this form was completed:** 12/18/07
Title of research: Binaural Interference in Normal Hearing Children
Principal Investigator: Dr. Rose Allen; Sub-investigator: Robyn Drewes
Sponsor: Dr. Rose Allen

Version of the most currently approved protocol: 12/06/07
Version of the most currently approved consent document: 12/06/07

CHECK ALL INSTITUTIONS OR SITES WHERE THIS RESEARCH STUDY WILL BE CONDUCTED:
☒ **East Carolina University**
☐ **Pitt County Memorial Hospital, Inc**
☐ **Heritage Hospital**
☒ **Other** Coastal Ear, Nose, and Throat; New Bern, NC 28562
☐ **Beaufort County Hospital**
☐ **Carteret General Hospital**
☐ **Boice-Willis Clinic**

The following items are being submitted for review and approval:
☒ **Protocol: version or date** 12/06/07
☐ **Consent: version or date**
☐ **Additional material: version or date**

Complete the following:
1. **Level of IRB review required by sponsor:** ☐ **full** ☒ **expedited**
2. **Revision effects on risk analysis:** ☐ **increased** ☒ **no change** ☐ **decreased**
3. **Provide an explanation if there has been a greater than 60 day delay in the submission of this revision to the UMCIRB.**
4. **Does this revision add any procedures, tests or medications?** ☒ **yes** ☐ **no If yes, describe the additional information:** During the pitch pattern sequencing test, subjects were originally expected to complete a motor response by humming whether the tone was "high" or "low" in pitch. The revision will require the subject to point to the word "high" or "low" on a piece of paper as their response. Pointing to the word will replace the humming task. These stimuli will be presented to the right ear only versus binaural presentation.
5. **Have participants been locally enrolled in this research study?** ☐ **yes** ☒ **no**
6. **Will the revision require previously enrolled participants to sign a new consent document?** ☐ **yes** ☒ **no**

Briefly describe and provide a rationale for this revision Research has suggested that the hummed motor response for the pitch pattern task is highly likely to produce ceiling effects. The pointing motor task is considered to be a more difficult response mode. In an attempt to minimize ceiling effects, the protocol would be changed to a pointing task rather than a humming task. The appropriate normative data for this task are based on right ear presentation; therefore a change from a binaural presentation to a right ear presentation is necessary.

Rose L. Allen 12/21/07
Principal Investigator Signature **Print** **Date**

Box for Office Use Only

The above revision has been reviewed by:
☐ Full committee review on ______ ☑ Expedited review on 1-7-08

The following action has been taken:
☑ Approval for period of 1-7-08 to 12-5-08
☑ Approval by expedited review according to category 4
☐ See separate correspondence for further required action.

Susan McCammon 1-7-08
Signature **Print** **Date**

UMCIRB #:

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UNIVERSITY AND MEDICAL CENTER INSTITUTIONAL REVIEW BOARD
REVISION FORM

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UMCIRB #: 07-0650 **Date this form was completed:** 1/16/07

Title of research: Binaural Interference in Normal Hearing Children

Principal investigator: Dr. Rose Allen, sub-investigator: Robyn Drewes

LW **Sponsor:** ~~Dr. Rose Allen~~ Dept. of CSDI, ECU

Version of the most currently approved protocol: 12-06-07 ~ 12-05-08

Version of the most currently approved consent document: 12-06-07 ~ 12-05-08

CHECK ALL INSTITUTIONS OR SITES WHERE THIS RESEARCH STUDY WILL BE CONDUCTED:

☒ East Carolina University
☐ Pitt County Memorial Hospital, Inc
☐ Heritage Hospital
☐ Beaufort County Hospital
☐ Carteret General Hospital
☐ Boice-Willis Clinic
☒ Other: Coastal Ear, Nose, and Throat. New Bern, NC 28562

The following items are being submitted for review and approval:

☒ **Protocol: version or date: Newspaper advertisement and methods or recruitment**
☐ **Consent: version or date**
☐ **Additional material: version or date**

Complete the following:

1. **Level of IRB review required by sponsor:** ☐ full ☒ expedited
2. **Revision effects on risk analysis:** ☐ increased ☒ no change ☐ decreased
3. **Provide an explanation if there has been a greater than 60 day delay in the submission of this revision to the UMCIRB. N/A**
4. **Does this revision add any procedures, tests or medications?** ☐ yes ☒ no **If yes, describe the additional information:**
5. **Have participants been locally enrolled in this research study?** ☒ yes ☐ no
6. **Will the revision require previously enrolled participants to sign a new consent document?** ☐ yes ☒ no

Briefly describe and provide a rationale for this revision.

Recruitment of subjects would like to be extended to the following places: Ad in the local newspapers and posting of a research flyer (flyer has already been approved in the 12/-6-07 IRB approval) at local churches, and afterschool programs (ex: Boys and Girls Clubs, Girl Scouts of America, Young Men Christian Association (YMCA)). Recruitment from these sources will allow for a diverse subject pool.

Rose L. Allen (signature) Rose L. Allen 1/16/08
Principal Investigator Signature **Print** **Date**

Box for Office Use Only

The above revision has been reviewed by: ☐ Full committee review on ________ ☑ Expedited review on 1-25-08 The following action has been taken: ☑ Approval for period of 1-25-08 to 12-5-08 ☑ Approval by expedited review according to category 4 ☐ See separate correspondence for further required action. Susan McCammon (signature) Susan McCammon 1-25-08 Signature Print Date

UMCIRB Version 5/31/07 Page 1 of 1

UMCIRB #:

UNIVERSITY AND MEDICAL CENTER INSTITUTIONAL REVIEW BOARD
REVISION FORM

RECEIVED
JUN 24 2008
UMCIRB

UMCIRB #: 07-0650 **Date this form was completed:** 6-20-08
Title of research: Binaural Interference in Normal Hearing Children
Principal Investigator: Dr. Rose Allen, sub-investigator: Robyn Drewes
Sponsor: Dept. of CSDI, ECU

Fund number for IRB fee collection (applies to all for-profit, private industry or pharmaceutical company sponsored project revisions requiring review by the convened UMCIRB committee):

Fund	Organization	Account	Program	Activity (optional)
		73059		

Version of the most currently approved protocol: 12-06-07 - 12-05- 08
Version of the most currently approved consent document: 12-06-07- 12-05-08

CHECK ALL INSTITUTIONS OR SITES WHERE THIS RESEARCH STUDY WILL BE CONDUCTED:

- ☒ **East Carolina University**
- ☐ **Pitt County Memorial Hospital, Inc**
- ☐ **Heritage Hospital**
- ☒ **Other**: Coastal Ear, Nose, and Throat, New Bern, NC 28562
- ☐ **Beaufort County Hospital**
- ☐ **Carteret General Hospital**
- ☐ **Boice-Willis Clinic**

The following items are being submitted for review and approval:

- ☒ **Protocol: version or date:** 1-16-07 (The addition of an adult group consisting of 16 adults ages 18-30.)
- ☒ **Consent: version or date:** ~~12-06-07~~
- ☐ **Additional material: version or date**

Complete the following:

1. **Level of IRB review required by sponsor:** ☐ full ☒ expedited
2. **Revision effects on risk analysis:** ☐ increased ☒ no change ☐ decreased
3. **Provide an explanation if there has been a greater than 60 day delay in the submission of this revision to the UMCIRB.** After reviewing the completed data, it was recommended to compare the normative data of these children to an adult population. This recommended was made after all child data was completed, which took approx. 5 months.
4. **Does this revision add any procedures, tests or medications?** ☐ yes ☒ no **If yes, describe the additional information:**
5. **Have participants been locally enrolled in this research study?** ☐ yes ☒ no
6. **Will the revision require previously enrolled participants to sign a new consent document?** ☐ yes ☒ no

Briefly describe and provide a rationale for this revision. I would like to determine at what age a child performs at an adult level on the listening tasks I have collected on children between the ages of 7-12. By adding the additional group of adults, I will be able to determine at what age children performed equally to the adult population.

Rose L. Allen 6/20/08

Principal Investigator Signature **Print** **Date**

Box for Office Use Only

The above revision has been reviewed by:
☐ Full committee review on ________ ☑ Expedited review on 7-1-08

The following action has been taken:
☑ Approval for period of 7-1-08 to 12-5-08
☑ Approval by expedited review according to category 4
☐ See separate correspondence for further required action.

Susan McCammon Susan McCammon 7-1-08

Signature **Print** **Date**