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The measurement of auditory interhemispheric transfer time (IHTT) in children with normal auditory processing abilities

Brittany Suzanne Keahey
Louisiana Tech University

THE MEASUREMENT OF AUDITORY INTERHEMISPHERIC TRANSFER TIME (IHTT) IN CHILDREN WITH NORMAL AUDITORY PROCESSING ABILITIES

by

Brittany Suzanne Keahey, B.A.

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Supervisor of Dissertation Research

Head of Department

Speech

Department

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Abstract

Interhemispheric transfer time (IHTT) is the time it takes for information to be transmitted from one hemisphere to the other. The goal of this study was to determine if differences existed in the IHTT of children 6 to 9 years of age with normal auditory processing abilities by the use of an objective measure (auditory late evoked potentials [ALEPs]), specifically waves P1, N1 and P2. It was hypothesized that there would be no difference in IHTT between the groups due to the age range of participants being tested. The 16 participants were divided into two groups based on age and a 2000 Hz tone burst was presented to the test ear for the quiet condition while competing speech babble was presented to the non-test ear for the noise condition. When observing latency in the noise condition, the left ear shifted to a greater extent than the right ear in both groups; however, the younger group revealed longer latency for P1, N1 and P2. Although IHTT was longer in noise than in quiet, both groups reacted similarly due to the similarity in age of participants tested.

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CHAPTER I

Introduction

As words are spoken, music is played, or alerts are sounded, airborne signals propagate through space to the ear and travel up the complex auditory pathway to signal the brain that something was heard. The anatomical organization of the peripheral auditory system up to the primary auditory areas (i.e., Heschl's gyri) although complex, is well known; however, the complex physiological connection between the auditory cortices and these structures are not. The largest neural pathway, the corpus callosum, connects the two cerebral hemispheres, and consists of 200 to 800 million axons allowing the two hemispheres to communicate with one another (Damasio & Damasio, 1978). According to Yakovlev and Lecors (1967), the corpus callosum reaches adult-like maturation at approximately 11 or 12 years of age.

Behavioral dichotic listening tasks (i.e., different auditory stimuli presented to each ear simultaneously) have been used to measure the maturation of the corpus callosum and the right ear advantage for many years. Kimura and her colleagues (1961, 1964, & 1967) concluded that the right ear remained dominant for speech regardless of the site-of-lesion or handedness for the left hemisphere dominant language individuals and the right hemisphere dominant individuals reveal left ear dominance for speech. Kimura and her colleagues (1961, 1964, & 1967) also concluded that melodic patterns would reveal left ear dominance for those individuals whom are left hemisphere dominant for language.

Advances in neuroimaging have progressed to the point where dichotic listening has also been used in conjunction with magnetoencephalogaphy (MEG) to observe cortical difference when presented dichotic stimuli. Penna et al (2006) revealed that the left ipsilateral pathway is significantly inhibited by the right contralateral pathway; however, the right ipsilateral pathway is not suppressed. The authors concluded that the larger the competition between the right and left ear stimuli, the larger the inhibition of the pathways, resulting in cortical asymmetry.

Other studies (e.g., Barry & Sammeth, 1994; Jirsa & Clontz, 1990) have been conducted using electrophysiological measures, such as auditory late evoked potentials (ALEPs), along with dichotic testing to display hemispheric dominance. Barry and Sammeth (1994) concluded that left hemisphere dominance for language, for right-handed people presented with speech stimuli, is not only observed during behavioral testing, but can also be measured with electrophysiological testing.

One possible mechanism used in other fields (i.e., visual) to measure maturation is interhemispheric transfer time (IHTT). Researchers (e.g., Bellis & Wilber, 2001; Brizzolara et al., 1994; Hagelthorn et al., 2000; Iacoboni & Zaidel, 2004; Merola & Liederman, 1985) have investigated IHTT within the visual field and they discovered that younger children were less likely to display hemispheric independence and one hemisphere may influence the activity of the other. These authors also found that younger children would always display an increased IHTT (i.e., slower) compared to older children.

One area lacking is the measurement of IHTT in the auditory domain to further measure the maturation of the corpus callosum (CC). A study conducted by Cranford and Martin (1991) revealed that the recorded ALEP in the presence of competing speech babble is affected by age-related alteration in binaural processing; however, the P300 did not reflect age-related binaural competition effects. Krumm and Cranford (1994), on the other hand, revealed that competing speech babble did not affect ALEP latencies; however, amplitude was affected. Although Krumm and Cranford (1994) were not measuring IHTT, a difference in IHTT was later calculated and a significant difference was observed. Further investigation is needed to determine whether a difference in IHTT between age groups can be replicated. This normative data could then be used to compare to results obtain from children with (central) auditory processing disorders (C) APD to assist in the diagnosis. It is hypothesized that there will be no difference in IHTT between the young group and old group due to the specific age range of participants tested and age of corpus callosum maturation.

CHAPTER II

Review of Literature

Neuroanatomy

We perceive environmental noises binaurally, each ear projecting information to the right and left auditory cortices in the brain. The process begins with the peripheral auditory mechanisms (i.e., outer, middle, and inner ear). For the purpose of this discussion, the focus begins at the point where chemical energy within the auditory hair cells of the cochlea is transformed into electrical energy via neural synapses with the auditory nerve. Electrical impulses are sent via the auditory nerve to the ipsilateral cochlear nucleus (CN) located at the postero-lateral aspect of the ponto-medullary junction within the brainstem. The CN includes three subdivisions: the anterior ventral CN, the posterior ventral CN, and the dorsal CN. The CN also contains many different cell types, such as octopus, pyramidal, stellate, globular, and bushy cells each having a specific firing pattern. The firing patterns provide the temporal processing information necessary for the transferring of auditory information. The primary output from the CN is to the contralateral connections within three fiber bundles (i.e., dorsal, intermediate, and ventral acoustic stria).

The acoustic stria transfer the electrical impulses primarily to the contralateral superior olivary complex (SOC), which is located in the caudal pons of the brainstem. The SOC contains three main nuclei: the lateral superior olive (LSO), medial superior olive (MSO), and the medial nucleus of the trapezoid body (MNTB). The SOC also contains cells, such as stellate, fusiform, and bipolar cells, which produce unique firing patterns important for coding auditory stimuli. The SOC is the first area in the auditory system that provides binaural representation of auditory stimuli and plays an important role in integrating information from both ears for the purposes of sound localization. Neural fibers then exit from the SOC via the lateral lemniscus (LL).

The LL is a fiber pathway located in the pons that courses to the inferior colliculus (IC) located in the midbrain. The LL includes two major nuclei: the dorsal (DNLL) and ventral (VNLL). The commissure of Probst is the route of fibers connecting one DNLL to the DNLL on the opposite side. The commissure of the IC provides the connection between both ICs. The IC is the largest structure in the auditory pathway and receives information from all other auditory structures. The IC contains monaurally and binaurally sensitive cells and includes three subdivisions: the central, dorsal cortex, and peri-central nucleus. Neural impulses are then transferred via the brachium of the IC to the medial geniculate body (MGB) located at the posterior thalamus.

The MGB is divided into three sections (i.e., the ventral, dorsal, and medial nuclei) of which most auditory fibers are located within the ventral nucleus. Neural impulses are then transmitted via the internal capsule to the primary auditory cortex (i.e., Heschl's gyri) located in each temporal lobe. The contralateral pathway (i.e., sound heard in one ear is directed to the opposite hemisphere) is the strongest and quickest pathway for sound (Hall & Goldstein, 1968; Kimura, 1961, 1964 & 1967). In the majority of humans, the left hemisphere of the brain contains the expressive (i.e., Broca's area within the frontal lobe) and receptive (i.e., Wernike's area within the temporal lobe) language centers. Therefore, the right ear anatomically has an advantage for linguistic stimuli due the contralateral pathway transmitting auditory stimulation directly to the language centers within the left hemisphere. The left ear is at an anatomical disadvantage due to the increased time it takes to transfer information from the left ear, contralaterally to the right hemisphere, and then to the language centers within the left hemisphere via the corpus callosum (CC) (Berlin & McNeil, 1976). This contralateral pathway creates the right ear advantage and contralateral ear effect (Kimura, 1961, 1964 & 1967).

The corpus callosum (CC) is a network of 200 to 800 million highly myelinated fibers, which allows the two cerebral hemispheres to communicate. The CC is also composed of the splenium which is located in the posterior region and connects the occipital lobes; anterior to the splenium is the isthmus which connects the temporal lobes and is the most highly myelinated portion; the body is located anterior to the isthmus and connects the parietal lobes; and the genu curves downward toward the rostrum and connects the frontal lobes (Aboitiz, Ide, & Oivares, 2002). The most important physiologic measure of the CC is IHTT (i.e., measurement made to determine the latency of impulses going from one side of the cortex to the other) (Musiek & Chermak, 1997). Smaller nerve fibers yield an IHTT of around 19 to 25 ms, whereas, larger nerve fibers yield an IHTT of around 3 ms. The change in IHTT is due to the amount of myelination on the CC (Musiek & Chermak, 1997). Due to the fact that very old and very young individuals have decreased amounts of myelin, increased IHTTs are recorded (Musiek & Baran, 2007). The maturation of the CC has a great effect on whether auditory information is accurately transmitted, therefore, many children under the age of 11 to 12 years (i.e., point of CC maturation) have displayed a right ear advantage due to an immature auditory system (Musiek & Baran, 2007). Many researchers have investigated the maturational process of the CC and the right ear advantage, and one way that has been used to study this topic has been through the use of dichotic listening tests.

Behavioral Dichotic Listening

Dichotic listening tests are some of the most powerful behavioral tests used to assess hemispheric function, maturation of the auditory nervous system, interhemispheric transfer of information, identification of lesions within the CANS, and evaluation of (C) APD (Musiek & Chermak, 2007). During dichotic listening tests, different acoustic stimuli including consonant-vowel nonsense syllables, digits, words, spondees, or sentences are presented to each ear simultaneously (Musiek & Chermak, 2007).

The earliest experimentation with dichotic listening tests was conducted on individuals with brain lesions. In a study by Kimura (1961), it was concluded that no matter the site of the brain lesion (i.e., epileptogenic foci in various areas of the brain), stimuli presented to the ear contralateral the dominant hemisphere for language were more efficiently recognized than stimuli presented to the ipsilateral ear. These results were in agreement with previous electrophysiological evidence from animal studies that also suggested that the crossed auditory pathway was stronger than the uncrossed auditory pathway (Rosenzweig, 1951; Tunturi, 1946). Kimura theorized that individuals with speech represented in the right hemisphere would recognize verbal material arriving at the left ear more efficiently on dichotic listening tests. To test this hypothesis, 120 participants with various brain lesions were selected for this study. Out of these participants, 107 were speech dominant in the left hemisphere and were mostly right-handed; 13 were speech dominant in the right hemisphere and mostly left-handed; and 13 were right-handed subjects without brain lesions for the control group. Hemispheric dominance was determined by injecting sodium amytal into the internal carotid artery, temporarily inhibiting the function of one hemisphere. Dichotic digits were presented through headphones in 32 groups of six so that three digits were presented to the right ear and three were presented to the left ear for each presentation. The subjects were asked to repeat all the digits they heard. Kimura (1961) concluded that the right ear remained dominant regardless of the site-of-lesion or handedness for the left hemisphere dominant language group and control subjects, and the right hemisphere dominant group revealed left ear dominance. These results were in agreement with previous studies in that the contralateral pathway was stronger than the ipsilateral pathway, and the dominant temporal lobe was more significant than the non-dominant temporal lobe for speech perception.

Until 1962, researchers were primarily concerned with using verbal stimuli (e.g., words and digits) to investigate the asymmetry of the cerebral hemispheres; however, Kimura (1964) theorized that ear superiority for melodic patterns could also be elicited, and superiority would be in the direction opposite that of spoken digits. To test this theory, two different, unfamiliar melodies were presented dichotically to 20 normal adults and these two melodies were selected from a group of four. These results were compared to a dichotic digits test. Correct responses were made for the left ear during tonal testing; however, correct responses were made for the right ear for digits testing. Therefore, when observing left hemisphere dominance for speech, melodic patterns will reveal left ear superiority while spoken words will reveal right ear superiority.

Kimura (1967) further reviewed the asymmetrical functioning of the two hemispheres of the brain and lateral asymmetry in auditory perception. She thought it necessary to investigate different characteristics of words and digits to account for the left hemispheric representation using nonsense syllables. Nonsense syllables were presented to 20 normal adults in the same way words were previously presented (i.e., dichotic presentation of a series of syllables with a report from a specified ear). The right ear was still reported much more accurately than the left ear. Kimura and her colleagues (1967) completed a second study using a multiple-choice recognition in which three syllables were quickly presented to make a nonsense syllable. Two of the sounds were presented dichotically to be chosen from four other sounds. Although subjects did not have to verbally report any of the sounds, more sounds were again correctly identified in the right ear. It was discovered that the processing of spoken nonsense words is also carried out in the left hemisphere, further proving left hemisphere dominance for speech and language.

To further research on cortical dominance, Moulden and Persinger (2000) investigated the significance of age and sex differences when administering a dichotic word listening task. These researchers selected 200, right-handed subjects between the ages of 6 to 15 years (i.e., 91 males and 109 females). Subjects were placed in one of five age groups (i.e, 6 to 7 years, 8 to 9 years, 10 to 11 years, 12 to 13 years, and 14 to 15 years). The subjects had no learning difficulties and were native English speaking. The Dichotic Word Listening test was individually administered and 60 trials were presented. The total number of correct responses for the right ear only, left ear only, and both ears was calculated. After the Dichotic Word Listening test was completed, the subjects were asked to say as many words as they could that started with the letters P, S, and C, excluding proper nouns. The subjects were then asked to name as many animals they could within a minute. The authors found that the girls were consistently more accurate than the boys. This result was seen throughout dichotic listening, animal naming, and verbal fluency testing. Moulden and Persinger (2000) discovered an increase in correct responses and a decrease in the right ear advantage as age increased, especially between the 8 to 9 year old group and 10 to 11 year old group. This age influence on amount of correct responses for dichotic listening tests was in agreement with previous literature (e.g., Kimura, 1961, 1964 & 1967) discussing the maturation process of the cerebral cortex and left hemisphere dominance for language.

Imaging

Research has also been conducted using neuroimaging to visually observe cortical responses to auditory stimuli. One study by Penna et al. (2006) discussed cortical function measured by magnetoencephalography (MEG) using consonant-vowel (CV) dichotic listening tests. These researchers hypothesized that sounds with higher intensities would cause a stronger response from the cortices. To test this hypothesis, the experiment was designed where one stimulus of the dichotic pair was held at a constant (i.e. 60 dB HL) intensity while the other stimulus was presented separately at two different intensities (i.e. 60 and 80 dB HL). It was assumed that this would inhibit the ipsilateral pathway and reveal asymmetries between the cortices. There were 10 right-handed subjects selected for this experiment between the ages of 20 to 31 years. These subjects had no significant medical problems and no history of otologic dysfunction according to patient report. Behavioral testing was administered which consisted of 60 CV dichotic listening items (i.e., /ba/, /ka/, /ga/, /da/, /ta/ and /pa/) generated by a computer. This test was used to determine which CV stimuli they heard the best by comparing the left and right ear correct responses. The CV dichotic listening test was then administered while recording via MEG and adjusting stimuli intensity between 60 and 80 dBA. A total of five CV syllables were utilized to make up the 80 presentations. The recordings were made by a 165 channel MEG system that covered the whole head. The behavioral test results revealed a right ear advantage. The results obtained from the MEG recordings with the different intensity levels revealed that the left ipsilateral pathway was significantly inhibited by the right contralateral, but the right ipsilateral pathway was not suppressed. The authors concluded that the larger the competition between the right and left ear stimuli, the larger the inhibition of the pathways, resulting in cortical asymmetry.

Electrophysiological Measurements

Although behavioral tests have been utilized mostly in the diagnosis of (C) APD and in testing cortical asymmetry, interest is now being focused on the use of electrophysiologic measures to objectively report cortical differences and begin to diagnose (C) APD (Jirsa & Clontz, 1990). Objective assessment of (C) APD has been accomplished using auditory brainstem response, although this only evaluates the VIIIth nerve to the lower brainstem (Weihing & Musiek, 2008). One of the earliest recordings of auditory evoked potentials (AEP) dates back to 1913, and was performed by a Russian scientist named Vladimirovich Pravdich-Neminsky. Later, in 1970, Don Jewett discovered auditory brainstem evoked responses (ABR), which, by the help of current computer technology, are used in our clinics today to test hearing sensitivity and perform other measures. These electrophysiological measures are recorded using electrodes placed at specific areas on the face, ears, and scalp. The placement of electrodes requires some preparation and cleaning to decrease impedance. As sound comes through the transducers (i.e., earphones, inserts) into the patient's ear, waveforms appear on the screen as many quick measurements are made. These waveforms include: ABR (1 to 20 ms post-stimulus), middle latency auditory evoked potentials (MLAEP) (18 to 80 ms post-stimulus), late auditory evoked potentials (LAEP) (50 to 250 ms post-stimulus), and the auditory event-related endogenous potential (ERP) or P300 (220 to 380 ms post-stimulus) (McPherson & Ballachanda, 2000). The LAEP is thought to encompass the exogenous component, reception and transmission of information at the level of the cortex, and the endogenous component, having to do with selective attention to the stimulus (Cranford & Martin, 1991). While positive results have been obtained using middle latency responses (MLR), it is not easy to observe, especially in children younger than 10 years of age. The MLR can also be affected by unwanted myogenic noise (Jerger & Jerger, 1985). The LAEP and ERP have also been shown to be sensitive to (C) APD, although the responses are highly variable and the patient must be awake and attentive to the auditory stimuli (Jirsa & Clontz, 1990).

Electrophysiological tests have been utilized along with dichotic listening tests to display hemispheric dominance. As noted previously, the left hemisphere is dominant for language in most right-handed individuals. Barry and Sammeth (1994) developed a procedure that would further investigate these results by recording behavioral information along with electrophysiological data using dichotically presented consonant-vowel (CV) stimuli. There were 16 right-handed females selected for this study that ranged from 23 to 38 years of age and had no history of otologic issues, and were all monolingual

English speakers. The CV dichotic listening test was administered at 85 dB SPL simultaneously with Auditory Event-Related Potentials (AEP) recordings. Electrodes were placed at T3 and T4 with filter settings of 1 to 100 Hz and sweep duration of 500 ms. The subjects were asked to identify the stimuli that they heard. The behavioral results revealed a right ear advantage and the AEP recordings revealed an increase in amplitude and decrease in latency for N1 and P1 components of the LAEP over the left hemisphere. The P3 component of the ERP also revealed a decrease in latency over the left hemisphere. These authors concluded that left hemisphere dominance for language, for right-handed people presented with speech stimuli, is not only observed during behavioral testing, but can also be measured with electrophysiological testing.

IHTT in the Visual Domain

With the successful measurement of IHTT in the visual domain, it holds potential for this measure in the auditory domain. A study by Merola and Liederman (1985) examined the visual domain and interhemispheric interaction with a pubescent population. Within this study, 120 children were selected and placed in one of three age groups (i.e., 10 years, 12 years, or 14 years). Half of the children selected were from a high achieving academic group and the other half were from a low achieving academic group (Otis-Lennon School Ability Test, 1971). Children with a history of emotional or learning disabilities were not chosen for this study. Subjects first underwent a series of tasks prior to the visual testing (i.e., handedness assessment, somatic growth assessment, and maturation measurements). The research design involved two types of stimuli that required different types of processing, such as identification of letters rotated upside-down (inverted) and the identification of upright letters (non-inverted). These letters included: B, C, D, F, G, J, K, L, Q, R, T, and V. Each of the eight trials involved a presentation of two inverted letters and two non-inverted letters printed on cards. A random digit from 1 to 4 was also printed at the fixation point of each display. There were also four visual field conditions: all four letters presented unilaterally to the right visual field, all letters presented unilaterally to the left visual field, letters presented bilaterally in the horizontal plan, and letters presented bilaterally in the diagonal plane. Letters and a random center number were displayed on cards via a tachitoscope (i.e., an instrument that measures time), and the subjects were asked to name the center number and as many letters as possible. Subjects were presented with 20 cards until consecutively naming 10 center numbers correctly. The researchers concluded that the older group of children benefited from the bilateral presentation of the conflicting stimuli versus the unilateral presentation; whereas, the younger group did not show benefit from a bilateral presentation. This interhemispheric separation of the conflicting task with the older group was predicted due to the hemispheric independence that occurred with age. Therefore, these authors proposed that the younger children were less likely to display hemispheric independence, and one hemisphere may influence the activity of the other. The authors also gave support to the process of cortical maturation.

Brizzolara, Feretti, Brovedani, Casalini, and Sbrana (1994) researched the IHTT in the visuo-motor domain of children 7 to 11 years of age. These researchers wanted to determine if the crossed-uncrossed difference (CUD) was larger in children than in adults indicating an underdeveloped corpus callosum. They also wanted to determine if the CUD continuously decreased with age indicating corpus callosum maturation. There were 171 right-handed children selected for this study. The children were placed in one of three age groups (i.e., 7 years, 9 years, and 11 years). These subjects had no history of emotional, neurological, or learning deficits. This experimental procedure consisted of a visuo-motor reaction time (RT) task, which required the subjects to be seated 57 cm away from the central fixation point. The subjects were asked to press a button on the specified hand each time they saw the stimulus on either side (i.e., see stimuli on right side, press the right button). Four different conditions were measured, which included right hemisphere-right visual field (RH-RVF), left hemisphere-left visual field (LH-LVF), uncrossed response (i.e., stimulus presented and hand response on the same side), and crossed response (i.e., stimulus presented and hand response on opposite side). The RTs between 130 to 1000 ms were the only ones accepted and a total of 80 stimuli were presented. Eye fixation was monitored via a closed circuit TV system to allow rejection of non-fixated responses. A definite decrease in CUD from the 7-year-old group (21.5 ms) to the 11-year-old group (6.6 ms) was noted, indicating a decrease of IHTT (i.e., quicker) with age.

The speed of visual sensory information between both hemispheres can also be measured using visual evoked potentials. Research has shown that visual evoked potentials include the positive waveform (P1 at 100 ms) and the negative waveform (N1 at 150 ms). Single visual field recordings (i.e., recordings observed from one eye) over the ipsilateral hemisphere have shown an increase in latency of 10 to 15 ms, and also a decrease in amplitude of the P1 and N1 waveforms compared to recordings over the contralateral hemisphere. This has been found to be an example of IHTT measurement. Hagelthorn, Brown, Amano, and Asarnow (2000) wanted to determine whether recording evoked potentials in the bilateral visual field would have an effect on IHTT. These researchers expected that EP-IHTT (i.e., evoked potential interhemispheric transfer time) would become faster and that cross-callosal (i.e., ipsilateral to the visual field of stimulation) EP amplitude differences would decrease with child development, which would suggest a more efficient callosal transfer. These researchers also expected to find that the BFA (i.e., bilateral field advantage) measured by RT and error rate would progressively increase with age resulting from more rapid and accurate bilateral comparison of visual stimuli. There were 43 children placed in one of three age groups (i.e., 7 to 9 years, 10 to 12 years, and 13 to 17 years). These participants were asked to press buttons on a keyboard when they decided if the symbols presented on the computer screen were a match (M) or non-match (N). They were asked to press M with the middle finger and N with the index finger for the right hand and to press M with the index and N with the middle for the left hand. These symbols were presented unilaterally (i.e., both in same visual field) and bilaterally (i.e., one letter in each visual field). Error rate and RT was calculated throughout the task. While the participants performed this task, visual evoked potentials were also recorded using electrodes. The P1 and N1 latencies and IHTT were recorded separately. These researchers observed significant age-related changes in the BFA and IHTT. BFA RT increased and IHTT decreased considerably with the older groups. Visual evoked potentials showed no major differences for the P1 and N1 waveforms between the three age groups, although the N1 latency did decrease as age increased. As previously stated, the increased callosal myelination, occurring around 12 years of age, assists with this quicker transfer of information between the cortices.

Bellis and Wilber (2001), focused on effects of age and gender on interhemispheric function. At the time of this study, no study had been attempted to relate temporal measures to other behavioral measures of interhemispheric function within the same individuals to determine the relationship between function and more complex interhemispheric tasks. Bellis and Wilber (2001) also stated that the issue of handedness was not reported. Due to the lack of literature, the first purpose of this study was to determine whether aging and gender affected interhemispheric function. The second purpose was to identify if age and gender related changes occur across the adult life span. Participants for this study consisted of 15 men and 15 women in four distinct age groups (i.e., 20 to 25 years, 35 to 40 years, 55 to 60 years, and 70 to 75 years). These participants exhibited no history of otologic or neurologic trauma, were free from peripheral visual field deficits, consistently right-handed, normal hearing, normal receptive vocabulary, normal visual motor processing speed, and normal cognition. These participants ranged in education levels from 10 years of school up to more than 20 years of school. The experimental tasks consisted of two auditory behavioral measures: Dichotic Listening and Linguistic Labeling of Nonverbal Auditory Stimuli and one visuo-motor temporal measure (i.e., visuo-motor Interhemispheric Transfer Time). The Dichotic Digits paradigm was scored by subtracting the left ear percent correct from the right ear percent correct, giving the researchers an index of interhemispheric integrity. The Pitch Patterns Sequence test was scored by subtracting the percent correct in the labeling condition from the percent correct in the humming condition, which also gave the researchers an index of interhemispheric integrity and the humming labeling differential (HLD). During the Visuo-motor Interhemispheric Transfer Time testing, the subjects were asked to press a button when they saw the lighted stimulus on the computer screen. Visuo-motor reaction time was recorded using a time resolution of 1 ms via a response box, Cedrus RB-400, placed in front of the response hand. A total of 320 trials were conducted and RT values for each hand were obtained. IHTT was calculated by subtracting the crossed RT from the uncrossed RT or CUD. The authors concluded that aging had an effect on both visuo-motor temporal and auditory behavioral measures of interhemispheric transfer function. A decrease in interhemispheric function was discovered between the ages of 40 to 55 years with no further decline with increased age. Gender, on the other hand, only affected performance on auditory measures (i.e., dichotic listening tasks) of interhemispheric function in the middle years. For example, men may reveal binaural processing difficulties by 35 to 40 years of age; however, women did not reveal binaural processing difficulties until 55 to 60 years of age (i.e., postmenopausal years) (Bellis & Wilber, 2001). These findings were in agreement with previous studies stating the decreased amount myelin at very young and very old ages can cause decreased function of the corpus callosum (Musiek & Baran, 2007).

One study by Iacoboni and Zaidel (2004) discussed the measurement of visuo-motor transfer time using function magnetic resonance imaging (fMRI). It was hypothesized that the crossed condition fMRI recording would elicit a more intense response than the uncrossed condition. Within this study, three normal, right-handed subjects, consisting of two females and one male, were selected. These subjects had a mean age of 23.5 years and had no neurological abnormalities according to an examination prior to testing. Two different conditions were recorded, including crossed condition (i.e., light stimulus and response hand on opposite sides) and uncrossed condition (i.e., light stimulus and response hand on same side). The crossed condition required information to be transferred from one hemisphere to the other due to the fact that one hemisphere is visually stimulated while the other is in charge of the motor response. These conditions were also subtracted from each other and divided by two to obtain the CUD. Black flashes on a light grey background were presented for 50 ms on a computer screen, and the subjects were asked to press a button with their left or right index finger when they saw the stimulus. There were 18 random trials recorded via fMRI (i.e., nine right-sided stimuli and nine left-sided) and 12 s trials were considered one fMRI run. The subjects were asked to respond with the left index finger for one fMRI run, and with the right index finger for the other fMRI run. The GE 3.0T MRI scanner with an echo-planar imaging upgrade was used to record the responses from the visual stimuli. The researchers concluded that the crossed responses resulted in greater signal intensity than the uncrossed responses in the right superior parietal, prefrontal, and dorsal premotor cortices. This research found that many types of information are transferred through the corpus callosum, and all are related to some aspect of motor behavior (i.e., sensory-motor integration and motor intention to decision making and response preparation). The researchers also concluded that the CUD correlated with the signal intensity changes in the right superior parietal cortex, signifying the importance of the right superior parietal cortex in interhemispheric transfer of visuo-motor information. These authors further suggest the maturation of the cerebral cortex and strength of the opposing pathways.

IHTT in the Auditory Domain

Many studies have been conducted using LAEPs to investigate the pathologies at the level of the cortex within the pediatric population; most of these studies used binaural pure-tone stimuli. It is known that pure-tone stimuli through basic audiological testing are not sensitive enough to diagnose cortical lesions (Jirsa & Clontz, 1990). Due to the insensitivity of the pure-tone stimuli, Cranford and Martin (1991) used competing speech babble in one ear and a pure-tone stimulus in the other to investigate binaural processing of the elderly population. These researchers hypothesized that presence of contralateral speech noise might have a significant effect on the P300 (i.e., cognitive potential). Within the study, subjects also underwent ABR, MLR and LLR testing with the same contralateral speech babble to compare all the evoked potentials. Ten subjects with no known neurologic or otologic dysfunction were tested from four different age groups, including 20 to 34 years, 35 to 49 years, 50 to 64 years, and 65 to 80 years. These subjects reported no significant history of neurologic or otologic dysfunction. The Nicolet Compact Auditory Electrodiagnostic System (Nicolet products, 1991) was used to generate pure-tone stimuli and record electrophysiological data. The Auditec Four-Talker tape was used to present competing speech babble at 55 dB SL above the speech reception threshold. An "oddball" stimulus was used to present either a rare (2000 Hz) tone or a frequent (750 Hz) tone at 70 dB nHL to the test ear. Four recordings of 200 artifact free presentations were completed for each subject for the right and left ear. When recording ABR and MLR, no observable change was noted for amplitude or latency. When observing N1 and P2 with frequent tones in the presence of contralateral speech competition, as age increased, there was a reduction in peak-to-peak amplitude; however, the age effect was not statistically significant for the rare tones. A slight increase in latency for both N1 and P2 was noted with contralateral speech competition when using frequent and rare tones. The magnitude of this change, however, was not affected by age (i.e., latency did not differ among the four age groups). A significant age-related increase in latency and decrease in amplitude was noted for the P300 with no competing speech competition. Although there was a decrease in P300 to N3 amplitude and an increase in latency with competing speech competition, no age effect was noted (i.e., did not differ among the four age groups). Therefore, the only significant effect from competing speech babble, that also revealed an age effect, was the decrease in amplitude of the ALEP. Although the P300 amplitude did decrease in the present of competing speech babble, this change did not vary among the four age groups. An increase in latency was also noted for the N1, P2 and P300 components in the presence of competing speech babble; however, this increase also did not vary among the four age groups. These authors revealed that the recorded ALEP in the presence of competing speech babble is affected by age-related alteration in binaural processing; however, the P300 did not reflect age-related binaural competition effects.

During a more recent study by Krumm and Cranford (1994), the same test protocol was used to investigate whether the same age-related competition effect, possibly related to maturational factors, may also occur with younger children. There were 54 children in one of three age groups: 7 to 9 years, 10 to 12 years, and 12 to 14 years. Five of the 54 were eliminated due to receiving special education services or evidence of middle ear pathologies. All of the children were within normal limits for all other audiological testing. The Nicolet Compact Auditory Electrodiagnostic System was utilized to record AEPs. The Auditec Four-Talker tape was used for the competing speech presented, at 50 dB SL above patient's pure-tone average, to the non-test ear, and a 750 Hz (frequent) and 2000 Hz (rare) tone at 70 dB nHL were presented to the test ear at 20 ms duration. There were two presentation modes of the stimuli: 1) tones presented without competing noise in the non-test ear and 2) tones presented with competing noise in the non-test ear. Krumm and Cranford (1994) observed that the N1 and P2 latencies decreased between the ages of 7.5 to 15 years when no competing speech babble was present (i.e., decreased with age); however, the latencies were not affected by contralateral speech competition (see Table 1). Krumm and Cranford (1994) confirmed the results of the Cranford and Martin (1991) study in finding that the N1 to P2 amplitude decreased in both ears with competing speech babble. Where Cranford and Martin (1991) found an age-related decrease in amplitude with competing speech babble, Krumm and Cranford (1994) discovered that amplitude did not vary among the three young age groups they tested, which could be due to the greater response variability of children. In conclusion, although Martin and Cranford (1991) found age-related decreases in amplitude with the elderly group in the presence of competing speech babble (i.e., compromised binaural processing); Krumm and Cranford (1994) concluded that there are no age effects with amplitude for younger subjects when focusing on binaural processing. Krumm and Cranford (1994) latency results are listed below (see Table 1) along with the estimated interhemispheric transfer time (IHTT).

Table 1.
Latencies and Estimated IHTT

Waves	7:6 to 9:1 years			10:0 to 12:5 years			12:6 to 14:11 years		
	Left ear	Right ear	IHTT	Left ear	Right ear	IHTT	Left ear	Right ear	IHTT
N1 Latency									
Quiet	149.9	147.2	2.7	123.5	119.7	3.8	102.4	99.7	2.7
Speech	160	144.3	15.7	124.5	111.7	12.8	102.9	102.4	0.5
P2 Latency									
Quiet	243.4	241.3	2.1	205.9	201.9	4	198.6	188.3	10.3
Speech	255.2	238.4	16.8	207.2	192.3	14.9	188.5	190.7	-2.2

Modified from original version. Krumm, M. P., & Cranford, J. L. (1994).

Although Krumm and Cranford (1994) found no statistical difference between the quiet and noise conditions, an increase in latency is noted in the left ear as compared to the right ear in the noise condition for the two younger groups; while the older group's latencies are similar in quiet and in noise. Although Krumm and Cranford (1994) did not calculate the IHTT, for the present study, the IHTT was calculated and placed in the original graph (see Table 1). In the quiet condition (i.e., no competing speech in the opposite ear), there was no observable difference in IHTT for any age group. However, in the speech condition (i.e., four talker speech babble presented to the opposite ear) latency differences between ears within the two youngest groups of children created an increased (i.e., slower) IHTT. The oldest group of children (i.e., at the age of cerebral maturation) revealed latencies with slight differences, therefore, creating a decreased (i.e., quicker) IHTT. These authors were not researching IHTT; however, their findings provided a great deal of information for the present study.

Results from the previously discussed studies reveal the maturational process of the cortical hemispheres and the right ear advantage in children under the age of 11 to 12 years, due to the language centers being present in the left hemisphere for most humans. Further investigation is needed to determine whether a difference in IHTT between age groups can be replicated. This normative data could then be used to compare to results obtained from children with (central) auditory processing disorders (C) APD to assist in the diagnosis. The present study will be a modification of the study conducted by Krumm and Cranford (1994) to confirm their findings and attempt to observe the IHTT. It is hypothesized that there will be no difference in IHTT between the groups tested due to the similarity in age (i.e., 6 to 7 years of age and 8 to 9 years of age).

CHAPTER III

Methods and Procedures

The goal of the project was to determine if differences existed in IHTT in children 6 to 9 years of age with normal auditory processing abilities through the use of an objective measure (i.e., auditory late evoked potentials [ALEPs]). It was hypothesized that there would be no difference in IHTT between the two groups due to the similarity in ages tested (i.e., 6 to 7 years of age and 8 to 9 years of age).

Methods

Participants

Prior to initiating this project, the Institutional Review Board (IRB) at Louisiana Tech University approved this study (Appendix A). The participants were recruited via volunteer and network sampling by the use of flyers (Appendix B) and word of mouth. Sixteen participants, nine females and seven males between the ages of 6 to 9 years, volunteered to participate and were placed in their appropriate age group. There were seven participants in the older group (8 to 9 years of age; Mean age = 8.7 years) and nine participants in the younger group (6 to 7 years of age; Mean age = 6.7 years). The participants' parents and teachers were asked to complete the appropriate sections of a central auditory processing disorder ([C] APD) case history form (Appendix C) to ensure the participants were performing at or above grade level both scholastically and socially.

Any participants with known neurological disorders such as autism, mentally handicapping conditions, head injury resulting in loss of consciousness, (C) APD or persuasive developmental delays were excluded from this study. All participants were monolingual English speakers. Participants were not excluded due to diagnosis of attention deficit disorder (ADD), although each child had to be medicated as directed by a physician at the time of testing. A written informed consent form was signed by both the participants (Appendix D) and their parent/guardian (Appendix E) prior to beginning any testing as approved by the Human Subject Committee IRB at Louisiana Tech University. All participants were right-handed according to Edinburgh Handedness Inventory (Oldfield, 1971; Appendix F). Testing was completed at the Louisiana Tech University Speech and Hearing Center in Ruston, Louisiana.

Instrumentation

Otoscopy was completed using a Welch Allen otoscope (SN: 25020A). Tympanometry was performed using a Grason-Stadler Tympstar Version 2 Middle-Ear Analyzer (ANSI S3.39, 1978, R2002; SN: AL072614). Pure-tone and speech testing was performed with a Grason-Stadler GSI 61 audiometer (ANSI S3.6-1969, R-1973, R-2004; SN: AA063067). Speech testing was administered using recorded Northwestern No. 6 (NU 6) word list. The NU 6 word lists, Staggered Spondaic Word (SSW) test, and Tests for Auditory Processing Disorders for Children (SCAN-3) were routed through the GSI 61 audiometer and coupled to a Tascam CD-160 CD player.

Staggered Spondaic Word (SSW) Test: The SSW test evaluates central auditory function by dichotically presenting staggered spondaic words at 50 dB SL (in reference to the pure-tone average; Katz , 1962, 1968). For example, the first syllable of the first spondee is presented in isolation to the right ear, the second syllable of the first spondee in the right ear overlaps with the first syllable of the spondee presented to the left ear, and the second syllable of the spondee delivered to the left ear is presented in isolation. The beginning ear order is alternated from right to left. The participant is required to repeat both spondees beginning with the presentation in the first ear; the presentation level is 50 dB SL above the pure-tone average. Four conditions (Right Non-Competing, Right Competing, Left Non-Competing, Left Competing) provide the eight cardinal numbers necessary to score the *SSW*. The *SSW* provides a standardized measure of dichotic testing for individuals 5 to 69 years; however, it uses spondaic words. This test was included to identify that participants had normal auditory processing skills.

The SCAN-3 (Keith, 2009) test provides a valid and reliable test to help identify children with auditory processing disorders and describe the impact on their daily life. The SCAN-3 includes three screening subtests: Random Gap Detection (RGD), Auditory Figure Ground at +8 dB SNR (AFG+8), and Competing Words Free Recall (CWFR). There are four other diagnostic tests: AFG+8, Filtered Words (FW), Competing Words (CW), and Competing Sentences (CS). Additional supplementary tests were included (AFG +0, AFG+ 12, and Time Compressed Sentences [TCS]). This test was used to identify normal auditory processing skills and ear advantage.

All children were right-handed according to Edinburgh Handedness Inventory (Osfield, 1971). EARTone 3A insert earphones were used for presentation of all audiometric testing and (C) APD testing (i.e., SSW and SCAN-3). All of the equipment received an annual electroacoustic calibration and a daily biological check to ensure consistency of performance. A Bruel & Kjaer Type 2150 sound level meter and digital oscilloscope /spectrum analyzer was used to verify proper output and calibration of equipment. All preliminary testing was performed in a double suite, double-walled soundproof booth meeting the ANSI S3.1-1999 standards. The electrophysiological testing was performed in room 119 Robinson Hall, which contains little electrical interference.

The Nicolet Compact Auditory Electrodiagnostic System (SN: 8064989) with EARTone 3A insert earphones was used to measure auditory brainstem (ABR) responses using an international 10-20 vertical electrode array. Output of the Nicolet Compact Auditory Electrodiagnostic System was measured using the Bruel & Kjaer Type 2150 sound level meter and digital oscilloscope/spectrum analyzer. Upon performing calibration, it was noted that 7 dB SPL must be subtracted from the input level to maintain a 70 dB nHL output level (i.e., 63 dB was utilized in the electrical acoustic parameters). During experimental testing, the commercially available Auditec Four-Talker babble was routed through the Grason-Stradler GSI 16 audiometer (SN: A1067) via a personal iPod (SN: DQ5HH1P9DPMW) and simultaneously presented to the non-test ear. The audiometer and personal iPod were calibrated using the Bruel & Kjaer Type 2150 sound level meter and digital oscilloscope /spectrum analyzer and the Auditec St. Louis calibration tone.

Procedures

Participants underwent two hours of testing and had to meet all inclusion criteria to continue with the experimental testing. The participant's parent/guardian brought the completed (C) APD case history form, Edinburgh Handedness Inventory (Osfield, 1971), and the consent forms on the day of testing. If the child met all the necessary requirements, testing was initiated and data was included in the analysis.

The participants received a complete audiological assessment to ensure that there were no peripheral hearing deficits. This included an otoscopic examination, tympanometry, pure-tone air conduction testing, recorded word recognition, and recorded speech reception thresholds. Hearing was considered normal if thresholds were obtained from 0 to 20 dB HL for 250 through 8000 Hz. Normal tympanogram tracings were considered to be peak pressure of no less than -100 daPa and static compliance of no less than .2 mL. Speech reception thresholds were considered normal at +/– 10 dB of the pure-tone average. Word recognition abilities were considered normal if participant scored 88 percent or better. If the participants did not meet the inclusion criterion listed above, they were excluded from this study and referred for further appropriate testing. All participants tested within normal limits for the audiological testing listed above.

The SSW Test was completed to rule out a (C) APD. Participants could score no more than two standard deviations below the mean in more than one condition of the SSW (i.e., RNC, RC, LNC or LC). Participants who failed more than one condition were excluded from the study and referred for further testing. One participant failed more than one condition and was excluded from the study.

The SCAN-3 for Children was administered according to protocol. Participant scoring more than two standard deviations below the mean in more than one subtest for any screening, diagnostic, or supplementary test were excluded from the analysis and referred for further testing. One participant failed the SCAN-3 and was excluded from the study.

Auditory brainstem response (ABR) test: The ABR was used to verify that Waves I, III and V were present and repeatable. The electrode array included: right/left mastoid (inverting electrodes), Fpz (ground electrode), and Fz (non-inverting electrode). Once the scalp and face were thoroughly cleansed to decrease impedance (maintained at 5000 ohms or less), a 100 μs click stimulus was presented at an intensity of 70 dB nHL at a 19.1/s stimulus rate with 1500 sweeps using alternating polarity. The filter was set at 100 to 3000 Hz with a 15 ms epoch was utilized. A correction factor of 7 dB SPL was used to maintain a 70 dB nHL output level. The interpeak latencies, absolute latencies, and between ear differences had to be age appropriate. Participants received the following instructions:

You are going to hear some beeps in your ears. I just need you to lay still and quiet and watch the movie.

Breaks from testing were given upon request by the participants. If participants did not meet the inclusion criteria, they were excluded from the study and the appropriate referrals were made.

Experimental Testing

Auditory late evoked potential (ALEP) recordings were completed using an international 10-20 vertical electrode array [i.e., Fz, (non-inverting); A1/A2, mastoid (inverting); Fpz, (ground)] to observe IHTT and examine changes during maturation. ALEPs were not recorded from vertex (Cz) as with the Krumm and Cranford (1994) study due high impedances at the electrode site. A 2000 Hz tone burst was presented with a rise-fall time of 2 msec at 70 dB nHL, again using the -7 dB HL correction factor. An "oddball" stimulus (i.e., 750 Hz as the frequent tone and 2000 Hz as the rare tone) was not used in the present study as with the Krumm and Cranford (1994) study. Stimulus parameters included: low-frequency filter at 1 Hz, high frequency filter at 30 Hz, time window at 500 ms, presentation-stimulus at 0.7/s, 200 artifact free sweeps, and condensation polarity. This tone was routed through the Nicolet Compact Auditory Electrodiagnostic System and presented to the test ear to investigate the P1-N1-P2 component of the ALEP. Electrode impedance was maintained below 5000 ohms and a total of 200 artifact-free trials (i.e., one complete run) were calculated and computer analyzed to produce the final tracings. The commercially available Auditec Four-Talker babble routed through the Grason-Stradler GSI 16 audiometer via a personal iPod was simultaneously presented at 50 dB HL to the nontest ear. Four total runs per ear were completed as follows: 1) The signal was first presented to the right ear (quiet condition); 2) then repeated for test re-test reliability; 3) the signal was presented a third time to the right ear and the Four-Talker babble was presented to the left ear (noise condition); 4) this was again repeated for test re-test reliability. The same procedure was then completed on the left side for a total of four funs per ear or eight runs total. The right ear always received the initial stimulus (quiet condition). The child received the following instructions:

> *Now you are going to hear a sound in one ear and then people talking in the other ear. I just want you to remain still and quiet and watch the movie. Do you have any questions?*

Extra-ocular electrodes were not utilized to automatically reject contaminated trials due to eye movement; therefore, the children were asked to watch a silent movie of their choice to minimize contamination from eye movement artifact. The participants were not asked to press a button upon hearing the tones as with the Krumm and Cranford (1994) study. Electrophysiological data was recorded and saved for further analyzing and testing results were stored in a locked file cabinet in Robinson Hall room 306.

CHAPTER IV

Results

The present study was a modification of the study conducted by Krumm and Cranford (1994) to confirm their findings and attempt to observe the IHTT. A 3-way repeated measures analysis of variance (RM-ANOVA) was performed to determine if the IHTT for the P1, N1 and P2 were different from the quiet condition to the contralateral four-talker speech-in-noise condition for two groups of participants. All waves utilized were noted to have fair to good repeatability and morphology. Effect sizes (Large $\geq$ .138; Medium = .059 – .137; Small = .01 – .058; Nolan & Heinzen, 2007) were also reported for each variable and revealed the level of clinical significance or magnitude of the observed effect.

The latencies for each wave (P1, N1 and P2) in both the quiet and noise condition for both groups were analyzed in SPSS version 17. The means and standard deviations for the latencies (P1, N1 and P2) and conditions (quiet right [QR], quiet left [QL], noise right [NR], noise left [NL]) for both age groups (i.e., 6 to 7 years and 8 to 9 years) can be found in Table 2. To clarify the abbreviations, QR signifies that the signal was presented to the right ear and it was in the quiet condition. For a QR NL P1, as an example, indicates the stimulus (2000 Hz tone) was presented to the right ear and the noise (four-talker babble) was presented to the left ear for wave P1 of the auditory late-evoked potential.

Table 2

Means and Standard Deviations	Young Group (6 to 7 years)		Old Group (8 to 9 years)	
	Mean	SD	Mean	SD
QR P1	85.89	10.02	80.53	9.47
QR N1	113.77	10.34	110.39	8.1
QR P2	142.77	8.96	141.1	14.3
QR NL P1	93.77	11.43	89.39	14.2
QR NL N1	112.21	10.53	118.24	14.6
QR NL P2	144.89	15.71	142.81	16.3
QL P1	85.99	10.13	77.53	10.1
QL N1	109.66	9.06	104.81	12.8
QL P2	133.32	7.31	129.67	19.2
QL NR P1	123.54	37.99	112.96	29.4
QL NR N1	152.99	35.85	155.81	48.3
QL NR P2	195.1	37.99	180.24	51.4

Note: All numbers denote ms. QR= quiet right; QR NL= signal right, noise left; QL= quiet left; QL NR= signal left, noise right; P1, N1 and P2= latency

To calculate IHTT, participants' individual quiet conditions were separately subtracted from the contralateral synonymous noise conditions (e.g., QL NR P1- QR NL P1) in Excel prior to analysis (see Table 3). This data was entered into SPSS version 17. A 3-way RM-ANOVA was used to determine if IHTT was significantly different between the younger group (6 to 7 years) and the older group (8 to 9 years). The within subject factors were waves (P1, N1 and P2) and noise (quiet and noise) with the between subjects factor as group. The main effect of waves was found to be not significant, $F\,(2, 28) = 1.10$, $p = .344$, *partial* $\eta^2 = 0.073$. The interaction was not found to be significant in terms of the waves and the groups, $F\,(2, 28) = 0.284$, $p = 0.755$, *partial* $\eta^2 = 0.020$.

Table 3
Measurement of IHTT

Waves	6:0 to 7:0 years			8:0 to 9:0 years		
	Left ear	Right ear	IHTT	Left ear	Right ear	IHTT
P1 Latency						
Quiet	85.99	85.88	0.11	77.53	80.53	-3
Speech	123.54	93.77	29.77	112.96	89.39	23.57
N1 Latency						
Quiet	109.66	113.77	-4.11	104.81	110.39	-5.58
Speech	152.99	112.21	40.78	155.81	118.24	37.57
P2 Latency						
Quiet	133.32	142.77	-9.45	129.67	141.1	-11.43
Speech	195.1	144.88	50.22	180.24	142.81	37.43

The main effect of noise (quiet versus noise conditions) was found to be significant, $F\,(1, 14) = 21.06, p < 0.000,$ *partial* $\eta^2 = .601$. That is, when the contralateral four-talker noise was added to the nontest ear, the IHTT was found to be significantly different than that of the quiet condition IHTT. As can be observed in Table 3, the IHTT progressively increased (i.e., became longer) for the noise condition and remained relatively unchanged for the quiet condition. Post-hoc paired sample *t*-Test using a Bonferonni correction with a significance value of $p < .017$ (.05/3 using three paired *t*-Tests) revealed that the scores increased significantly from the quiet to noise condition for all three waves (see Table 4 for Means and Standard Deviations and Table 5 for t statistics, df, and *p* value). The interaction for noise and group was not significant, $F\,(1, 14) = 0.081, p = 0.780,$ *partial* $\eta^2 = 0.006$. However, a significant interaction was found for waves and noise, $F\,(2, 28) = 10.28, p < 0.000,$ *partial* $\eta^2 = 0.423$ (see Figures 1 and 2). That is, when waves were compared between the quiet and a noise condition, IHTT was significantly affected. As noted in Figures 1 and 2, IHTT decreased from P1 to P2 in the quiet condition; however, IHTT increased from the P1 to P2 in the noise condition. When all waves (P1, N1 and P2), conditions (quiet versus noise), and groups (young versus old) were compared for an interaction, no significance was found, $F\,(2, 28) = 0.354, p. = 0.705,$ *partial* η^2 .025. The main effect of the group was not found to be significant, F (1.14) .224, p = .643, *partial* $\eta^2 = .016$.

Table 4
Means and SD: Quiet versus Noise Paired Sample *t*-Test

	Mean	SD
Quiet IHTT P1	-1.25	13.224
Noise IHTT P1	27.06	34.159
Quiet IHTT N1	-4.75	10.142
Noise IHTT N1	39.38	36.6
Quiet IHTT P2	-10.31	10.051
Noise IHTT P2	44.63	43.282

Table 5
Paired Sample *t*-Test for Quiet versus Noise

	t	df	Sig. (2 tailed)
Quiet IHTT P1- Noise IHTT P1	-3.301	15	0.005*
Quiet IHTT N1- Noise IHTT N1	-4.613	15	0.000*
Quiet IHTT P2- Noise IHTT P2	-5.483	15	0.000*

Note: Sign. at $p < .017$ (Bonferroni correction .05/3 paired *t*-Test)

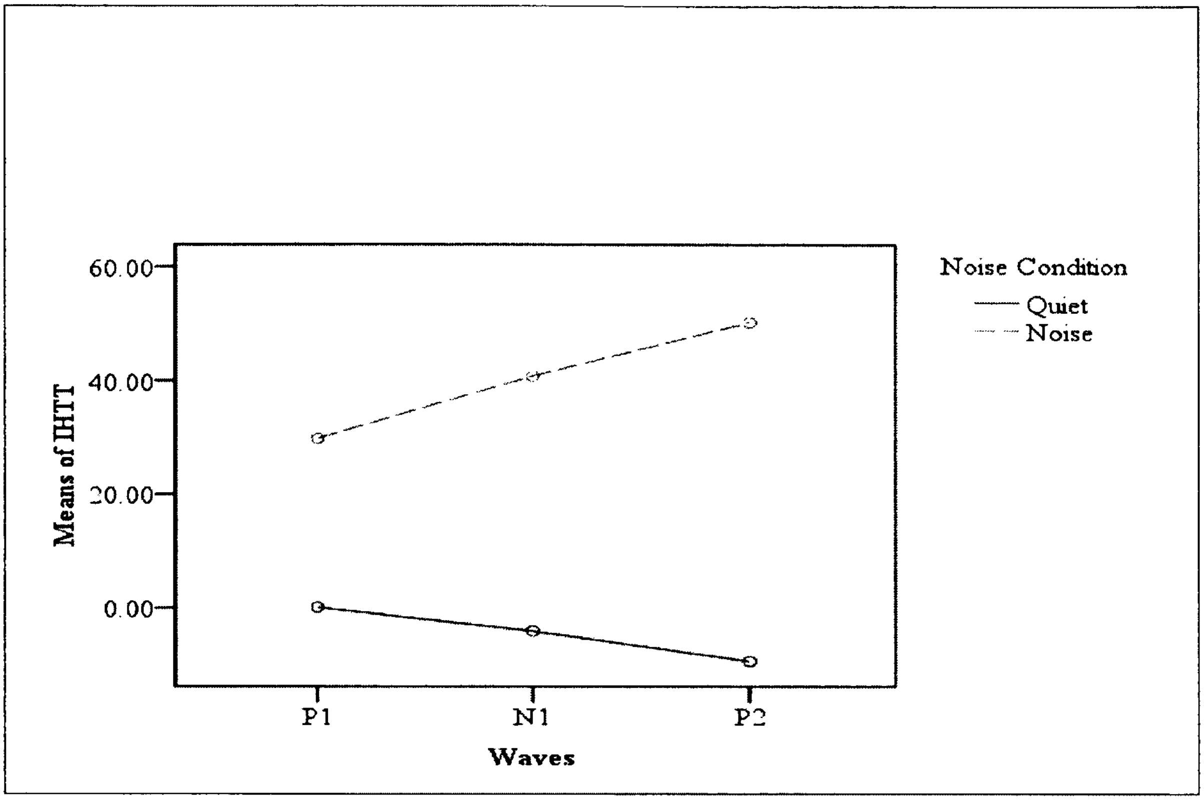

Figure 1. Young Group Quiet versus Noise Conditions Compared to IHTT of P1, N1, P2

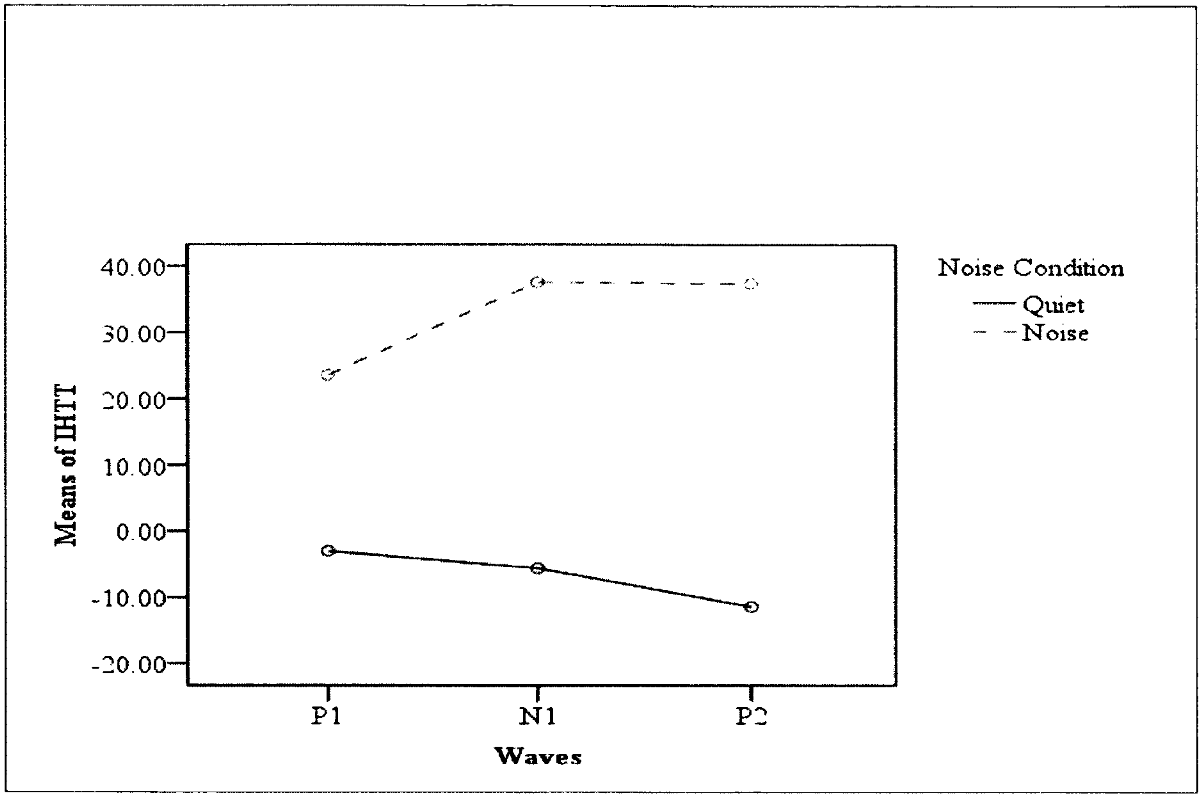

Figure 2. Old Group Quiet versus Noise Conditions Compared to IHTT of P1, N1, P2

CHAPTER V

Discussion

The overall goal of the present study was to investigate the use of auditory late evoked potentials in the attempts to measure IHTT. Two groups of normal hearing children were recruited where central auditory processing skills were identified as being within normal limits. Both groups of children were asked to participate in the experimental condition where auditory late evoked potentials were recorded in a quiet condition and when contralateral four-talker noise was added. It was hypothesized that there would be no difference in IHTT between the groups. The present study revealed there was no statistically significant difference between groups in the measure of IHTT (Figures 1 and 2), which supported the hypothesis.

IHTT

Although IHTT is a new measure under exploration in the auditory domain, the investigation revealed that it is possible to calculate IHTT similar to that within the visual domain (Bellis & Wilber, 2001; Hagelthorn, et al., 2000). However, the difference between visual studies such as of Bellis and Wilber (2001) and Hagelthorn et al. (2000) is that IHTT reveals a bilateral advantage when both visual fields are being assessed compared to one visual field. In audiology, however, contralateral competing noise or rather dichotic testing is a well-received testing paradigm for assessing maturation of the auditory system (Kimura, 1961, 1964 & 1968). Therefore, in merging the two (i.e., visual measures of IHTT and auditory measures of dichotic listening) it was postulated that calculating IHTT may be possible in the auditory domain. The current study was able to replicate with some modifications a Krumm and Cranford (1994) study to identify whether measuring IHTT might be possible. This investigation identified when contralateral noise was added, IHTT was significantly longer in the noise condition as compared to the quiet condition in both groups (see Table 5). That is, IHTT in the quiet condition remained stable while the contralateral four-talker babble condition changed considerably. As can be seen in Table 5, this change in IHTT is a direct result of a prolongation of the left ear latency in the noise condition. This finding can be explained by the right ear advantage (i.e., left ear disadvantage) first described by Kimura et al. (1961, 1964, & 1967), a direct result of the natural maturation process of the corpus callosum process.

As expected, both groups were not significantly different from each other in IHTT revealing no age-related effect (Figures 1 and 2). In other words, the groups did not react differently when contralateral noise was added. The supposed rationale for this finding is due to the similarity in ages tested.

Some of the present findings were similar to those obtained by Krumm and Cranford (1994). Although data is not available for comparison between the Krumm and Cranford study (1994) and the present study for P1, both studies revealed that IHTT continued to decrease in the quiet condition from N1 to P2 (see Tables 1 and 3). It is unknown why this decrease occurs in quiet; therefore, more investigation is necessary. The present study also agreed with the findings obtained by Krumm and Cranford (1994) in that IHTT continued to increase in the noise condition from N1 to P2 (see Tables 1 and

3). This is thought to be due to the corpus callosum maturation and right ear advantage (Kimura, 1961, 1964, & 1967; Musiek & Baran, 2007).

Although the present study and the study conducted by Krumm and Cranford (1994) were similar, slight differences were observed between the two. A decrease in IHTT was in fact noted from N1 to P2 in quiet in both studies; however, the decrease was not as severe in the Krumm and Cranford study (1994) as that observed in the present study. This difference was noted in the 8 to 9-year-old group as well. Another difference was noted in the noise condition. Although both studies revealed an increase from N1 to P2 in the noise condition, a more severe change was again noted for the present study (i.e., significant difference in IHTT between the quiet to noise conditions). The 8 to 9-year-old group IHTT; however, did not fluctuate in noise from N1 to P2 as did the younger group. These discrepancies between the studies could be explained by differences in protocol utilized, such as the use of Fz versus Cz electrode placement. According to research (Picton, Woods, Baribeau-Braun & Healey, 1977), ALEPs are best recorded at frontal and central scalp locations; however, responses are maximal at vertex. The discrepancies between studies could also be caused by the inclusion of 6-year-olds in the present study. Research has shown that the N1-P2 complex is adult-like by the age of 7 to 9 years of age (Goodin, Squires, Henderson & Starr, 1978); therefore, the inclusion of 6-year-old participants, with an immature N1-P2 complex, could have affected the average IHTT of the young group. Both of these factors could potentially cause an increase in latency. The use of an "oddball" paradigm would not affect the latencies obtained due to the exogenous nature of the ALEPs (i.e., passively elicited). The use of a 2000 Hz stimulus versus a 750 Hz stimulus also would not have caused an increase in latency with the present study. Researchers have revealed that the use of a high frequency stimulus will actually cause a decrease in latency of the ALEPs as compared to a low frequency stimulus (Jacobson et al, 1992), which does not agree with the present study's findings.

Limitations

One limitation of the present study included the right ear receiving the stimulus first instead of alternating presentations between participants. For improved comparison between studies, future researchers should counterbalance ear presentation. Another limitation was the fact that specific age groups were not tested (i.e., 6:0 to 6:11 years compared to 7:0 to 7:11 years). To obtain specific normative data, future research could further specify ages of participants tested.

Future Research

In conclusion, the possibility of being able to identify correlates of compromised dichotic processing (i.e., auditory processing issues) in children using electrophysiological testing could assist with the process of aural (re) habilitation and help expedite the diagnosis of (central) auditory processing disorders (C) APD. To continue this study, future research should include testing children 10 to 12 years of age and 12 to 14 years of age to continue obtaining normative data. The same process can be used to assess children with (C) APD and results can be compared to the normative data. This comparison will allow future researchers to evaluate if a true objective difference can be observed with the P1-N1-P2 complex in children with (C) APD.

APPENDIX A

IRB HUMAN USE APPROVAL LETTER

IRB HUMAN USE APPROVAL LETTER

TO: Dr. Brittany Keahey and Dr. Sheryl Shoemaker

FROM: Barbara Talbot, University Research

SUBJECT: Human Use Committee Review

DATE: April 10, 2013

RE: Approved Continuation and Revision of Study HUC 922

TITLE: **"The Measurement of Interhemispheric Transfer Time (IHTT) In Individuals with Normal Auditory Processing Abilities"**

HUC 922

The above referenced study has been approved as of April 10, 2013 as a continuation of the original study that received approval on March 20, 2012. **This project will need to receive a continuation review by the IRB if the project, including collecting or analyzing data, continues beyond April 10, 2013.** Any discrepancies in procedure or changes that have been made including approved changes should be noted in the review application. Projects involving NIH funds require annual education training to be documented. For more information regarding this, contact the Office of University Research.

You are requested to maintain written records of your procedures, data collected, and subjects involved. These records will need to be available upon request during the conduct of the study and retained by the university for three years after the conclusion of the study. If changes occur in recruiting of subjects, informed consent process or in your research protocol, or if unanticipated problems should arise it is the Researchers responsibility to notify the Office of Research or IRB in writing. The project should be discontinued until modifications can be reviewed and approved.

If you have any questions, please contact Dr. Mary Livingston at 257-5066.

APPENDIX B

RECRUITMENT FLYER

RECRUITMENT FLYER

WE NEED YOUR CHILD'S HELP!!!!!!

Brittany Keahey, an audiology doctoral student in the Department of Speech, needs your child's help conducting her dissertation experiment. This experiment will help expedite the diagnosis of children with an auditory processing disorder ((C) APD). If you are interested in supporting the department of speech, please check that your child meets the following criteria.

- AGE: 7 or 9 years (1^{st}-3^{rd} grades)
- AUDITORY ABILITIES: Normal
- AUDITORY PROCESSING ABILITIES: Normal
- SCHOLASTIC ABILITIES: Normal (age appropriate)
- LEARNING COGNITIVE ABILITIES: Normal
- POSSIBLE RISKS: None
- WHEN: Spring Quarter (March-May 2012) after school
- DURATION: Approx. 2 hours
- WHERE: Louisiana Tech University Speech and Hearing Center (Robinson Hall)

If you are interested and your child meets the criteria or you know someone who may be interested, please contact Brittany Keahey at bsk004@latech.edu or (318) 729-1624 for more information.

Thank you for your support ☺

APPENDIX C

(C) APD CASE HISTORY FORM

(C) APD CASE HISTORY FORM

LOUISIANA TECH UNIVERSITY
SPEECH AND HEARING CENTER
P.O. BOX 3165
120 ROBINSON HALL
RUSTON, LA 71272
Phone: (318) 257-4766
Fax: (318) 257-4492
Auditory Processing Case History

Date: ____________________
We are pleased that you have chosen to have your child evaluated at the Louisiana Tech University Speech and Hearing Center. In order to give us as much information as possible, we request that you complete this questionnaire and return it to as soon as possible to the address shown on above. An appointment for your child will be scheduled at that time. If you have additional test results, school papers, personal observations that you wish to share with us, please enclose them with this questionnaire on page
GENERAL HISTORY

Child's Name: _________________________________ Age: _______ D.O.B.

Address: ____ Phone:

City: ___________________________ State: ____________ Zip Code:

Name of person answering questionnaire:

Does your child live with both parents? Yes No. If no, which parent is the primary custodial guardian? _________________________

Relationship to child: _____________ Has your child been seen in this Center before?

If yes, when?

Father's Name: ___________________________________ Age:_________________

Occupation: _________________________________Education:_________________

Mother's Name: _________________________________ Age:_________________

Occupation: __________________________________ Education:________________

Referred by:

____

NAME AGE GENDER ANY PROBLEMS?

_____________________ ________ ________ ______________________
_____________________ ________ ________ ______________________
_____________________ ________ ________ ______________________
_____________________ ________ ________ ______________________
_____________________ ________ ________ ______________________

List other adults in the home:

____

What is the primary language spoken in your home? _____________ Other? ________

STATEMENT OF THE PROBLEM

Describe as completely as you can, your child's Speech/Language/Auditory problem(s).

____
____
____
____
____
____
____
____

When were the problems first noticed and by whom?

____
____
____

Please describe what has been done to address the problem(s).

____
____
____
____

What specific questions would you liked answered about your child's problem?

____
____
____

BIRTH INFORMATION

Age of parents at child's birth: Mother: __________________ Father: ____________

Is this an adopted child? ____________________ Child's age at adoption:__________

Mother's general health during pregnancy: Normal? ___________________________

Amount of weight: Gain: _________________ Loss: ______________ Diet:________

Medications taken during pregnancy:

____

____

Any unusual conditions during pregnancy?

____

__________ Chicken Pox ________ Asthma _________ Flu
__________ German Measles ________ Pneumonia _________ Mumps
__________ Urinary Infections ________ Sinusitis _________ Toxemia
__________ High Blood Pressure ________ Bronchitis _________ Anemia
Other:

____

Full-term child? ___________________________ Birth weight:__________________

Labor and delivery: Spontaneous__________ Induced ___________ Length of labor____

Type of delivery: Head first _______ Feet first ________ Breech _______ Caesarian ___

Check all that apply to your child as a newborn:
______Alert _______ Oxygen _______ Slow to breathe
______ Bruised _______ Poor sucking _______ Slow weight gain
______ Jaundiced _______ Swallow
Other:

____

Were there any feeding problems or formula changes?

____

Is there a Rh factor in your family? ______ Other blood incompatibilities: ___________

Health of baby during first few months:

____

Describe your child's personality as an infant:

____

____

____

____

DEVELOPMENTAL HISTORY

Identify the age at which your child completed the following (approximate ages are fine):
Turned from stomach to back: ________________ Sat alone: ____________________
Crawled: ____________________________ Walked alone: ______________________
Dressed self: ___________________________ Fed Self ________________________
Tied shoes: ____________________________ Cut with scissors: ________________
Skipped: ______________________________ Rode a bike: _______________________
Bowel trained: __________________________ Bladder trained: _____________________

Established hand preference:

____

Used single words (e.g., no, mom, doggie, etc.)

____

Combined words (e.g., me go, daddy shoe, etc.)

____

Named simple objects (e.g., where's doggie?, etc.)

____

Engaged in conversation

____

Does your child have difficulty walking, running, or participating in other activities, which require small or large muscle coordination? If so, please describe

____
____
____

Are there, or have there ever been, any feeding problems (e.g., problems with sucking, swallowing, drooling, chewing, etc.). If yes, please describe

____
____
____

What leisure activities does your child like to engage in alone?

____
____

What activities does your child like to do with his parent(s) or others?

____
____

At what age did your child begin to play organized sports? Which sports?

____
____

What is your child's reaction to organized sports?

____
____
____

Were there any factors that you considered may have interrupted your child's "normal" development? If so, please describe

____
____
____

MEDICAL HISTORY
Is your child generally healthy?

____

Which of the following medical conditions has your child experienced?
Age/Severity Age/Severity

Tonsillitis Head injuries_______________ Pneumonia Frequent Colds_____________
Earaches __________________________ Allergies___________________________
Seizures Rubella ____________________ Scarlet Fever_______________________
Tonsillitis _________________________High Fever _________________________
Encephalitis ________________________ Mastoiditis _________________________
Headaches _________________________ Meningitis__________________________
RSV ______________________________ Pneumonia _________________________
Sinusitis ___________________________ Asthma ____________________________
Tinnitus (ringing ears) _______________Croup ______________________________
Convulsions ________________________ Mumps _____________________________
Measles ____________________________ Digestive upsets______________________
Chicken pox_________________________ Other_______________________________

Surgeries: Age Age
Tonsillectomy____________________ Adenoidectomy______________________

Ear Surgery (tubes) (number of tubes placed)____________________

Does anyone in the family (parents, siblings, uncles, grandparents, etc.) have similar problems?
Has your child ever been tested for allergies? When? Results?

____
____

Describe any major accidents or hospitalizations of your child.

____
____
____

Is your child taking any medications? Please list and identify and note any negative reactions that may have occurred with each medication.

____

____

____

Are your child's immunizations up-to-date?

____

PERSONALITY TRAITS/PHYSICAL CHARACTERISTICS

Which of the following descriptors best identify your child? Circle as many as are appropriate:

hyperactive	self-sufficient	tires
circles under eyes	puffiness around eyes	nasal voice
bed wetting	joint aches	easy to anger
dependent	independent	aggressive
underactive	distractible	impulsive
short attention span	calm	too happy
itchy rashes	doesn't try	too controlled
difficulty sleeping	has few friends	depressed
easily frustrated	frequently nauseated	irritable
cries easily	bruises easily	helps others
lacks confidence	temper tantrums	sulks
fast worker	dawdles	hard to love
fearful	disorganized	takes turns
follows directions	responsible	good memory
good social skills	poor social skills	competitive

Check all that apply

______Appears to have a hearing loss

______Has difficulty comprehending speech in the presence of background noise

______Has difficulty processing distorted or rapid speech

______Has an expressive and/or receptive language problem

______Has poor auditory memory

______Has difficulty following multi-step commands

______Frequently says "huh" or "what"

______Distractible

______Inattentive

______Restless

______Has poor phonic skills

______Has poor reading, writing, and spelling abilities

______Has a history of chronic otitis media

______Inconsistently responds to auditory stimuli

______Frequently requests that auditory information to be repeated

______Needs for increased time to respond

______Is sensitive to loud sounds
______Has difficulty with localization (finding a sound source)

Does your child prefer to be a leader or a follower?

Does your child have any unnatural fears?

What additional information would you like to tell us about your child's personality and physical characteristics?

SPEECH AND LANGUAGE HISTORY

When did your child use his/her first word?

When did your child begin to use-two word sentences?

Does your child use speech: Frequently ________Occasionally _______Never

Does your child prefer to use speech (e.g, single words, short phrases) or gestures? (Give examples)

Which does your child prefer to use? Complete sentences:__________Phrases ________
One or two words _________ Sounds_________________

Check all that apply
______Responds to greetings
______Makes requests
______Attends to tasks
______Takes turns
______Describes events
______Maintains topics
______Sequences actions
______Defines words
______Imitates activities or conversation
______Interacts with same age peers
______Volunteers for activities
______Follows multi-step commands

How well can your child's speech be understood by: Parents____________ Strangers
Brothers and sisters __________________ Friends and
playmates_________________________

If your child has difficulty with speech and/or language, what do you think may have caused the problem(s)?

____

Has the problem changed since it was first noticed?

____

If yes, please describe changes.

____

____

HEARING HISTORY

Describe your child's auditory behavior

____

____

____

Is noise a factor in your child's ability to understand information? Please describe:

____

____

____

Describe your child's response to sound (e.g., responds to all sounds, responds to loud sounds only, inconsistently responds to sounds, etc.)

____

____

____

Are there any other speech, language, learning or hearing problems in your family? If yes, please describe.

____

____

____

READING HISTORY

How does your child feel about reading?

____

Has your child changed schools recently? What was the effect on his reading ability?

What comments do you get from the school about your child's reading ability?

At what age did your child begin to recognize letters by sight?

At what age did your child begin to identify the sounds of letters?

Does your child like to read to himself?

How do you rate your child's reading problem(s)? Mild, Moderate, or Severe
__________________ Does not know letters and sounds
__________________ Cannot decode words (sound-out word)
__________________ Poor comprehension of what he/she reads
__________________ Inattentive to instruction
__________________ Inadequate reading vocabulary

How often do you read to your child?
__________ frequently __________ often
__________ occasionally __________ seldom

Does your child reverse numbers or letters when reading or writing?

Does your child learn best by seeing ___________ hearing doing

EDUCATIONAL INFORMATION
Name of
School(PreSchool)____

Address:____

Principal's Name:

____

Teacher's Name:

____

Grade:____________
Has he/she ever failed a grade? _________________Which
grade(s)?____________________

Does he/she excel in any subjects?

Does he/she have any serious difficulty in any subjects?

How does he/she feel about school and his/her teachers?

____

Has he/she ever had any psychological tests? _________ When ____________________
Where: ____
By Whom: ____
Were the results interpreted to
you?____

____

Have any other speech-language specialists or audiologists seen your child? Who and when? What were their conclusions or suggestions?

____

____

____

Have any other specialists (e.g., physicians, psychologists, special education teachers, etc.) seen the child? If yes, indicate the type of specialist, when the child was seen, and the specialist's conclusions or suggestions.

____

____

____

Does the child now receive special services? If yes, where? Describe.

____

____

____

How does your child interact with others (e.g., shy, aggressive, uncooperative, etc.)?

____

____

If enrolled for special education services, has an Individualized Educational Plan (IEP) been developed? If yes, describe the most important goals as discussed with you. If you have a copy of this IEP, please attach it to this form.

____

____

Provide any additional information that might be helpful for providing services to your child.

____

____

____

Please send copies or attach reports, finding, IEPs, etc. that would be helpful in the evaluation and remediation of the client to:

Coordinator, Speech, Language, and Hearing Services
Louisiana Tech University
Department of Speech
P.O. Box 3165
Ruston, LA 71272

Person completing this form____
Relationship to child____
Signed____ Date ____________

Parents please complete this form and return with case history.

Parent's Name:

Child's Name:

Read each item carefully and decide how much you think this child exhibits the following behaviors. Put your check in the box that is true of this child at the present time.

	Not At All	Just a Little	Pretty Much	Very Much
1. Restless in the "squirmy" sense				
2. Demands must be met immediately				
3. Temper outbursts/unpredictable behavior				
4. Distractibility/attention span is a problem.				
5. Disturbs other children				
6. Pouts and sulks				
7. Mood changes quickly and drastically				
8. Restless; always on the go				
9. Excitable, impulsive				
10. Fails to finish things that he starts				

OPTIONAL

How much of a problem do you think this child has at the present time (compared to others of the same age)?

NONE MINOR MODERATE SEVERE

Teacher please complete this form and return with case history.

Teacher's Name: ____

Child's Name: ____

Read each item carefully and decide how much you think this child exhibits the following behaviors. Put your check in the box that is true of this child at the present time.

	Not At All	Just a Little	Pretty Much	Very Much
1. Restless in the "squirmy" sense				
2. Demands must be met immediately				
3. Temper outbursts/unpredictable behavior				
4. Distractibility/attention span is a problem.				
5. Disturbs other children				
6. Pouts and sulks				
7. Mood changes quickly and drastically				
8. Restless; always on the go				
9. Excitable, impulsive				
10. Fails to finish things that he starts				

OPTIONAL
How much of a problem do you think this child has at the present time (compared to others of the same age)?

NONE MINOR MODERATE SEVERE

APPENDIX D

CHILD'S CONSENT FORM

CHILD'S CONSENT FORM

Louisiana Tech University Speech and Hearing Center

We want to use the results of what you do to help us learn more to help other children.

1. We will ask you to raise your hand when you hear the "beep" and say the words you hear.

2. We will then ask you to lay quiet and still for the next test. You will hear clicks in one ear and people talking in the other.

I have read and understand what I'm supposed to do and want my results to be used.

______________________ ________________

Child's Signature Date

I do not want my results to be used.

______________________ ________________

Child's Signature Date

APPENDIX E

HUMAN SUBJECT'S CONSENT FORM

HUMAN SUBJECT'S CONSENT FORM

The following is a brief summary of the project in which you are asked to participate. Please read this information before signing the statement below.

TITLE OF PROJECT: The Measurement of Auditory Interhemispheric Transfer Time (IHTT) in Children with Normal Auditory Processing Abilities

PROJECT DIRECTOR(S): Sheryl Shoemaker, Ph.D., Au.D., Brittany Keahey

EMAIL: sshoemaker@latech.edu
PHONE: (318) 257-4764
DEPARTMENT(S): Department of Speech

PURPOSE OF STUDY/PROJECT: To determine if differences exist in the maturation of the corpus callosum (CC) in 6 to 9 year old individuals with normal auditory processing abilities through the use of an objective measure (i.e., auditory late evoked potentials [ALEPs]).

PROCEDURE:
A case history form will be completed and an audiological exam will then be administered to rule out hearing loss (i.e., otoscopy, tympanometry, pure-tone thresholds, speech-reception thresholds, and word recognition thresholds). A central Auditory Processing Testing (i.e., SSW and SCAN-3: C) will then be completed to rule out a central auditory processing disorder. Next, electrodes will be placed on various places on your head and face. You will be asked to relax and listen to clicks, speech or tonebursts and noise while we record brain activity.

INSTRUMENTS: Each procedure will be performed using all of the following standard audiological instruments: Welch Allen otoscope, Grason-Stadler Tympstar Version 2 Middle-Ear Analyzer or similar instrument, a Grason-Stadler GSI 61 audiometer or similar instrument, recorded Northwestern No. 6 (NU 6) word list, Staggered Spondaic Word (SSW) test, Tests for Auditory Processing Disorders for Children (SCAN-3: C), a Tascam CD-160 CD player or similar instrument, and EARTone 3A insert earphones. Standard electrophysiological equipment will be used to complete the electrophysiological testing. All testing will be performed in a double suite, double-walled soundproof booth. All collected information will be held confidential and only viewed by the researchers.

RISKS/ALTERNATIVE TREATMENTS: The participant understands that Louisiana Tech is not able to offer financial compensation nor to absorb the costs of medical treatment should you be injured as a result of participating in this research.

BENEFITS/COMPENSATION: None

I, ___________________, attest with my signature that I have read and understood the following description of the study, "The Measurement of Auditory Interhemispheric Transfer Time (IHTT) in Individuals with Normal Auditory Processing Abilities", and its purposes and methods. I understand that my participation in this research is strictly voluntary and my participation or refusal to participate in this study will not affect my relationship with Louisiana Tech University or the Louisiana Tech University Speech and Hearing Center. Further, I understand that I may withdraw at any time or refuse to answer any questions without penalty. Upon completion of the study, I understand that the results will be freely available to me upon request. I understand that the results of my survey will be confidential, accessible only to the principal investigators, myself, or a legally appointed representative. I have not been requested to waive nor do I waive any of my rights related to participating in this study.

________________________________ ______________

Signature of Participant or Guardian Date

CONTACT INFORMATION:
The principal experimenters listed below may be reached to answer questions about the research, subjects' rights, or related matters.

Researcher: Dr. Sheryl Shoemaker and Brittany Keahey
Email: sshoemaker@latech.edu
Phone: (318) 257-4766

Members of the Human Use Committee of Louisiana Tech University may also be contacted if a problem cannot be discussed with the experimenters:
Dr. Les Guice (257-3056)
Dr. Mary M. Livingston (257-2292 or 257-4315)

APPENDIX F

EDINBURGH HANDEDNESS INVENTORY

EDINBURGH HANDEDNESS INVENTORY

Developed by R.C. Oldfield, Edinburgh University,
Edinburgh, Scotland (1971)

Last Name/First Name/M.I.______________________________

Date of Birth____________________

Sex______________________

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent put + in both columns. Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted in brackets. Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	LEFT	RIGHT	
1. WRITING			
2. DRAWING			
3. THROWING			
4. SCISSORS			
5. TOOTHBRUSH			
6. KNIFE (without fork)			
7. SPOON			
8. BROOM (upper hand)			
9. STRIKING MATCH (match)			
10. OPENING BOX (lid)			

TOTAL number in each column L_______ R_______

Laterality quotient (LQ) is defined as (R-L) / (R+L) x 100 = _______.
McMeekan&Lishman (1975) defines right-handed as +30 to +100 and left-handed as -30 to -100. Handedness of -29 to +29 is indifference (or ambidexterity).

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REFERENCES

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