CHAPTER I:

BACKGROUND AND OBJECTIVES BEHIND EXAMINING DICHOTIC INTERAURAL INTENSITY DIFFERENCE TRAINING (DIID) IN CHILDREN

Central auditory processing is the manner in which the central nervous system (CNS) analyzes incoming auditory signals. Some individuals have deficits in auditory processing despite normal peripheral auditory system functioning. Like a peripheral hearing loss, a central auditory processing deficit can significantly hinder an individual's ability to communicate effectively. These central deficits are clinically known as (Central) Auditory Processing Disorder (APD). APD has been documented in a variety of populations, including adults with confirmed lesions of the central auditory nervous system (Damasio et al., 1976, 1979; Milner et al., 1968; Musiek et al., 1979, 1982; Sparks, 1968) and children with communication disorders (Musiek, Gollegly, & Baran, 1984).

Throughout the relatively short history of APD, its operational definition and clinical focus evolved rapidly. Some researchers would argue that this evolution occurred so quickly that evidence supporting the theories and definitions of APD, as well as the clinical utility of diagnostic materials and management strategies, is lagging. This lack of empirical support forces clinicians to rely on clinical intuition and expert opinion regarding diagnostic and management procedures (Cacace & McFarland, 2005a). This lack of support also prompted controversy among researchers and clinicians who strive for American Speech-Language-Hearing Association's (ASHA) gold standard of evidence-based practice (2005).

Of particular interest for the present study is the controversy related to APD intervention techniques. Numerous theoretically based, direct therapy techniques have been proposed and popularized with little or no empirical evidence of treatment effectiveness (Kimura, 1967;

Kinsbourne, 1970). These direct therapy techniques have become the focus of management approaches for APD (ASHA, 2005), exacerbating the need to test the efficacy of direct therapy techniques.

The remainder of the present chapter briefly presents the specific aim of this project. Detailed hypotheses accompanying the aim are presented in the methods proposed in Chapter III.

Specific Aim: Test Dichotic Interaural Intensity Difference (DIID) Training

This study aimed to address the validity of direct therapy for APD. Particularly, this study evaluated dichotic interaural intensity difference (Weihing & Musiek, 2007) training as a rehabilitation strategy for school-aged children with auditory processing deficits. Only one empirical study was published to date that addressed the clinical utility of DIID training in this population (Moncrieff & Wertz, 2008). These researchers administered DIID training to 21 children between the ages of 6 and 14 years in Phase I and Phase II clinical trials. The participants had either a bilateral dichotic listening deficit or a unilateral, left ear deficit. All children were at risk for or had been diagnosed with a language disorder. While Moncreiff and Wertz demonstrated that DIID training could lead to improved left ear performance on dichotic tests, their study procedures did not appear to be driven by ASHA's consensus regarding the operational definition and diagnostic recommendations for APD. The authors did not report whether the children's deficits met ASHA's operational definitions for the diagnosis of APD, did not use baseline, diagnostic tests that represent a comprehensive APD battery, and did not conduct analysis on an individual basis. Additionally, the *Dichotic Digits test* (Musiek, 1983) was the only dichotic listening test used in Phase I. Phase II used the *Dichotic Digits test* (Musiek, 1983) and competing words subtest of the *SCAN-C* (Keith, 2000). The use of a single test was a design weakness because dichotic listening tests vary in difficulty. For example,

closed-set response and open-set response tests are both available commercially (Katz, Basil & Smith, 1963; Musiek, 1983). The closed-set prove easier because the limited number of options makes it easier for the listener to accurately guess the answer. Open-set format is more difficult because the listener must choose the answer from her entire lexicon. Additionally, the stimuli used in tests contain varying degrees of contextual information (Bellis, 2003), thus affecting the difficulty level of the tests. For example, each test item on the *Staggered-Spondaic Words test* (Keith, 1983) consists of one spondee that is presented to each ear. If the listener can process one half of the spondee and possesses adequate linguistic experience and problem solving skills, she can infer the other half of the spondee.

For my thesis, I conducted a study employing an approximate multiple baseline ABA design to evaluate the effectiveness of an intensive, in-home DIID training program and addressed the limits of Moncrieff & Wertz (2008). In order to address these limits, I employed a full battery of behavioral tests as per ASHA's (2005) recommendations, and all participants met ASHA's (2005) operational definition for the diagnosis of APD. Before, during, and after training, I gathered outcome data using multiple APD diagnostic tests, including 4 dichotic listening tests. I conducted a visual examination of the plotted outcome data from each child across tests to determine the effect of training. I predicted these data would suggest that intensive listening training affected performance on the outcome measures. I propose that this investigation of the intensive, in-home DIID training program will allow me to determine whether DIID is efficacious in the context of the field's current construct of APD. Evaluating the efficacy of the listening training is the first step, a back-door entrance, to a long process that will ultimately allow researchers to chip away at the heterogeneous, complex construct that is

APD. I hope that this process will lead to the development of a complete, testable model of APD.

CHAPTER II: REVIEW OF LITERATURE

What is APD?

ASHA is the governing body for the fields of Audiology and Speech-Language Pathology in the United States. Clinicians typically treat information distributed from ASHA as guidelines to ethical and evidence-based practice. Researchers look to ASHA for an understanding of general consensus within the field. The most recent Consensus Statement on APD from ASHA (2005) defined APD as a difficulty/deficit in the neural/perceptual processing of auditory stimuli/information in the CNS that is not due to higher order language, cognitive, or related factors or due to dysfunction in other modalities. A child with APD displays deficits in one or more of the skill areas listed in Table 1 (ASHA, 2005).The present study is particularly concerned with auditory performance in the skills area referred to as *competing acoustic signals*. This skill and the process of dichotic listening that underlies this skill are discussed in detail on page 11.

Skill	***Description***
Sound Localization/Lateralization	the ability to locate sounds on a horizontal plane based on interaural time differences (ITD) and interaural intensity differences (IID)
Auditory Discrimination	the ability to differentiate between different types of auditory stimuli (Bellis, 2003) *e.g.,* gross discrimination such as the difference between a dog's bark and a baby's cry, as well as fine-grained speech sound discrimination
Auditory Pattern Recognition	the ability to recognize patterns in the duration, pitch, and volume of sounds, and in the intervals between sounds It is important for the perception of prosody.
Temporal Aspects of Audition	time-related factors Temporal aspects are important for the perception of speech and music. They are necessary in order to perceive voiced/voiceless distinctions, and the difference between such words as cast and cats (Bellis, 2003)
Auditory Performance in Competing Acoustic Signals	the ability to hear in background noise or with competing messages. This is important for children who must hear a teacher's voice among the rustling of paper and chatter of classmates.
Auditory Performance in Degraded Acoustic Signals	the ability to understand incomplete or corrupted auditory signals For instance, those with deficits in this skill are less able to understand individuals who speak rapidly, mumble, or speak with an accent.

Table 1. Six skills (and their accompanying descriptions) that underlie auditory processing.

The ASHA working group also provided an operational definition to guide clinicians' diagnostic procedures. The operational definition includes three options to yield diagnosis: 1) performance at least 2 standard deviations below the mean accuracy on at least 2 diagnostic tests in the battery 2) performance 3 standard deviations below the mean accuracy on one test in the diagnostic battery, or 3) performance 2 standard deviations below the mean accuracy on one test in the battery with accompanying significant difficulty performing skills that require the process that was 2 standard deviations below the mean.

Evolution of APD

The relatively short history of APD began in the 1950's with adults with confirmed lesions of the central auditory nervous system and children with communication disorders. At that time, some physicians began to note that peripheral auditory tests (*e.g.,* pure-tone audiometry) were not sensitive to detecting the listening problems their neurologically impaired patients faced. In response, these physicians developed auditory tests sensitive to auditory deficits resulting from lesions of the CANS (Baran & Musiek, 1999; Bocca, Calearo, & Cassinari, 1955). These tests evolved into the current diagnostic measures for APD.

Also in the 1950's, Dr. Helmer Myklebust first expressed belief in the importance of evaluating central auditory function of children suspected to have communication disorders (Myklebust, 1954; Wertz, Hall & Davis, 2002). Myklebust believed that traditional, peripheral auditory tests did not provide a *true* measure of hearing. He argued that central auditory processing was cognitively separate from language. He suggested that "true hearing measures" (*i.e.,* measures that incorporate both the peripheral and central auditory systems) may reveal auditory, as opposed to language, deficits in children suspected to have communication disorders (Myklebust, 1954; Wertz, 2002). In the 1970's this belief was set into practice when Willeford developed a battery of CAP tests to assess young children (1976). These tests were similar to the sensitized auditory tests previously used to document deficits in individuals with known CANS lesions. At this point in history, the goal was to *test* the integrity of and look for weaknesses in the CANS. Based on the theories set forth by Myklebust, Willeford and others, researchers hoped that weaknesses within the CANS would explain the children's academic and communication difficulties. Performance on these tests sometimes resembled results documented in adults with lesions (*e.g*., depressed left ear performance on dichotic listening

tasks), leading researchers to infer that a similar physiological mechanism was responsible for the deficits noted in both the adults and the children (Milner, Taylor, & Sperry, 1968; Musiek & Geurkink, 1982; Musiek, Gollegly & Baran, 1984; Musiek, Wilsion, & Pinheiro, 1979; Sparks & Geschwind, 1968).

Controversial Issues

APD has aroused considerable controversy throughout its short history. These controversies typically surround one or more of the following issues: the relationship between APD and cognitive, linguistic, and related factors; relationship between APD and other similar disorders; diagnostic validity; and treatment efficacy.

The relationship between APD and cognitive linguistic factors such as phonological processing, attention, and memory underlies most of the other controversies that have abounded in the study and practice of APD. In 1996, the first ASHA working group charged with alleviating the aforementioned controversy argued that APD was not a diagnostic entity, that cognitive linguistic factors were included in the definition of APD as long as they were being employed for the purpose of processing auditory information (1996). With this philosophy in mind, the working group members argued that it did not matter whether deficits in auditory processing were due to language factors or to deficits in the CANS. They further argued that language processing and auditory processing are intertwined and that treatment in either area would ameliorate deficits in the other areas.

The consensus statement of the ASHA working group failed to placate the field. Some researchers began to argue that the inclusive, lax definition of APD was inadequate (ASHA, 2005; Bellis, 2003; Cacace & McFarland, 1998, 2005a, 2005b; Jerger & Musiek, 2000; McFarland & Cacace, 1995). Specifically, Cacace and McFarland (1998) argued that APD must

be viewed separately from cognitive/linguistic factors. They believed that APD was caused by deficits in only the auditory modality, not by cognitive/linguistic factors that could affect all sensory modalities. These researchers began to investigate the efficacy of testing multiple sensory modalities. They believed that an individual with APD should perform much worse in the auditory modality than in other sensory modalities. These investigations represent an attempt to differentiate the influence of auditory and non-auditory factors on CAP tests using within subject/patient comparisons.

In 2005, another ASHA working group published a second consensus statement on APD. The working group argued against the multimodality testing proposed by Cacace and McFarland, citing a functional mapping study of the auditory activation areas of primates that demonstrated that involvement of a significant portion of the brain, including areas that have been implicated as primary vision areas (Poremba et al., 2003). Despite rejecting Cacace and McFarland's attempts to differentiate auditory processing from cognitive linguistic factors and failing to offer other differentiation methods, the members of the working group concluded that APD is a diagnostic entity that is fundamentally separate from cognitive linguistic functions. Unfortunately, the working group members did not explicitly state what changes occurred between 1996 and 2005 that allowed them to conclude that APD is now a diagnostic entity.

The issues outlined in the 1996 position statement were not settled by the 2005 statement, as evidenced by continued debate within the field and the call for further research towards developing a testable model of APD (ASHA, 2005). However, the diagnostic label caused an ethical dilemma, as clinicians begin to bill for and diagnose a disorder without a complete, testable model and without proper differentiation methods. The working group argued that multidisciplinary assessment is sufficient for separating these two entities, but researchers

continue to assert that better diagnostic measures are needed (ASHA, 2005; Bellis, 2003; Cacace & McFarland, 1998, 2005b; Jerger et al., 2000; McFarland & Cacace, 1995; Poremba et al., 2003).

Controversies have also abounded due to the relationship between APD and similar disorders. If language and cognition are not a part of APD, then cognitive and language disorders must be differentiated from APD. Differentiation is complicated, however, because many disorders show deficits similar to those reported for children with APD. These disorders include, but are not limited to, language/communication disorders, learning disabilities and Attention Deficit/Hyperactive Disorder. The symptoms of these disorders are so similar to the symptoms of APD that some researchers have doubted the existence of APD. (Chermak, Hall, & Musiek, 1999; Jerger & Musiek, 2000). Others have questioned whether APD is a result of attention deficits (Burd & Fisher, 1986; DeMarco, Harbour, Hume, & Givens, 1989; Robin, Tomblin, Kearney & Hugg, 1989) or have hypothesized that APD and ADHD represent a single developmental disorder (Cook et al., 1993; Gascon, Johnson, & Burd, 1986). As with cognitive and language factors, the overlap of APD symptoms with other disorders' symptoms, as clinicians bill for and diagnose a disease that cannot be properly differentiated from other disorders (Jerger & Musiek, 2000).

Without appropriate diagnostic measures that are capable of differentiating APD from the cognitive linguistic factors and similar disorders, clinicians cannot be sure that the recommendations they make are valid and ethical. If APD is solely an auditory disorder, then treatment aimed at correcting this auditory disorder *through stimulation of the CANS* (Bellis, 2003) will not prove beneficial to a misdiagnosed child with an attention or language disorder.

Therefore, the field has an ethical obligation to continue working to develop adequate, differential diagnostic measures and valid, efficacious intervention methods.

The complexities that make APD controversial are problems not only for the clinicians who aim to diagnose and treat APD, but also for researchers who aim to unscramble the complexities and heterogeneities of APD. I argue that if treatment aimed at stimulating the CANS is effective, we may be able to work from what we learn about treatment to begin to tease apart the issues, provide better diagnostic measures, and get to the root of APD.

What is Dichotic Listening?

Dichotic listening allows a listener to understand auditory input with competing acoustic signals. During dichotic listening tasks, different auditory stimuli are presented to each ear individually, but simultaneously (Bellis, 2003). It is then the listener's job to either recall stimuli presented to both ears or attend to particular stimuli presented to only one ear. Formal measurements of dichotic listening consist of tasks of binaural integration and binaural separation. Binaural integration refers to auditory tasks that require the listener to attend to both ears simultaneously and report both stimuli. Binaural separation refers to auditory tasks that require the listener to attend to and report the stimulus presented to one ear, while ignoring the stimulus that serves as an informational masker in the opposite ear. See Figure 1 for a graphic depiction of binaural integration and binaural separation tasks.

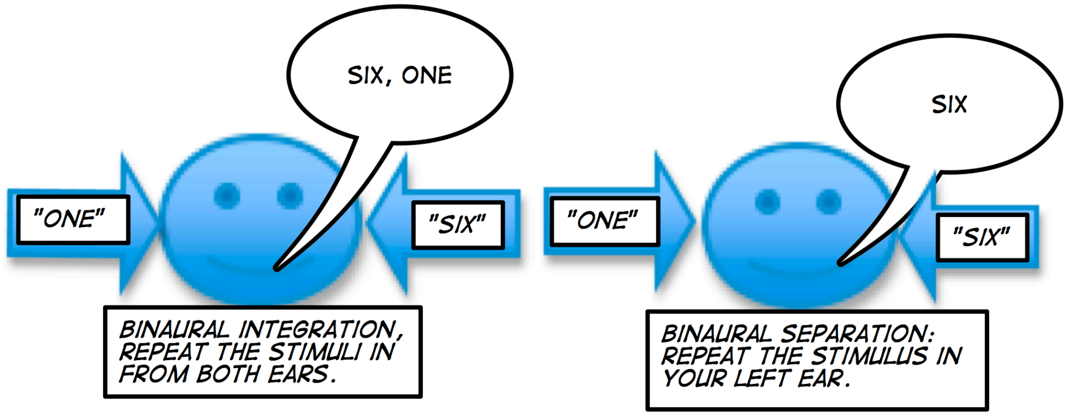

Figure 1. Representations of binaural integration and binaural separation. The stimuli enter each ear simultaneously. During tasks of binaural integration, the person attends to stimuli in both ears. During binaural separation, the person attends to stimuli in only one ear.

Physiology of Dichotic Listening

The behavior of dichotic listening is a result of the physiology of the auditory system. There are two afferent pathways that lead from each ear to each respective hemisphere of the brain. The contralateral pathways lead from the left ear to the right hemisphere and from the right ear to the left hemisphere (Kimura, 2006). See Figure 2.

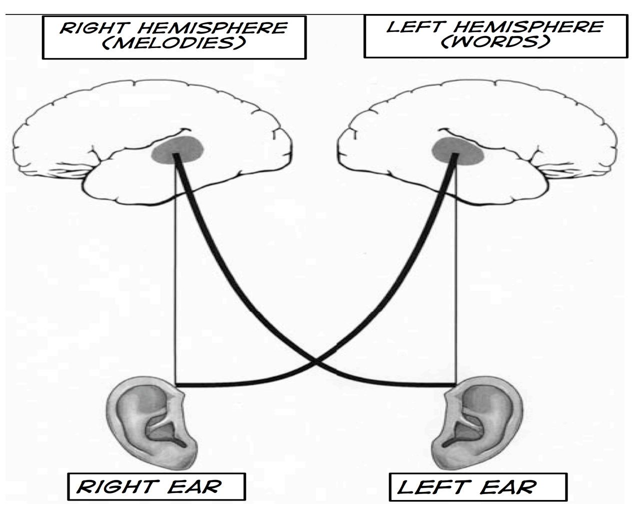

Figure 2. Illustration of the physiological mechanism that underlies dichotic listening, including the stronger, contralateral and weaker, ipsilateral pathways (Kimura, 2006).

The contralateral pathways are larger and more salient than the ipsilateral pathways. They lead from the left ear to the left hemisphere and from the right ear to the right hemisphere (Rosenzweig, 1951). The majority of spoken language processing occurs in the left hemisphere in 98% of right-handed people, and 60% of left-handed people (LaPointe, 2005). This means that for the majority of human listeners, the right ear is directly connected to the language regions of the brain via the strong, contralateral pathway. Research indicates that this direct, contralateral connection results in what is known as a *right ear advantage* during dichotic listening tasks in individuals with normal development and peripheral and central hearing systems. The right ear advantage refers to listeners' ability to accurately attend to and identify more information in the right ear compared to the left ear (Bellis, 2003; Broadbent, 1954). Among individual theorists, the consensus is that the contralateral auditory pathways suppress the ipsilateral auditory pathways during dichotic listening tasks. Therefore, stimuli presented to the right ear directly access the language processing regions in the brain through the contralateral connection, while stimuli presented to the left ear must cross the contralateral pathway to the right hemisphere and cross the corpus callosum before accessing the language regions (Kimura, 1967; Kinsbourne, 1970). See Figure 3.

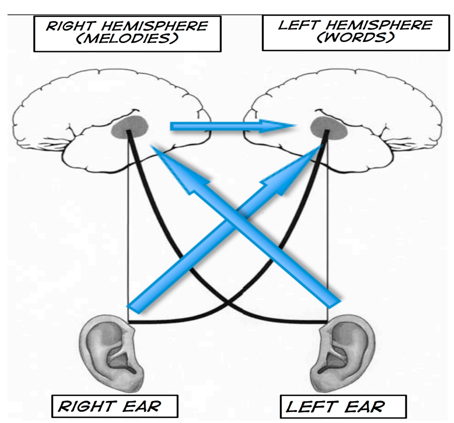

Figure 3. Depiction of the primary, contralateral pathways from each ear to the language domain of the brain, in the left hemisphere.

Just as there is a right ear advantage in listeners with normal hearing and development, *deficits* in dichotic listening tend to be asymmetrical, with greater deficits in the *left* ear. In other words, listeners with dichotic listening deficits usually present inflated, right ear advantages as a result of a significant left ear *disadvantage* within the CANS. This left ear disadvantage is observed in adults with lesions of the corpus callosum, some of whom cannot repeat aloud information presented to the left ear during dichotic listening tasks at all (Damasio et al., 1976, 1979; Milner et al., 1968; Musiek et al., 1979, 1982; Sparks & Geschwind, 1968). The same left ear disadvantage is observed in children diagnosed with APD (Moncrieff, 2006). That is—one of the diagnostic landmarks of children with APD is a significant left ear *disadvantage* on dichotic listening tasks. Details of the physiological theories behind the right ear advantage are described on page 15.

The signature right ear advantage observed in listeners with normal hearing and those with APD allows for within-subjects (*i.e.,* interaural) comparisons on formal tests, thus strengthening the validity of test results and studies that aim to test the efficacy of dichotic listening training using these tests as a measure of performance. The hallmark, left ear disadvantage of dichotic listening deficits is difficult to ascribe to non-auditory cognitive factors, such as attention and language, because it is assumed these non-auditory factors would affect both ears similarly given each individual's neurophysiology (Martin, Jerger & Mehta, 2007). This aforementioned interaural comparison is not possible with monaurally and binaurally presented tests because there is no noted left ear disadvantage in auditory processing when stimuli are presented monaurally or diotically. There is no right ear advantage for monaural tests, because there are no competing stimuli to suppress the ipsilateral pathways in the listener's CNS. During binaural tests, there is only one listening measure collected from the listener,

which represents the accuracy achieved when *both* ears work together. The right ear advantage noted during dichotic listening tasks is one reason I chose to study dichotic listening, as opposed to the other processes documented to contribute to a diagnosis of APD. See Table 1. Dichotic listening tasks provide a ready-made, within-subjects experimental design.

Theoretical Models of Dichotic Listening

The two most influential models of dichotic listening are the *Structural Model* (Kimura, 1967) and the *Attention Model* (Kinsbourne, 1970). Both of these models are based on the right ear advantage observed in normal listeners and the physiological data presented in the preceding section, as well as data documenting left ear deficits in dichotic listening in patients post corpus callosotomy. The Structural Model is the most widely accepted in the pediatric APD literature. It states that the stronger, contralateral and the weaker, ipsilateral auditory pathways discovered by Rosenzweig (1951) physically overlap at some location along the afferent auditory pathway. When competing stimuli are presented to both respective ears, the contralateral connections inhibit the ipsilateral connections at each point of overlap in the pathway. The Attention Model is typically cited in the psychology literature examining auditory attention. In contrast to the Structural Model, the Attention Model states that the right ear advantage occurs because the listener's anticipation of verbal stimuli primes the language-dominant (left) hemisphere, thereby *directing attention* to the contralateral (right) ear.

Although the Structural model is cited more frequently in the pediatric APD literature, both models support the efficacy of the training that I used in the present study. Weihing and Museik (2008) cite the Structural Model and argue that dichotic listening training can strengthen the weaker, ipsilateral connection that has direct access to the language-dominant hemisphere. The Attention model could easily account for a decrease in left ear disadvantage following

training as well. According to the Attention Model, improvements in dichotic listening after Dichotic Interaural Intensity Difference (DIID) training could be ascribed to training the listener to direct attention to the ipsilateral (left) ear.

Dichotic Listening in Children

Children became the center of clinical utility for dichotic listening in the same manner that children became the center of clinical utility for APD. Recall, scientists first used dichotic listening tests to assess the integrity of the CANS in children suspected of communication disorders (Myklebust, 1954) in the hopes of discovering a causal link between auditory processing deficits and language disorders. Like adults with callosal lesions, children with deficits in dichotic listening typically performed significantly better in the right ear as compared to the left ear. For example, in a study by Moncreiff (2006) 84% of children with dichotic listening deficits on a binaural integration task also had significant left ear disadvantage on a binaural integration task when required to repeat the auditory stimuli aloud, suggesting that children with dichotic listening deficits perform similar to adults with lesions of the corpus callosum. Researchers inferred that a similar physiological mechanism is responsible for findings of left ear disadvantage (decreased left ear performance) in adults with lesions of the CANS and children who perform similarly on dichotic tests (Milner et al., 1968; Musiek, Geurkink & Kietel, 1982; Musiek, Gollegly, & Baran, 1984; Musiek, Wilsion & Pinheiro, 1979; Sparks & Geschwind, 1968).

As previously stated, the dichotic listening tests used by both populations were developed for adults with callosal lesions since the corpus callosum is implicated in interhemispheric transfer. Electrophysiological evidence also supports the theory that a similar physiological mechanism is responsible for the deficits shown by children with APD and adults with lesions of

the corpus callosum. Electrophysiological evidence indicated that full myelination of the corpus callosum does not occur until 10 to 12 years of age (Salamy, 1978). Salamy calculated myelin development using evoked potentials to track the development of the myelination of the corpus callosum. He placed electrodes on the temporal areas of the head and subtracted the latency of the contralateral connection from the latency of the ipsilateral connection during dichotic listening. This calculation was considered a measure of transfer time across the corpus callosum.

A time course similar to the maturational time course noted by Salamy was reported for left ear dichotic listening development (Musiek & Gollegly, 1988). This is important because it provided correlation data favoring previously outlined dichotic listening models that implicated the corpus callosum in the right ear's pathway. Left ear stimuli must travel over the corpus callosum to get to the language center during dichotic listening. The authors of the training regiment assert a causal link between delays in myelination of the corpus callosum and left ear performance on dichotic digits task. Musiek, Gollegly, & Baran theorize that children with significant delays in myelin development experience decreased interhemispheric transfer, resulting in a left ear disadvantage for dichotic listening (1984). However, research has shown that decreases in interhemispheric transfer after corpus callosum section also lead to implication for visual perception (Gazzaniga, 1970). Specifically, patients with reduced interhemispheric transfer following section of the corpus callosum have difficulty cross-integrating visual information (Gazzaniga, 1970). Salamy's (1978) findings explain similarities in test findings between children with dichotic listening deficits and concomitant language and academic difficulties and adults with lesions in the corpus callosum. However, if the deficits in dichotic listening observed in pediatric populations were caused by difficulty in interhemispheric transfer, we would expect to see problems in other sensory modalities as well (Gazzaniga, 1987).

Dichotic Interaural Intensity Difference (DIID) Training

Dichotic Interaural Intensity Difference (DIID) training is a direct remediation strategy that attempts to habilitate dichotic listening deficits (Weihing & Musiek, 2007). The goal of DIID training is to raise left ear performance to a “typical level” without decreasing right ear performance. Briefly, there are two steps involved in conducting DIID training. The first step is to decrease the strength of the contralateral auditory pathways leading from the right ear to the left hemisphere, thereby decreasing the degree to which the contralateral pathway suppresses the ipsilateral pathway leading from the left ear to the left hemisphere (Weihing & Musiek, 2007). In order to reduce this suppression, the intensity of the signal presented to the right ear is decreased relative to the left ear. Evidence (Musiek, Wilson, & Pinheiro, 1979) showed that decreasing the volume in the right ear leads to higher accuracy in the left ear on dichotic listening tasks. The authors (Weihing & Musiek, 2007) of “Dichotic Interaural Intensity Difference (DIID) Training,” who advocate for DIID training, theorize that the lower intensity sound uses less neural substrates, thereby releasing suppression of the ipsilateral pathway. The second step of DIID training is to train the left ear ipsilateral connection under increasingly challenging listening conditions. The increasingly challenging listening conditions are created by systematically increasing the intensity in the right ear over time (Weihing & Musiek).

Theoretical Basis of DIID

All direct remediation strategies for APD are based on the theory that stimulating the CANS can change the structure of the brain and improve auditory processing abilities (Bellis, 2003). Like other direct remediation APD strategies, DIID training aims to establish long-term change in the CANS by taking advantage of the plasticity of the human brain (DiFilippo et al., 2009; Weihing & Musiek, 2007). DIID training has theoretical parallels in the adult

neurogenically disordered population. For example, research (Moncrieff & Wertz, 2008; Page, Sisto & Levine, 2002, Schaecter et al., 2002) showed that after a cerebrovascular accident, stroke victims with unilateral motor weakness benefited from motor training that involved inhibiting the stronger side of their bodies while exercising the weaker side in order to take advantage of plasticity that would lead to reorganization of central motor pathways.

Based on the Structural Model, there are two possible physiological explanations for successful remediation of dichotic listening deficits using DIID training. See page 15 for more information on the Structural Model. As previously stated, scientists theorized that insufficient myelination leads to reduced interhemispheric transfer of auditory information, which in turn causes a greater-than-normal left ear disadvantage in dichotic listening tasks. If DIID training leads to cortical reorganization (as implied by its reliance on the brain plasticity for change), there must be a physiological correlate within the CANS that accounts for training effects. There are two possibilities. The first proposed physiological correlate of change is increased myelination of the corpus callosum. However, a delay in myelination of the corpus callosum would results in a host of problems unrelated to audition (Gazzaniga, 1987). The second proposed physiological correlate of change is that the ipsilateral connection becomes stronger and more resistant to the suppression of the contralateral connection. This proposed physiological correlate is consistent with the Structural Model, and Weihing and Musiek argue that stronger, more resistant contralateral pathways are the physiological cause of behavioral changes in dichotic listening observed following training (2007).

Efficacy Data

There is very little data to support the efficacy of DIID training. However, several studies have been undertaken to document the changes that occur as a result of specific auditory training. Particularly, evoked potential studies have demonstrated treatment focused on speech discrimination (Kraus et al., 1995; Tremblay & Kraus, 2002) and speech sound training (Tremblay & Kraus, 2002) caused physiological changes within the CANS.

The efficacy data provided by Weihing and Musiek, the authors of the training regiment, are limited. In a non-peer-reviewed text, Weihing and Musiek (2007) referenced two case studies of neurologically impaired adults who received benefits from training. The authors also included one case study of a fifteen-year-old boy with a learning disability (Musiek & Schochat, 1998) in this text. This boy had a bilateral deficit in dichotic listening. Following 6 weeks of training, accuracy in both ears improved to within normal limits. Although these studies suggest that DIID may benefit listeners, they lack the rigor of an empirical study with an *a priori* hypothesis. To date, there was only one empirical study (Moncrieff & Wertz, 2008) that examined the efficacy of DIID training.

Following a training format loosely described by Bellis (2003), Moncrieff & Wertz ran Phase I and Phase II clinical trials to test whether dichotic listening could be trained using DIID training in children with left ear disadvantages on the Dichotic Digits test. Phase I included children between 7 and 13 years of age with normal intelligence and pure-tone thresholds. The children were divided into two groups based on their dichotic performances: Left Ear Deficits (LED) and Bilateral Deficits (BLD). LED children had normal right-ear accuracy scores, below-normal, left-ear accuracy scores, and significant left ear disadvantages. BLD children had accuracy scores below the normal range bilaterally on dichotic listening tests along with

significant left ear disadvantage. Phase I included a diverse sample of children: 7 of the children had language disorders, 1 was taking medication for Attention-Deficit/Hyperactive Disorder, and 1 had Arnold Chiari Malformation. This diverse sample was used to test whether benefits of DIID training were similar across special populations. While this was an important question, it complicated the interpretation of results relative to the current study, due to the comorbidity of auditory and cognitive linguistic disorders.

Moncrieff and Wertz's dependent variables included accuracy on the Dichotic Digits test of binaural integration (Musiek, 1983), the Low-Pass Filtered Speech test of monaural low redundancy (Willeford, 1977) and the Frequency Pattern Sequencing Test of temporal ordering (Ptacek, 1971). Over a 4-week period, the children participated in 8 to 11 training sessions in a sound-attenuating booth. Stimuli were presented via loud speakers, and the experimenter subjectively judged when to adjust the presentation levels. Recall that during DIID training, the volume in the right ear is decreased at the start, and then systematically increased to make the task more challenging. Following training, Moncrieff and Wertz showed that 7 of 8 participants improved in left ear accuracy scores on the Dichotic Digits test. Paired samples t-tests showed significant growth across all 8 children on left ear performance on the Dichotic Digits test. Additionally, upon visual inspection, 5 of 8 children improved right ear performance on the Dichotic Digits test from pre-training to post-training. LED children improved more than BLD children. However, only 2 of the 8 children achieved the ultimate goal of attaining performance levels within normal limits in both ears. No significant improvement in performance accuracy was noted on non-dichotic tests.

During Moncrieff & Wertz's Phase II trial, the number of training sessions was increased to evaluate whether training duration correlated with improvements on dichotic listening tests.

This phase included 13 children between 6 and 11 years of age who were at risk for language disorders. This phase included two measures: the *Dichotic Digits* test (Musiek, 1983) of binaural integration and the Competing Words section of the *Scan-C* test (Keith, 2000) of binaural separation. Training took place in a sound-attenuating booth using soundfield presentation, 4 times per week and lasted between 4 and 7 weeks. Phase II included the LED and BLD groups and an additional control group of children who scored within normal limits bilaterally on both measures. Results of Phase II indicated significant improvements in accuracy bilaterally for both tests, with greater gains in the left ear. The left ear disadvantages in the BLD and LED groups disappeared on the Dichotic Digits test, but remained on the Competing Words test. Similar to Phase I, LED children improved more than BLD children. Though no significant effect of training was noted, some children continued to tolerate decreasing interaural intensity differences over the entire 6-week duration of training.

As a whole, results of Moncrieff & Wertz (2008) support the efficacy of DIID training—the majority of children receiving the training showed left-ear improvement on dichotic listening tasks. However, there are several weaknesses that need to be addressed before the DIID training method can be recommended clinically for the remediation of dichotic listening deficits. First, the experimenters provided a loosely detailed description of DIID training, which does not constrain or regulate the training across participants. Thus, each trainer is allowed to decide on the duration of training and to subjectively determine when and by what degree to adjust volumes during training. Secondly, Moncrieff & Wertz only used one measure of dichotic listening in Phase I and only two measures in Phase II. Improvements in dichotic listening resulting from DIID training should be demonstrable across different dichotic listening tests. As stated in Chapter I, the use of multiple tests of dichotic listening is ideal because the tests vary in

difficulty and in the amount of contextual information inherent in each. Additionally, neither phase included a complete behavioral APD battery (ASHA, 2005). Therefore, the researchers did not test the effects of training on all of the auditory processes (Table 1). In Moncrieff & Wertz's Phase II, no non-dichotic tests were used to test the generalization of benefits to non-dichotic auditory processing, so it is unclear whether additional training led to benefits in non-dichotic processes. Another weakness of this study is that the researchers' inclusion criteria were not clinically motivated. They never mentioned whether participants were diagnosed with APD by an audiologist or whether they met ASHA's operational definition for the diagnosis of APD. Finally, the use of soundfield presentation is a big limitation because stimuli presented tin a soundfield reach both ears, thereby making the task one of diotic listening, not dichotic listening. My study outlined in Chapter III addresses these weaknesses in hopes of laying a foundation upon which differential diagnostic materials can be developed to assess dichotic listening.

Summary of the Current Study

The complex, heterogeneous nature of language, auditory processing, and general cognitive processing continues to cause controversy and complicate the diagnosis of APD in children. Without appropriate diagnostic measures, the validity of direct remediation strategies and the ethics of providing and billing for these services are, at best, questionable. After reviewing the confounding issues, it is clear that a "back door", reductionist approach is the best option for unscrambling the construct of APD. I argue that dichotic listening is an appropriate starting point for unscrambling because interaural auditory differences are difficult to ascribe to non-auditory factors (Jerger & Musiek, 2000; Moncrieff, 2006). This auditory independence lends validity to dichotic listening test measures within the clinic and the laboratory. I predict

that if DIID training can remediate dichotic listening deficits, results of this study would support the use of this training method and would provide data about the nature and construct of dichotic listening. Particularly, results in the predicted direction would support both the Structural Model and Attention Model of dichotic listening discussed on page 15.

CHAPTER III: METHODS

I tested the effects of Dichotic Interaural Intensity Difference (DIID) training in 4 children. In order to complete this study, I conducted 10 weeks of in home, DIID training. I gathered baseline, probe and post-treatment measurements and compared performance over time. The assessments consisted of dichotic and non-dichotic auditory processing diagnostic tests. These methods allowed me to address the following hypotheses. Based on the only empirical study to date (Moncrieff & Wertz, 2008), I predicted that left ear performance on dichotic listening tasks would improve as a result of intensive, in-home, DIID training from baseline to probe measures and from probe to post-assessment measures. This hypothesis was motivated by the results of Moncrieff and Wertz's study. I also predicted that participants in my study would show no notable improvements on non-dichotic auditory processing tasks. This prediction was based on theoretical models of dichotic listening. Neither the Structural Model nor the Attention Model would account for improvement in non-dichotic processing, because the goal of training is to release the ipsilateral pathways from suppression. The non-dichotic tests, are presented either diotically or monotically, so that the ipsilateral pathways are not suppressed. For more information, see page 14.

Participants

Four (1 female) school-aged children recently assessed for APD at Louisiana State University's Speech, Language & Hearing Clinic participated in the current experiment. Participants ranged in age from 9 years; 1 month to 10 years; 2 months (M = 9 years; 5 months SD= 5 months) at baseline (B2). All participants were previously diagnosed with APD in accordance with ASHA's (2005) standards. All participants also demonstrated a deficit in dichotic listening, defined as 2 SD below the mean performance level for each participant's

respective age group on at least one formal dichotic listening test in the diagnostic battery at Louisiana State University. All research participants had hearing levels and cognitive functioning within normal-limits. All participants came from language environments consisting solely of American-English speakers. Participants were compensated $20.00 for each assessment and $10.00 for each week of training.

Experimental Design

This study employed an approximation of a multiple baseline ABA design to study the effects of treatment with DIID training on the dichotic listening deficits of children with APD. Baseline phase consisted of 2 or 3 (B1, B2, B3) preliminary APD assessments with no training. The treatment phase consisted of 10 weeks of DIID training. A probe measure followed after approximately 5 weeks of training (probe). Finally, a post-assessment (P1) was conducted between 7 and 10 weeks (M = 7.75; SD = 1.30) following the completion of training.

Inclusion Measures

A*pparati*

Middle ear integrity was assessed using a Granson Stradler, Inc. GSI-33 Middle Ear Analyzer. Pure-tone audiometry was conducted with a GSI-63 Clinical Audiometer and bilateral insert earphones. Cognitive function, birth history, and language environment were determined via a parent questionnaire (see Appendix A).

Objective Definitions for Inclusion

I sent recruitment letters to families with children between the ages of 9 and 12 years if clinical records indicated that the child's previous APD assessment rendered performance 2 SD below the mean for their respective age groups on at least one dichotic listening test in the battery. In conjunction with ASHA (2005) recommendations, each child also had to perform 2

SD below the mean for his respective age group on at least one additional test in the battery (Chermak & Musiek, 1997). Participants' hearing was screened at the Louisiana State University Hearing Clinic. The screening consisted of tympanometry and a pure tone audiometry screenings at 15 dB HL for the frequencies 500, 1000, 2000, and 4000 Hz, in a double-walled, sound attenuating booth. Participants' mothers also reported cognitive function within normal limits on a questionnaire by indicating "no" on the following question: "Has your child been diagnosed with a cognitive disorder? Or is his/her cognitive function below average?" While answering the same questionnaire, all participants' mothers also wrote that English was spoken in their homes 100% of the time.

Baseline Measures

Accuracy on an APD assessment served as a baseline for six of the seven tests within the battery. Number of errors served as a baseline for the final test.

Stimuli

The assessment included 4 dichotic listening tests: the *Dichotic Digits* (DD; Willeford, 1977) and *Staggered Spondaic Words* (SSW; Katz,1962)—tests of binaural integration—and the *Competing Sentences* (CS; Willeford & Burleigh, 1994) and *Synthetic Sentence Identification with Contralateral Competing Messages* (SSI-CCM; Jerger & Jerger, 1975)—tests of binaural interaction. Three additional audiologic tests were included as measures of non-dichotic auditory processing: the *Frequency Pattern Sequencing Test* (FPST; Pinheiro & Ptacek, 1971)—test of temporal patterning, the *Word Recognition in Noise* (WRN; Etymotic Research, 1993)—of monaural low redundancy, and the *Rapidly Alternating Speech Perception* test (RASP; Willeford, 1977) of binaural interaction (see Table 2).

Test Name	Process Assessed
Dichotic Digits Test	Binaural Integration, Dichotic Listening
Staggered Spondaic Words Test	Binaural Integration, Dichotic Listening
Competing Sentences Test	Binaural Separation, Dichotic Listening
Synthetic Sentence Identification with Contralateral Competing Messages	Binaural Separation, Dichotic Listening
Frequency Pattern Sequencing Test	Temporal Ordering
Word Recognition in Noise Test	Speech in Noise
Rapidly Alternating Speech Perception Test	Binaural Interaction

Table 2. List of the names of each tests used in the current study and the process that each test assesses.

Apparatus

The baseline assessments took place in a double-walled, audiological testing suite at the Louisiana State University Hearing Clinic using a *GSI-63 Clinical* Audiometer, bilateral insert earphones, and either a *Sony* five-disc changer or *Dell Inspiron* laptop with *iTunes* music player software (Apple, 2000).

Procedures

All participants completed the baseline assessments individually. Figure 4 presents a schema of the procedures for the present study. The first baseline assessment was gathered from the clinic records used to recruit participants. Upon each participant's arrival, informed participant assent and caregiver consent were obtained. The participant then completed the pure-tone testing and tympanometry while the caregiver completed the questionnaire (Appendix A).

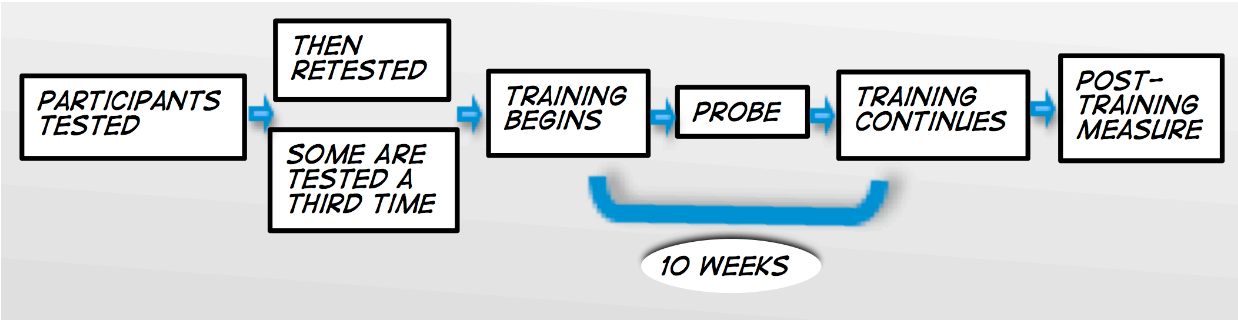

Figure 4. Visual schemata of the procedures use in this study. Note that there are 10 weeks between the beginning and end of training.

If a participant met all inclusion criteria, the baseline assessment followed. The researcher seated the participant in a chair facing the observation window of the testing suite. Before inserting the earphones, the researcher explained the procedures to the participant. The researcher told the participant that she (the researcher) would be seated on the other side of the window. She showed the participant a microphone above the window and told the participant that he could speak to the researcher through the microphone. The participant was told to listen carefully through the earphones. The participant was told that he would hear words, sentences, and beeps, and that he should pay close attention. The participant was also instructed that if he needed a break, he should tell the researcher and would be granted a break at any time. Additional test-specific oral instructions were given before each test. A certified audiologist recommended the instructions for individual tests. The instructions for each individual test can be found in Appendix B. Baseline assessments lasted between one and three hours depending on the attention span of the child and the number of breaks requested. A *Nintendo DS* (Nintendo, 2004) was given to the participants to play with during the test interims while the experimenter calibrated the audiometer for each test's stimuli. Parents were not present during assessments.

Treatment: weekly dichotic listening training

Stimuli

Five (3 female) native-English, Baton Rouge residents recorded the training stimuli. Talkers' ages varied between 20 and 37 years. Stimuli were recorded using a *Marantz PMD670* professional solid-state digital recorder and a *Shure KSM9 Performance* microphone in a single-walled, sound booth. Prior to recording, each talker was instructed to read each item on the list clearly and naturally into the microphone. Each talker was also told to pause between each item to avoid coarticulation of stimuli. The recorded sound files were transferred from the digital recorder to a *Dell Latitude* Laptop where they were edited and equated for r.m.s. amplitude level using *Adobe Audition 2.0*.

The training stimuli consisted of the *Modified Rhyme Test* (House, 1963), the *Northwestern University Auditory Test Number Six* word lists (NU-6; Wilson & Oyler, 1997), *Central Institute of the Deaf W-22* word lists one and two (W22; Wilson & Oyler, 1997), the digits 1 through 10 (excluding 7), Monsen (1983) sentences, and words inspired by the *Peabody Picture Vocabulary Test* (PPVT-III; Dunn, 1997) pictures. NU-6 and W-22 word lists, along with the list of digits, were ordered randomly using a random number generator. These stimuli were employed during training to emulate tasks of binaural separation and binaural integration. During tasks of binaural separation, one of the stimuli lists was presented to one channel and *CID Multitalker Noise* was presented to the opposite auditory channel. For tasks of binaural integration separate lists were simultaneously delivered via each channel. Edited stimuli lists had the same start time regardless of the channel of delivery. Due to variation in stimulus duration, the lists were equated for duration by manipulating each list's interstimulus interval using *Adobe Audition* 2.0.

Apparatus

A Dell Latitude laptop computer, *Adobe Audition 2.0*, and *Peltor Listen-Only High-Attenuating circumaural* headphones were used to administer the weekly, in home listening training to each participant. The laptop computer and headphones were calibrated prior to training using a 6cc coupler and a sound level meter.

Procedures

Two experimenters were trained to conduct the weekly DIID training. Training took place after school between 3:30 PM and 6:30 PM on weekdays. Each participant received training 3 days/week individually in a quiet room with an experimenter. Three children received training in their homes. The remaining participant received training at an after-school care facility.

Crossover. During the first training session, recordings of the monosyllabic digits were used to establish the crossover level for the participant. Crossover level is "the [interaural intensity difference] at which performance in the poorer ear exceeds performance in the better ear" (Weihing & Musiek, 2007, p. 289). For this study crossover levels were established as follows, in conjunction with the recommendations of Weihing and Musiek. The experimenter told the participant that she would hear different numbers in each ear. The experimenter further instructed the participant to repeat the numbers aloud. The experimenter placed the headphones on the participant and set the computer's volume at the appropriate level. Twenty digits were presented simultaneously in each of the two auditory channels resulting in a binaural integration task. All digits were of equal intensity. The experimenter recorded and scored the participant's verbal responses for accuracy. The ear that demonstrated the higher percent accuracy was deemed the dominant ear. The intensity in the dominant ear was decreased in 7 dB increments

until the accuracy of the non-dominant ear exceeded the accuracy of the dominant ear. The remainder of training focused on the non-dominant ear.

Listening training. Training began immediately after establishing crossover for each participant. The interaural intensity difference used at the start of training was 3 dB greater than the crossover level (*i.e.,* the intensity in the dominant ear was 3 dB softer than the crossover level). Each training session lasted approximately 20 minutes. During each session, the experimenter provided directions similar to those used while establishing crossover. The experimenter adjusted the directions according to the task at hand (e.g., binaural separation or binaural integration). During binaural separation tasks, the experimenter told the participant that she would hear something that sounded like a party in her right (dominant) ear (i.e., multitalker babble). The experimenter instructed the participant to ignore the party she could hear in their right (dominant) ear and report what she heard in the left (non-dominant) ear. During binaural integration tasks, directions were similar to those used to initially establish crossover. The instructions were also adjusted based on the type of stimuli used. For example, the participant was informed whether she was listening to words, sentences, or numbers. As during crossover, the experimenter recorded verbal responses. At the start of each of the 10 weeks, an attempt was made to lower the interaural intensity difference by 5 dB. If the participant did not tolerate the change (the performance in the dominant ear again exceeded performance in the dominant ear), the experimenter again increased the intensity level in the dominant (right) ear in 1 dB increments until the experimenter found a level at which the listener was again performing more accurately in the non-dominant (left) ear as compared to the dominant (right) ear.

Post-treatment Assessment

Training Assessment Probe

A mid-training assessment probe was conducted after approximately 5 weeks of training. This assessment was identical to the last baseline assessments.

Two-Month Post-Treatment Assessment.

A post-treatment assessment (P1) was conducted approximately 2 months after training ended. This assessment was also identical to the last baseline assessment.

CHAPTER IV: RESULTS

This study was an approximation of a multiple baseline ABA design. Due to complications with data collection and measurement, I interpreted the results following one of the methods of Moncrieff and Wertz (2008) and visually inspected each indivdiual's graphed outcome data. This chapter will report the outcome data for each of the 4 participants on all of the 7 APD tests. Graphs for each participant show either accuracy or number of errors (depending on test's outcome measure) across baseline (B1, B2, B3), treatment (probe) and post-treatment (P1) phases. Norms for each test are also depicted in the graphs. Note that these norms represent the test writers' recommendations for each individual test. The norms are *not* based on psychometrically sound, normative data collected in a traditional manner. Because of the longitudinal nature of this study, norms sometimes change for an individual child, for the same score, within one graph. On each of the graphs, data plotted in the color red represents the performance of the right ear and data plotted in the color blue represents the performance of the left ear. Additionally, normative scores for the right ear are plotted in red with dotted lines, and normative scores for the left ear are plotted in blue with dotted lines.

Staggered Spondaic Words (SSW) Test

Performance results on the *Staggered Spondaic Words test* of binaural integration are graphed for each participant in Figures 5. The X-axis displays time of assessment in weeks, relative to the start of training (week 0). The *SSW* test is scored according to the number of errors the listener makes. Therefore, improvements in dichotic listening are visualized when a *decrease* in scores on the y-axis is noted over time. This test includes two scores for each ear: the competing score and non-competing score. The competing scores indicate that the stimulus was presented at the same time as another stimulus; the non-competing score indicates that the

stimulus was presented alone. Note the normative values on each graph, which show that errors are more likely to occur in the competing condition than the non-competing condition. There was no group trend among participants' performance on the *SSW* test; thus DIID training did not seem to affect the errors made by participants on the *SSW*.

RP1 SSW Results

RP1's individual data is pictured in Figure 5, Quadrant I (top left). Note the number of errors for the non-competing condition in each ear were (left = blue X data points, right = red ● data points) greater than the normative values for both baseline measures (B1, B2). At probe, the left ear non-competing measure decreased to 0 errors and remained as such during the post-treatment measure (P1). At the time of probe, the right ear non-competing measure decreased to just within normative values. During P1, there were no errors in non-competing right ear measures.

During the first baseline measure (B1), RP1 made errors in the right ear competing stimuli condition (red ▲ data points) that exceeded the normative values. By the second baseline measurement (B2), however, performance was just within normative limits. The left ear competing performance (blue ■ data points) was within normative limits at B2, and decreased slightly at probe. During P1 assessments, the number of errors increased relative to B2 measures and exceeded normative limits.

RP2 SSW

RP2's individual data is pictured in Figure 5, Quadrant II (top right). Overall, *SSW* data indicated that RP2 did not benefit from training. Non-competing left ear (blue X data) and noncompeting right ear (red ● data) scores were within normative limits throughout B2, probe, and P1 measures. Though already within normative values, the number of errors in the right ear

decreased slightly from probe to P1. The number of errors for the competing condition for the left ear (blue ■ data points) exceeded normative limits for all measures. Right ear competing performance (red ▲ data points) was outside normative limits through B1 and B2 and decreased to within normative limits during probe. However, this effect was not reflected in P1, which again exceeded normative limits.

RP3 SSW

RP3's individual data is pictured in Figure 5, Quadrant III (bottom left). *SSW* data indicated that RP3's left ear performance in competing stimuli (blue ■ data points) improved both during training (probe) and after the completion of training (P1). Right ear competing and non-competing performance levels (red ▲ and red ● respectively) were within normative limits throughout B3, probe, and P1 measures. Non-competing left ear performance (blue X data points) was within normative limits throughout measures, with the exception of a probe error count above normative values

RP4 SSW

RP4's individual data for the *SSW* test is pictured in Figure 5, Quadrant IV (bottom right). In both competing conditions (left = blue ■ data points; right = red ▲ data points), RP4's errors decreased throughout the three baseline measures (B1, B2, B3), yet the number of errors in both ears continued to remain above normative limits. In the left ear competing condition (blue ■ data), RP4's number of errors decreased from B3 probe and remained consistent from probe to P1. Despite the decrease in the number of errors for left ear competing condition (blue ■ data points) from B3 to treatment probe, RP4 never reached normative limits in the left ear competing condition. The number of errors also decreased from B3 to probe in the

right competing condition (red ▲ data points). This decrease placed RP4 within normative limits for the number of errors in the right competing condition of the *SSW* test. Though errors in right ear competing performance (red ▲ data points) increased from probe to P1, performance remained within normative limits. In the right ear noncompeting condition (red ● data points), RP4 made more errors than allowed by test norms for this condition during all baseline measures and during the probe. However, when retested during the P1, RP4's number of errors in the right, noncompeting condition (red ● data points) decreased to within normative limits. The number of errors on left ear, noncompeting stimuli (blue X data points) were greater than the normative values provided by test writers throughout all measurements.

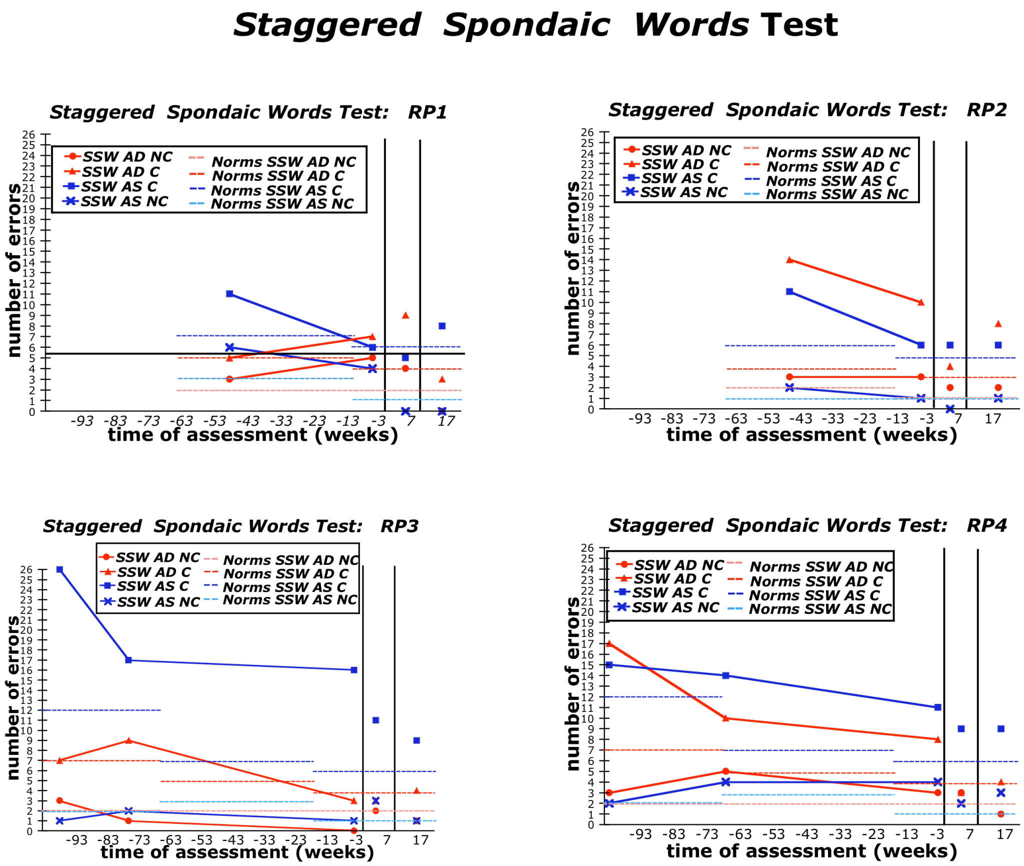

Figure 5. Depiction of the number of errors each participant made on the *Staggered Spondaic Words* test over time. RP1's data is on the top left (Quadrant I). RP2's data is on the top right (Quadrant II). RP3's data is on the bottom left (Quadrant III). RP4's data is on the bottom right (Quadrant IV).

Dichotic Digits (DD) Test

Results of the *Dichotic Digits* test of binaural integration are graphed in Figure 6 for each participant. The X-axis displays time of assessment in weeks, relative to training (week 0). The *DD* test is scored in accordance with individual ear accuracy. Therefore, improvements in dichotic listening are visualized when an *increase* in accuracy scores on the y-axis is noted over time. A brief scan of each graph shows that all participants were within normative limits for at least one condition throughout measures. One participant (RP2) was outside normative limits for

right ear performance, another (RP4) for left ear performance during B1 measures. During P1 measures, all participants were within normative limits bilaterally (see Figure 6).

RP1: DD

RP1's individual data is pictured in Figure 6, Quadrant I. RP1 was within normative limits throughout all measures.

RP2: DD

RP2's individual data is pictured in Figure 6, Quadrant II (top right). Performance was below normative limits bilaterally for both B1 measures on the *DD* test. B2 measures indicated that performance was within normative limits in the left ear (blue X data) before training began. Performance was below normative limits for B2 measures in the right ear (red ● data). There was an improvement in accuracy at probe, but the score remained below normative limits. P1 measures indicated that measures returned to within the normative range following training.

RP3: DD

RP3's individual data for the *DD* test is pictured in Figure 6, Quadrant III. Baseline measures indicated that RP3 performed within the normative limits of the dichotic digits test bilaterally before training began. The participant's scores remained within normative limits through probe and P1 measures.

RP4: DD

RP4's individual data is pictured in Figure 6, Quadrant IV. From B1 to B2 measures, there was a slight decrease in performance bilaterally on the *DD* test. Despite this decrease, right ear performance (red ● data) remained within the normative range throughout all measures, increasing from B2 to probe to P1. Left ear performance (blue X data) on the *DD* test was below the normative limits during B2, despite performance within normative limits during B1.

During the probe measure, performance in the left ear on the *DD* test increased to within normative limits. There was no change in left ear *DD* performance from probe measure to P1 measure.

***Dichotic Digits* Test**

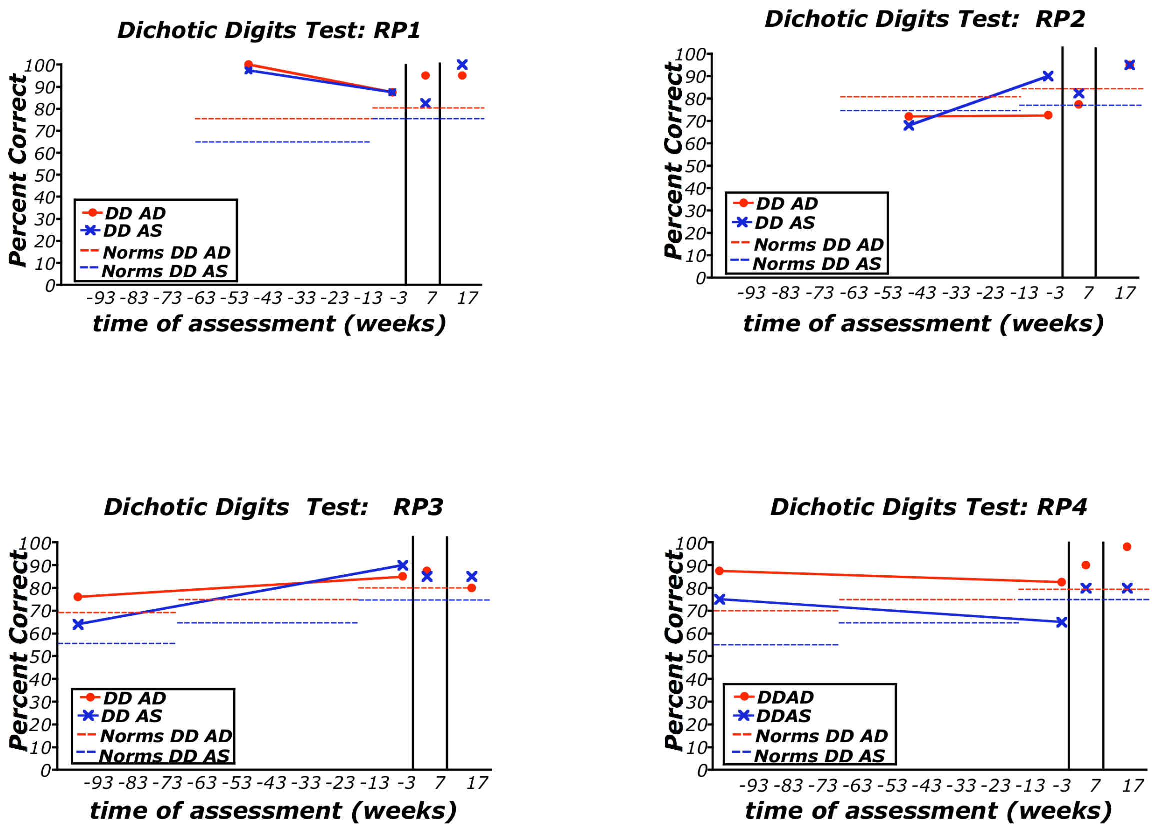

Figure 6. Depiction of each participant's right and left ear accuracy on the *Dichotic Digits* test over time. RP1's data is on the top left (Quadrant I). RP2's data is on the top right (Quadrant I). RP3's data is on the bottom left (Quadrant III). RP4's data is on the bottom right (Quadrant IV).

Competing Sentences (CS) Test Results

Results of the *Competing Sentences* test of binaural separation are graphed for each participant in Figure 7. The X-axis displays time of assessment in weeks, relative to the start of training (week 0). The *CS* test is scored in accordance with individual ear accuracy. Therefore, improvements in dichotic listening are visualized when an *increase* in accuracy scores on the y-axis is noted over time. There appears to be a group trend indicating an increase in accuracy on the *CS* test following training (see Figure 7).

RP1: CS

RP1's individual data for the *CS* test is located in Quadrant I of Figure 7. RP1's individual graph shows growth in accuracy bilaterally from B2 to probe, to P1. Both left (blue X data) and right ear (red ● data) scores increase from below normative limits at B2, before the start of training, to above normative limits during probe. In the left ear, performance accuracy again increased during P1. In the right ear, performance did not change from probe to P1. It is important to note, however, that B1 measures of right ear performance were notably higher than B2 measures of right ear performance. B1 accuracy are almost equal to probe and P1. Therefore, it is difficult to determine whether the notable increase in right ear performance from B2 to probe and P1 was due to training, an error in B2 measurement, or non-auditory factors such as attention.

RP2: CS

RP2's individual data is located in Quadrant II of Figure 7. Interestingly, RP2 accurately identified more sentences in the left ear (blue X data points) than in the right ear (red ● data points) throughout each measure over time. Left ear accuracy was within normative values for all but B2, while right ear accuracy remained below normative values throughout each measure.

During B1, RP2 performed at almost 100% accuracy in the left ear. However, during B2, RP2's identification accuracy dropped below normative values. It is worth noting that RP2 was unmotivated and inattentive during B2. RP2's left ear accuracy improved to within normative values during probe and was almost perfect at P1. Despite, or perhaps due to, RP2's inattentiveness during B2, right ear accuracy on the *CS* test did not change from B1 to B2. Accuracy decreased from B2 to probe and then improved greatly from probe to P1. At P1, right ear accuracy was just below normative values.

RP3: CS

RP3's individual data is located in Quadrant III of Figure 7. RP3's data showed a trend of increasing accuracy over time in the left ear (blue X data points). Each of his three baseline assessments (B1, B2, B3) yielded scores notably below normative values, yet increased from B1 to B2 and B2 to B3. The treatment probe revealed a notable increase in left ear performance, though the increase was not great enough for the left ear percentage accuracy score to fall within normative values. From probe to P1, accuracy again increased in the left ear, bringing left ear performance on the *CS test* within normative limits. Right ear (red ● data points) accuracy remained at or near 100% during all measures.

RP4: CS

RP4's individual data is located in Quadrant IV of Figure 7. RP4 underwent three baseline *CS* assessments (B1, B2, and B3). During B1, performance accuracy in the right ear (red ● data points) was far below the normative value, yet greater than the performance accuracy in the left ear (blue X data points). Left ear accuracy was within normative limits at B1 and B2. There was a notable increase in accuracy from B1 to B2 in the right ear, bringing right ear performance within normative values. There was no difference between B2 and B3 in either

ear. However, RP4 entered a new normative age bracket by the time of the B3 assessment because his birthday occurred between B2 and B3. Due to the shift in norms, RP4's B3 performance was not within normative limits in either ear. The probe measure in the right ear revealed accuracy within normative values, close to 100%. This high right ear accuracy persisted at P1. In the left ear, there was a decrease from B3 to probe. P1 indicated accuracy close to (but still below) normal levels in the left ear. Accuracy at P1 in the left ear was the highest left ear accuracy across assessments.

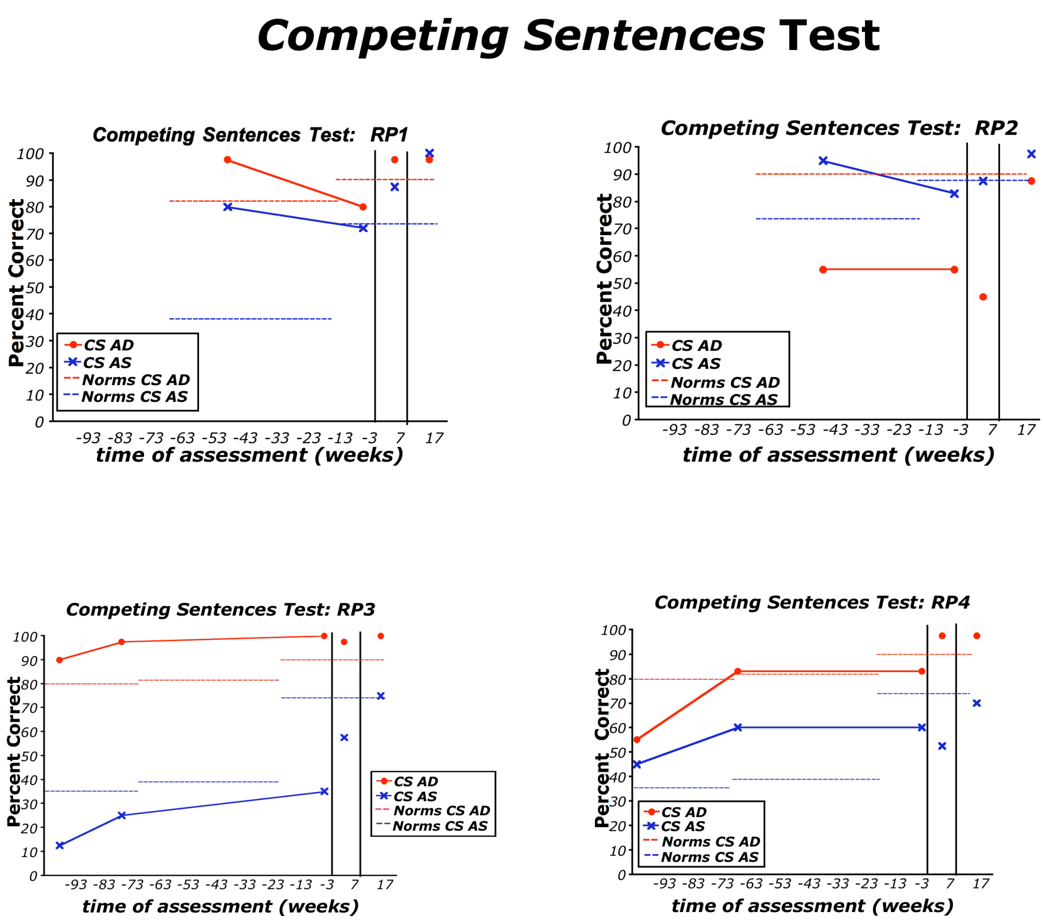

Figure 7. Depiction of percentage accuracy on the *Competing Sentences* test of binaural separation in each ear over time. RP1's individual data is shown on the top left (Quadrant I). RP2's individual data is shown on the top right (Quadrant II). RP3's data is shown on the bottom left (Quadrant III). RP4's data is shown on the bottom right (Quadrant IV).

Synthetic Sentence Identification-Contralateral Competing Messages (SSI-CCM) Test Results

The *SSI-CCM* is a test of binaural separation. After contacting the test distributors, I was unable to compile normative recommendations for this test. Additionally, this test is not used as part of the clinical diagnostic battery at the LSU Hearing Clinic. Thus, there was only one baseline measure for each participant. There was no notable group trend on the *SSI-CCM* for either individual ear measures or bilateral measures. The individual results of the *SSI-CCM* are shown in Figure 8.

RP1: SSI-CCM

RP1's individual data for the *SSI-CCM* test is depicted in Quadrant I of Figure 8. RP1 performed at or near 100% bilaterally, throughout assessments.

RP2: SSI-CCM

RP2's individual data for the *SSI-CCM* test is depicted in Quadrant II of Figure 8. This data was gathered at the end of the baseline testing session, after RP2 lost motivation. Due to a lack of participant compliance, I was unable to test the left ear (blue X data points) during B1. Additionally, the accuracy reported for the right ear (red ● data points) during the baseline assessment may not be an accurate measure of RP2's binaural separation abilities. Probe and P1 results were at or near 100% accuracy bilaterally.

RP3: SSI-CCM

RP3's individual data for the *SSI-CCM* test is shown in Quadrant III of Figure 8. Throughout baseline assessment, treatment probe, and post-assessment, RP3 achieved higher accuracy scores in the right ear (red ● data points) than in the left ear (blue X data points). There was a notable increase in accuracy in the left ear from B1 to probe. However, percentage accuracy in the left ear during P1 was the same as B1. RP3's right ear accuracy on the *SSI-CCM*

remained relatively consistent over time. It varied in the same manner as the left ear (though less notably), increasing during probe and then decreasing at P1.

RP4: SSI-CCM

RP4's individual data for the *SSI-CCM* test is depicted in Quadrant IV of Figure 8. RP4's data shows a decrease in accuracy in the left ear (blue X data points) from B1 to probe and from probe to P1. RP4's accuracy was the same bilaterally on the *SSI-CCM* during B1 and probe. From probe to P1, accuracy in the right ear (red ● data points) returned to the level of B1.

***Synthetic Sentence Identification-Competing Contralaterl Messages* Test**

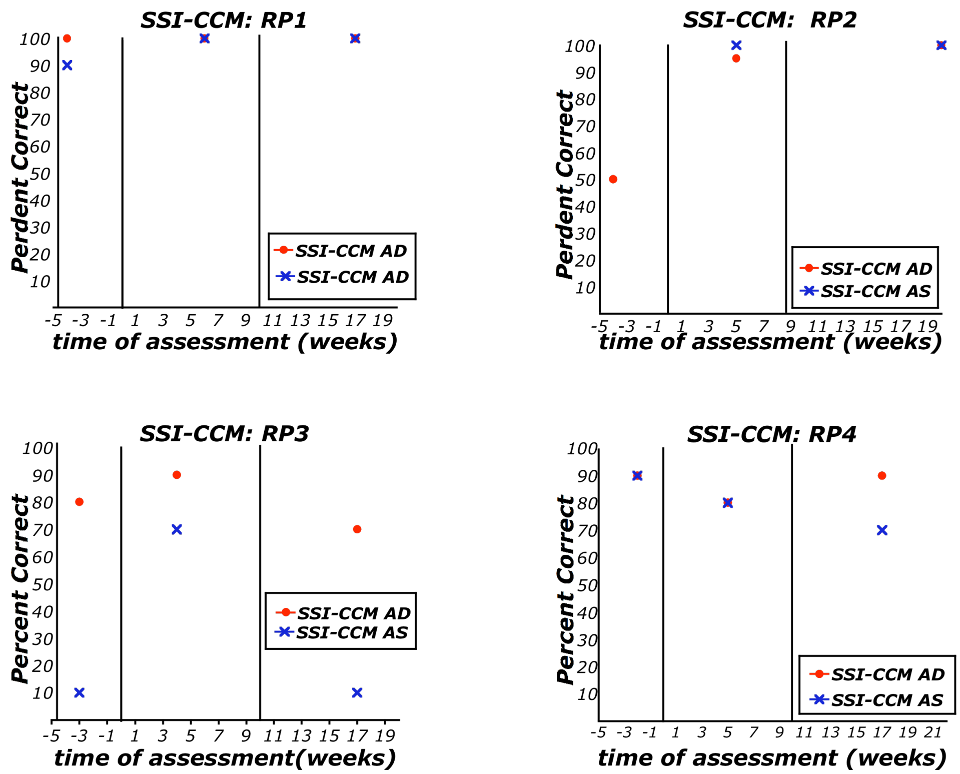

Figure 8. Depiction of percentage accuracy on the *Synthetic Sentence Identification with Contralateral Competing Messages* test of binaural separation in each ear over time. RP1's individual data is shown on the top left (Quadrant I). RP2's individual data is shown on the top right (Quadrant II). RP3's data is shown on the bottom left (Quadrant III). RP4's data is shown on the bottom right (Quadrant IV).

Non Dichotic Test Results

Three non-dichotic tests were included in the assessment battery. These tests covered a range of auditory processes and included the *Word Recognition in Noise* test (WRN; Etymotic Research, 1993) of listening in noise, the *Frequency Pattern Sequencing Test* (FPST; Pinheiro & Ptacek, 1971) of temporal ordering, and the *Rapidly Alternating Speech Perception* test (RASP; Willeford, 1977) of binaural interaction. Each participant's individual results for the non dichotic tests are depicted in Figure 9. Improvement on any of these tests is marked by an increase in percentage accuracy over time.

Word Recognition in Noise (WRN) *Test Results*

Results and norms for the *WRN* test are shown in Figure 9. The *WRN* includes two measures: left ear percent accuracy and right ear percent accuracy. As shown in the graph, this monaural test's norms are similar for each ear, with slightly increased accuracy for the right ear. There is no group trend in accuracy over time on the *WRN.*

RP1: WRN

RP1's individual data for the *WRN* test is depicted in Quadrant I of Figure 9. During first and second baseline measures (B1 and B2) and the treatment probe, RP1's *WRN* accuracy was below normative values bilaterally. During these measures (B1, B2, Probe), RP1's left ear (blue X data points) accuracy was consistently lower than her right ear (red ● data points) accuracy. This ear effect was reversed at P1. RP1's right ear accuracy at P1 was greater than her left ear accuracy, because right ear accuracy increased from probe to P1 and the left ear accuracy decreased from probe to P1. At P1, right ear accuracy was within normative limits, while left ear accuracy remained below normative limits.

RP2: WRN

RP2's individual data for the *WRN* test is displayed in Figure 9, Quadrant II. RP2's graph shows that his bilateral accuracy on the *WRN* was below normative values (left ear = blue X data points; right ear = red ⬤ data points) at B1. From B1 to B2, accuracy increased to within normative limits bilaterally. From B2 to probe, there was a notable decrease bilaterally, so that RP2's accuracy percentages reverted back to levels that were not within normative values. From probe to P1, accuracy in the left ear decreased further, while accuracy in the right ear increased to a value well within normative limits and greater than the value of any baseline or probe measures.

RP3: WRN

RP3's individual data for the *WRN* test is depicted in Quadrant III of Figure 9. RP3's *WRN* accuracy fluctuated over B1, B2, and B3. B3 accuracy was much lower than B1 and B2, probe, and P1. Although there were notable gains bilaterally from B3 to P1, these effects are diminished when comparing B1 or B2 to the probe and P1.

RP4: WRN

RP4's individual data for the *WRN* test is depicted in Quadrant IV of Figure 9. RP4's accuracy in the left ear (blue X data points) fluctuated along the limits of normative values during B1, B2, and B3. RP4's left ear accuracy increased from B3 to probe ad probe to P1. RP4's accuracy in the right ear (red ⬤ data points) on the *WRN* test was within normative values throughout baseline measures. There was a notable decrease from baseline to probe. However, P1 was equal to B3.

Frequency Pattern Sequencing Test (FPST) *Results*

Results and norms for the *FPST* are also shown in Figure 9. The *FPST* data are shown in purple. The *FPST* includes two response options: the listener can either label the pattern of the sounds or hum the pattern of the sounds. If a participant hummed the sounds, their data points were represented by ▼. If the participant labeled the sound, their data points are represented by ▲. Two of the 4 participants hummed the sounds (RP1 and RP4). The participants who hummed did so after demonstrating an inability to linguistically label the pitch patterns (e.g., high, low, high). The *FPST* was presented diotically and scored by percentage accuracy. There was only one condition for each measure. No group effect of accuracy on the *FPST* was noted over time. RP2 showed a trend of improved performance over time.

RP1: FPST

RP1's individual data for the *FPST* is depicted in Quadrant I of Figure 9. RP1 used humming as a response mode (purple ▼ data points) during the *FPST.* Her baseline, probe, and P1 data showed no trend and remained below the normative values provided by the test writers.

RP2: FPST

RP2's individual data for the *FPST* is depicted in Quadrant II of Figure 9. RP2 used labeling as a response mode (purple ▲ data points) during each administration of the *FPST.* RP2's accuracy increased from B1 to probe and probe to P1. Although RP2's accuracy was below normative limits during baseline, it reached and exceeded normative limits during P1.

RP3: FPST

RP3's individual data for the *FPST* is depicted in Quadrant III of Figure 9. RP3 used labeling as a response mode (purple ▲ data points) during the *FPST*. RP3's B1, probe, and P1

all yielded results within normative limits. RP3's accuracy on the *FPST* remained constant between B1 and probe but decreased notably at P1.

RP4: FPST

RP4's individual data for the *FPST* is depicted in Quadrant IV of Figure 9. RP4 used humming as a response mode (purple ▼ data points) during the *FPST*. All of RP4's *FPST* measures were within normative limits and there was little fluctuation in scores over time.

Rapidly Alternating Speech Perception (RASP) *Test Results*

Results and norms for the *RASP* test are shown in Figure 9. The *RASP* test data are shown in orange, with ◇ representing each data point. The *RASP* test was presented diotically and scored by percentage accuracy. Only one measure was taken when the *RASP* test was administered. Through visual analysis, I noted a group trend of increasing accuracy on *RASP* test measures over time.

RP1: RASP *Test*

RP1's individual data for the *RASP* test is depicted in Quadrant I of Figure 9 (orange ◇ data points). RP1's percentage accuracy was below normative limit during B1. However, RP1's percentage accuracy increased from B1 to B2, placing RP1's *RASP* test accuracy within normative limits. RP1's accuracy on the RASP test continued to increase from B2 to probe and from probe to P1.

RP2: RASP *Test*

RP2's individual data for the *RASP* test is depicted in Quadrant II of Figure 9 (orange ◇ data points). RP2's percentage accuracy on the *RASP* test was within normative limits during B1. RP2's percentage accuracy on the *RASP* test decreased from B1 to B2. This is likely due to RP2's poor compliance during this particular assessment session. RP2's accuracy on the *RASP*

test increased from B2 to probe, but remained below normative limits. The accuracy increased to within normative limits from probe to P1.

RP3: RASP *Test*

RP3's individual data for the *RASP* test is depicted in Quadrant III of Figure 9 (orange ◇ data points). RP3's measures on the *RASP* test were all within normative limits. Accuracy increased over time from B1 to probe, then remained constant from probe to P1.

RP4: RASP *Test*

RP4's individual data for the *RASP* test is depicted in Quadrant IV of Figure 9 (orange ◇ data points). All of RP4's accuracy percentages were within normative limits.

Non Dichotic Tests

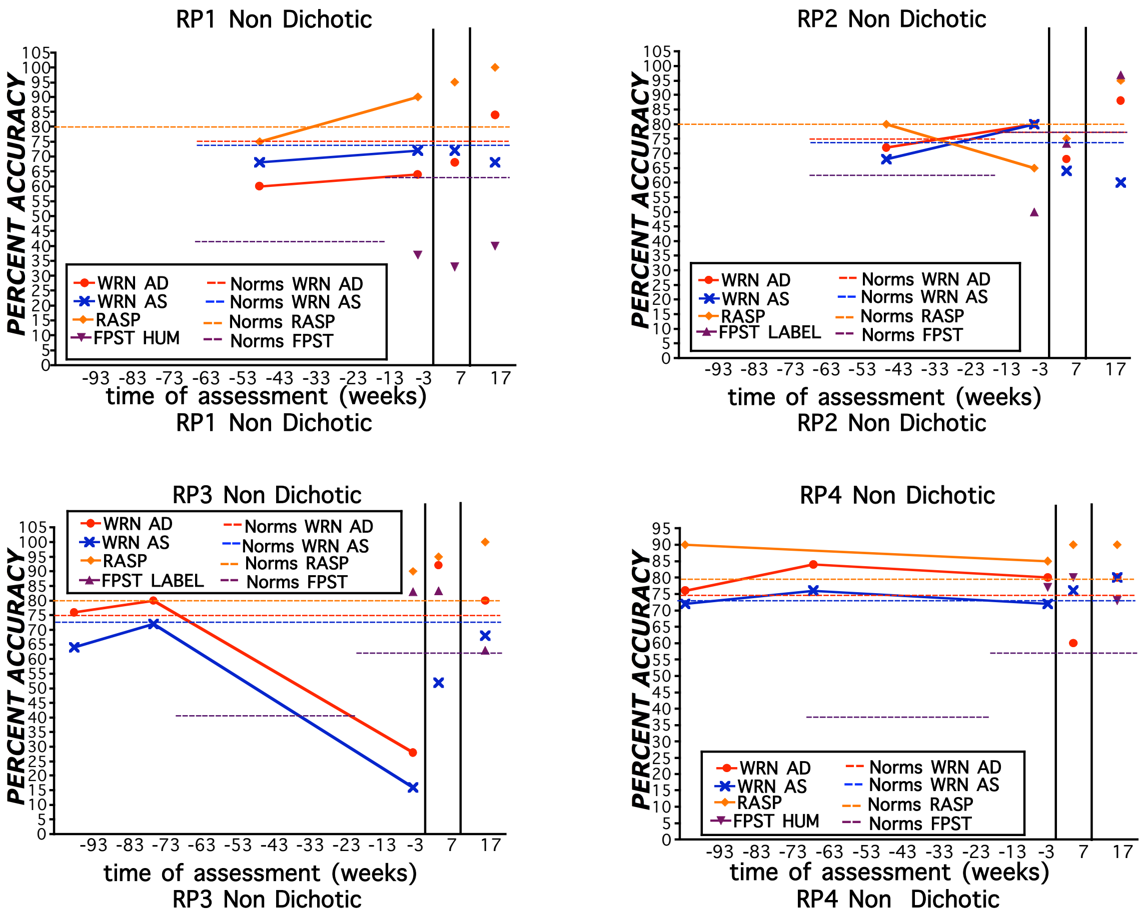

Figure 9. Depiction of percentage accuracy on the non-dichotic tests, including the *Word Recognition in Noise (WRN)* test of listening in noise, the *Frequency Pattern Sequencing Test (FPST)* of temporal ordering, and the *Rapidly Alternating Speech Test* of binaural interaction. RP1's individual data is shown on the top left (Quadrant I). RP2's individual data is shown on the top right (Quadrant II). RP3's data is shown on the bottom left (Quadrant III). RP4's data is shown on the bottom right (Quadrant IV).

CHAPTER V: DISCUSSION

In this chapter, I will discuss the results outlined in Chapter IV in relation to my hypotheses and specific aims. I will relate the results to my specific hypotheses: 1) Did left ear performance on dichotic listening tasks improve after 5 weeks of training? After 7 to 10 weeks without training? 2) Did scores on non-dichotic tests improve during and after training? I will relate these results to Moncrieff & Wertz (2008)? Finally, I will conclude as to whether there is sufficient evidence for the efficacy of using DIID training as a clinical treatment method.

Because APD is such a complex structure, with so many extraneous variables, this study aimed to use reductionist logic as the first step toward getting to the foundation of APD. Specifically, this study tested the effects of Dichotic Interaural Intensity Difference (DIID) training on dichotic listening deficits in school-age children. Measures were taken before, during, and after a 10-week, in-home DIID training regiment. Detailed results on dichotic and non-dichotic tests can be found in Chapter IV (see p. 34). If results indicated that DIID training was efficacious, this study would support the Structural and Attention Models of dichotic listening and DIID training as a management strategy. I argue that by examining the effects of DIID training in children with APD, we can learn about the processes involved in dichotic listening and the relationship between auditory and language variables.

Did left ear performance on dichotic listening tasks improve after 5 weeks of training? After 7 to 10 weeks without training?

It is important to look at the test results of each child individually and decide which of the four children showed improvements in left ear performance. While some may argue that group comparisons for each test are a better method, I argue that the individual comparisons are in keeping with the neural reorganization that theoretically underlies DIID training (Weihing &

Musiek, 20007). If neural reorganization took place in the individual listener's CANS, improvements on dichotic listening tests should have been identifiable across dichotic listening tests from baseline (B1, B2, B3) to treatment probe (probe) to post-assessment (P1) measures. Within the training chapter, Weihing and Musiek (2007) stated that training does not end when the listener leaves the clinical/research setting because dichotic listening situations abound within the listeners' daily lives. These natural dichotic listening exercises cause the listener to continue training without even knowing they are doing so. Additionally, the many variables that complicate the diagnosis of APD affected the measures in this study, because this study used the same diagnostic tests employed in the clinical setting to measure performance. Comparing results within individual listeners lends validity to result interpretation in the same manner that comparing scores between ears in dichotic listening lends validity to the interpretation of dichotic listening scores. Just as the influence of cognitive/linguistic factors affects both right and left ears equally, baseline, probe, and P1 measures should have been equally affected by cognitive/linguistic factors.

Based on the results provided in Chapter IV, no participant made consistent improvements in left ear performance on all tests from baseline to probe to P1. Only one participant (RP3) made notable improvements in left ear performance on dichotic listening tests over time that may reasonably be attributed to cortical reorganization. Two other participants (RP1 and RP4) made less noteworthy improvements in the left ear on some dichotic listening tests over time. RP1 may have demonstrated results consistent with cortical reorganization if her left ear baseline performance levels were not so high that she hit ceiling at both baseline or probe. RP4's conflicting results among dichotic listening tests indicate that cortical

reorganization did not occur. The final participant, RP2 made no notable improvements in the left ear on the dichotic listening tests as a result of training.

RP1

At probe, RP1 demonstrated improved left ear performance in both competing and noncompeting stimuli on the *SSW* test of binaural integration and in left ear performance on the *CS* test of binaural separation. The decreased number of errors on the *SSW* test was maintained for noncompeting stimuli from probe to P1. However, the decrease in number of errors from baseline to probe for competing stimuli on the SSW test was not upheld. In fact, the number of errors in the left ear competing condition during the P1 was greater than the number of errors during the B2, prior to beginning training. Increased percentage of accuracy observed on the *CS* test during probe was compounded by another increase in percentage accuracy from probe to P1. However, RP1's somewhat high levels of functioning baseline measures minimized possible growth. The *Dichotic Digits* test and *SSI-CCM* proved insufficient measures for RP1's left ear dichotic listening abilities, as she hit ceiling in both of these tests. RP1 made small gains on several tests from baseline to treatment probe. However, with the exception of the *CS* test, gains ended at this level, and performance from probe to P1 either did not change or decreased over time. If cortical reorganization occurred within the CANS, performance would continue to increase from probe to P1 on all tests. It is also possible that RP1 did not improve notably because she was within normal limits in the left ear on all measures by either baseline or probe. It may be the case that RP1 would have demonstrated more significant gains if I had administered more sensitive tests.

RP2

RP2 did not demonstrate any improvements in left ear performance on dichotic listening tests from baseline to probe. *SSI-CCM* scores could not be reported for RP2 because I was unable to get a baseline left ear measure on that test. At baseline, RP2 was within normal limits in the left ear on the *CS* and *DD* tests and the noncompeting portion of the *SSW test*, leaving little or no room for improvement. RP2 made more errors at B2 in the left ear competing portion of the *SSW* test than is allowed by normative values, leaving room for improvement. However, RP2 did not improve at all from B2 to probe to P1. Although RP2 performed within normal limits on stimuli presented to the left ear when training began, there was room for improvement on one test. The fact that RP2 did not improve on this measure allows us to conclude that training-induced, cortical reorganization was highly unlikely to have occurred in this participant.

RP3

RP3's left ear performance improved notably on three dichotic listening tests: the *SSW* test, the *CS* test, and the *SSI-CCM* test. RP3 made notably fewer errors in the left ear competing condition of the *SSW* test and performed at a higher percentage of accuracy on the *CS* test and *SSI-CCM* during probe than during baseline. The decrease in number of errors on the SSW test and increase in percent accuracy on the *SSW* test continued from probe to P1. However, left ear performance on the *SSI-CCM* reverted to baseline levels. The *Dichotic Digits* test was not sufficiently sensitive as of a measure for RP3, who had already reached normal levels during B1 and B2.

RP3's performance on two auditory tests (the *SSW* test and the *CS* test) increased notably from baseline to probe to P1. These findings are consistent with the interpretation that cortical reorganization occurred within the CANS. However, *SSI-CCM* measures contradict this

interpretation, as improvements from B1 to probe were reversed, indicating that treatment effects were not upheld. Though left ear performance on the *SSI-CCM* contradicted the interpretation that cortical reorganization occurred, visual inspections of the graphs revealed undeniable growth from baseline to probe to P1.

RP4

RP4's left ear performance improved slightly from baseline to probe on the two binaural integration tests administered: the *SSW* test, the *Dichotic Digits* test. RP4's small improvements on the *SSW* test consisted of 2 fewer errors each in the competing and non-competing conditions. Improvements on the *Dichotic Digits* test were very slight in comparison to B1 left ear percentage correct (a difference of only 2%). RP4 did not retain the improvements in noncompeting stimuli on the *SSW* test following the completion of training. RP4 retained improvements in the competing condition of the *SSW* and in the *Dichotic Digits* test from probe to P1. However, no additional improvements were demonstrated. The lack of improvement from probe to P1 on the *SSW* cannot be attributed to ceiling effects, as RP4's number of errors on the *SSW* competing stimuli was still above the normative limits at P1. While percentage accuracy of left ear performance was within normative limits at the time of probe and P1 measures, there was room for growth.

Additionally, RP4 demonstrated decreased performance from B1 to probe on the two binaural separation tests administered: the *SSI-CCM* and the *CS* test. RP4 consistently *decreased* in percentage accuracy from baseline to probe to post assessment measures on the *SSI-CCM.* Though percentage accuracy decreased from baseline to treatment probe in the left ear on the *CS,* an increase in accuracy from treatment probe to post assessment resulted in accuracy levels above any of the baseline levels and close to normal limits. This result may indicate that

the 5 weeks of training prior to probe were inadequate for causing neural reorganization, and that neural reorganization occurred between probe and P1. However, this finding contradicted the results of the *SSW* and *DD*, on which RP4 demonstrated no change from probe to P1.

Did scores on non-dichotic tests improve during and after training?

There were three non-dichotic tests included in assessments: the *Rapidly Alternating Speech Perception* test of binaural interaction, the *Word Recognition in Noise* test of speech in noise, and the *Frequency Pattern Sequencing Test* of temporal ordering. I predicted that non-dichotic test performance would not improve as a function of training, because the non-dichotic tests are presented either monaurally or diotically. DIID training aims to decrease the suppression of the ipsilateral pathway caused by competing stimuli presented to the contralateral ear. Competing stimuli are not presented to the contralateral ear during monaurally and diotically presented tests, therefore DIID training should not affect non-dichotic test performance.

Individual results for each participant are included in Chapter IV. Because each test requires a different auditory process, individual comparisons do not provide much comparative data. There is no overall trend of non-dichotic performance within each individual. The scores on non-dichotic tests for RP1, RP2, and RP3, were highly variable when visually inspected for each individual. The scores on non-dichotic tests for RP4 were relatively flat across all measures, remaining within normal limits.

Each participant achieved accuracy percentages within normal limits on the *RASP* test prior to beginning training. However, visual inspection of the graphs showed increased performance from baseline to probe to P1 for all participants. One of the four participants (RP2) increased in percentage accuracy from baseline to probe to P1 on the *FPST* test. These findings

are interesting, because RP2 did not show any left ear improvements on dichotic tasks. Two of the remaining participants were within normal limits on the *FPST* test at baseline. Only one participant (RP1) improved on the *WRN* test from baseline to probe to P1 in the right ear. No participant's left ear scores improved consistently across measures. RP2 and RP4 were performing within normal limits on the WRN tests before training began. RP3's *WRN* data is misleading. If one visually inspects only B3 and the treatment probe and post-assessments, it seems that a drastic increase took place. However, the *WRN* data at B3 do not seem to be representative of RP3's abilities. B1 and B2 measures (preceding B3 measures) indicated that RP3 was also performing within normative limits on the *WRN* test before training began. Overall, data supported my hypothesis and indicated that non-dichotic processing did not improve as a function of training.

How do these results relate to those reported by Moncrieff & Wertz (2008)?

Recall that Moncrieff and Wertz' study differed from this study in a number of ways. Although the current study shared similar goals with Moncrieff & Wertz (2008), the samples included were quite different, as were the APD profiles. Though all of the participants in the present study were in accordance with ASHA's operational definition of APD, they did not all have the same caliber of left ear disadvantages for which Moncrieff and Wertz controlled. RP3 was the only noteworthy subject in regards to increases in left ear performance during and following training. Throughout the different dichotic listening tests, RP3 shows the most drastic left ear disadvantage. There may be a correlation between the amount of left ear disadvantage and the amount of improvement that occurs as a result training. However, it is important to note that RP3's performance was also typically farther from the norms than the other participants'

performance on the dichotic listening tasks. It may be the case that RP3 simply had more room for growth.

It is important to note that while all of Moncrieff and Wertz's participants had strong left ear disadvantages, some of the participants in the current study had right ear disadvantages instead. Particularly, RP2, who made no improvements in left ear performance performed better in the left ear on all four of the dichotic listening tests at baseline. RP2 received training in the left ear, however because he exhibited left ear disadvantage during crossover calculations, just prior to beginning training. It is interesting to note that despite receiving training in the left ear, RP2 made improvements in the right ear on all four of the dichotic listening tests. This finding is interesting, because it shows that training can lead to benefits in the right ear when the left ear is trained and when the right ear is at a disadvantage. RP4 also improved on all dichotic tasks, though not to the same degree as RP2. These findings were in keeping with Moncrieff and Wertz, who also found increased right ear performance. However, because Moncrieff and Wertz did not analyze the participants individually, I was unable to compare the different cases demonstrated by RP2 and RP4 to the previous study.

As stated in Chapter II, this study was meant to address the weaknesses of the Moncrieff and Wertz study. The first weakness I mentioned was that the experimenters provided a loosely detailed description of DIID training, which did not constrain or regulate the training across participants. However, when considering the results of RP2 at baseline conflicted with crossover measures, Moncrieff and Wertz's flexible approach may be more appropriate in a clinical setting than the Weihing and Musiek's strictly defined approach (2007). Secondly, Moncrieff & Wertz used far fewer dichotic listening tests measures. I argue that the multiple dichotic listening tests that I presented provide a sounder picture of what has occurred during training than one sole

measure can provide. In Moncrieff & Wertz's Phase II, no non-dichotic tests were used to test the generalization of benefits to non-dichotic auditory processing, so it is unclear whether additional training would have led to benefits in non-dichotic processes. I used non dichotic tests in the present study, but failed to yield notable results. In future studies, it may be more appropriate to use multiple tests for each process, so that comparisons (like the ones made on the dichotic tests in the present study) within each process are possible. Another weakness of Moncrieff and Wertz (2008) was that the researchers' inclusion criteria were not clinically motivated. I continue to argue that it is important to work within the current construct of APD, so that findings are generalizable to current clinical practice.

My study has several weaknesses of its own. First, due to complications with data collection during treatment, this is only an approximation of an ABA design. Secondly, analysis was conducted using visual inspection, so that none of the results can be considered statistically significant. The small number of participants in this study is an additional weakness of the study. Other weaknesses abound from the nature of studying APD. I cannot control for all of the extraneous variables that affect performance on the measures any more than a clinician can control these variables during assessment and intervention.

Is there sufficient evidence for the efficacy of using DIID training as a clinical treatment method?

The results of this study indicated that children with dichotic listening deficits may benefit from DIID training. However, evidence is not strong enough to support billing for DIID training as an APD management strategy. More research is needed in this area.

Future Directions

In the future, I plan to employ a full ABA design, employing multiple baselines and multiple post assessments. I also will include treatment probe measures that are different form B1 and P1 measures. I propose that using a mathematical formula that accounts for changes in both accuracy and signal to noise ratio during treatment sessions is the best measure for treatment probes. Additionally, a control group of children who meet all criteria will receive the same periodic assessments as the participants in this study, but will not undergo training. More children will be included in order to increase the power of this study. In future studies, the field would also benefit from comparing the effects of training in children with different APD subprofiles. I would also be interested in seeing the effects of using nonverbal stimuli during training.

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Appendix A

Experiment: ________________ Today's Date: _________ RP# _____

Child History

Child's name: ___________________________ DOB: _______________ M F

Child's Apgar score at 1 min: 1 2 3 4 5 6 7 8 9 10

at 5 min: 1 2 3 4 5 6 7 8 9 10

What language(s) are spoken in your home for what percentage of time (e.g., English 75% and Spanish 25%?

Who is your child's primary caregiver? _____________________________________

Does you child have vision loss? Y N

How many ear infections has your child had to date? ________________ Resulting in tubes? Y N

Is there a history of hearing loss in your family? Y N If yes, what is the relationship? _______________

Does your child have a hearing loss? Y N

Has your child previously been diagnosed with Auditory Processing Disorder? Y N

Has your child received any therapy for the remediation of Auditory Processing Deficits? Y N
If so, please give dates, frequency, and types of therapy:

Appendix A

Experiment: ________________ Today's Date: _________ RP# _____

Has your child ever been diagnosed with a Speech or Language Deficit? Y N
If so, please list type of disorder and start/end dates of therapy:

Has your child ever been diagnosed with an attention disorder? Y N
If so, please write the approximate date of diagnosis and any medications that are currently or were formerly used for treatment:

Has your child ever been diagnosed with a cognitive disorder? Or is his/her cognitive functioning belowe average? Y N

Please describe:

Describe your child's current academic performance:

Appendix B

Test	Oral Directions
Dichotic Digits	You are going to hear some numbers. You will hear some of the numbers in your left ear, and some in your right ear. The numbers are going to come fast, so pay close attention. I need you to listen for four numbers before you answer. **Test includes practice items.
Staggered Spondee Words Test	This time you're going to hear some words. They're going play in both ears again. Wait until the words finish to answer. I need you to repeat it back in the same order that you heard it. **Test includes practice items.
Competing Sentences	This time, you will hear sentences. A different sentence will play in each ear. Right now I want you to listen to the one in your left ear. Show me left again. Keep your hand on your left cheek so that you can remember to tell me the sentence in your left ear. It's going to be louder in the right ear, but do your best to pay attention to the left ear. **No practice items.
Synthetic Sentence Identification with Contralateral Competing Messages	(This test includes an answer sheet. The participant must call out the number next to the synthetic sentence he hears. I would walk into the booth, and hand the participant the sheet before giving oral instructions.) This time, you will hear a story in your right ear. Then you will hear these mixed-up sentences in your left ear. When you hear one of these sentences in your left ear, call out the number next to it. **No practice
Frequency Pattern Sequencing Test	This time you're going to hear some beeps. Some times they are high (demonstrate high) and sometimes they are low (demonstrate low). Your job is to tell me when they are high and low. (We practice verbally until the RP seems to understand.) If the unable to apply verbal labels, he is asked to hum his response.
Word Recognition in Noise	You are going to hear some words in your right ear. Will you point to your right ear for me? You will also hear noise in the background. I need you to ignore the noise and call out the words.
Rapidly Alternating Speech Perception Test	This time, you are going to hear sentences. Part of the sentence will be in one ear, and the other part will be in the other. Put all the pieces together and tell me what you heard. (This is typically followed by an oral/visual demonstration in which I point to each ear alternately during each syllable of "I went to LSU today."