A COMPARISON OF FOUR TESTS OF TEMPORAL RESOLUTION:

AFTR, RGDT, BFT and GIN

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of JOWAN LEE find it satisfactory and recommend that it be accepted.

Chair

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Abstract

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Four temporal resolution tests: the Auditory Fusion Test-Revised, the Random Gap Detection Test, the Binaural Fusion Test, and the Gap in Noise Test were administered to ten children with normal hearing between the ages of 7 to 11 years. The same tests were also administered to one child age 13 years with minimal auditory processing deficits. Statistical analysis revealed a strong correlation between the Auditory Fusion Test-Revised and the click subtest of the Random Gap Detection Test. A repeated measures, one-way analysis of variance revealed a statistically significant difference ($p < .001$) among the six measures derived from the four temporal resolution tests. A Newman-Keuls' multiple-range test revealed significant differences for eight of the possible fifteen paired means. Mean differences seemed to result primarily from differences in stimulus type (i.e., clicks, tones, or noise). From a clinical perspective, however, all but one of the means were within one standard deviation from the published norms suggesting that all tests yielded results that would be interpreted similarly by clinicians. The participant with auditory processing deficits performed comparably to the participants with normal hearing, with scores on five of the six measures near the mean of the participants with normal hearing. Only on the left ear of the Gap in Noise Test was the score of the participant with auditory processing deficits significantly different from the mean of the participants with normal hearing. Implications for diagnostic testing of temporal resolution are discussed.

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Dedication

This thesis is dedicated to my mother and father

who have provided me with emotional and financial support.

CHAPTER ONE

LITERATURE REVIEW

Auditory Processing Disorders

An auditory processing disorder (APD) has been described as a deficit in one or more central auditory processes (in the absence of a peripheral hearing loss), including: sound localization and lateralization, auditory discrimination, auditory pattern recognition, and temporal aspects of audition (ASHA, 1996). Often times patients who are diagnosed with APD manifest the above problems by demonstrating difficulties in understanding speech in the presence of background noise, difficulties in auditory performance with competing signals, difficulties in auditory performance with degraded acoustic signals, and difficulty following verbal directions (Musiek and Chermak, 1994). Behavioral expressions of APD also include poor academic achievement in spite of normal or above-normal intelligence, problems with distractibility and inattentiveness, and poor performance in difficult listening environments including problems with reverberation and background noise (Chermak, 2001). Current prevalence data are sparse. Chermak (2001) estimated that two to three percent of children have APD, while Bamiou, Musiek, and Luxon (2001) have suggested the percentage may be closer to seven percent.

APD has been observed in a wide range of clinical populations (Jerger and Musiek, 2000). It has been seen in patients with central nervous system pathologies (i.e., aphasias, Alzheimer's disease), neuro-developmental disorders (i.e., learning disabilities), as well as neurologic changes due to aging (Chermak, 2001). From these observations it has been speculated that APD is caused by either neuromorphologic disorders, delays in maturation of the central auditory nervous system, or neurologic disorders or insults (Chermak, 2001).

APD can present on its own, or it can also present co-morbidly with other disorders. Aside from its presence in the above populations, APD has been associated with other disorders that exhibit similar behaviors including: attention deficit hyperactivity disorder (ADHD), language impairments, reading disabilities, learning disabilities, pervasive developmental disorders (PDD), and mental retardation (MR) (Jerger and Musiek, 2000). Due to APD's propensity to overlap with varying disorders, its differential diagnosis requires a test battery approach for accurate assessment (Jerger and Musiek, 2000).

Audiology service delivery today requires clinicians to provide a number of different services accurately and reliably in a short period of time. The issue of time management in clinical service delivery is becoming of greater importance today as the need to be able to serve more patients in a given work week, increases. In private practices and Otolaryngology clinics, hearing aid sales make up 75% of annual audiologic income (Schow, Balsara, Smedley and Whitcomb, 1993). Although diagnostic evaluations are certainly an important aspect of audiological service, it unfortunately does not provide the economic viability for a clinic to survive on such services alone. It is for this reason that diagnostic evaluations must be performed in a manner that enables the clinician to obtain all necessary information quickly and competently, so that more time can be spent in providing profitable treatment for patients. A gradual change in clinical practice has been seen over the past couple decades. In the earlier years of the profession, audiologists' duties consisted of primarily either diagnostics or rehabilitation. Today, due to increasing demands, more and more audiologists are required to juggle both aspects into their clinical responsibilities (Schow et al., 1993).

The length of an APD evaluation can extend to approximately four hours long. The average Medicare reimbursement for 2002 for CPT code 92506 – Evaluation of speech, language, voice, communication, and/or auditory processing was $94.84 (Thompson, 2002). The tendency for low reimbursement rates along with long test taking times, results in few diagnostic audiologists to perform such evaluations. It is necessary therefore, to create a test battery that is effective in correctly identifying individuals with APD, while at the same time be as time efficient as possible.

The time consuming process of the APD evaluation is further lengthened when other factors such as age, cognitive demands, attention, motivation, fatigue, educational level, language and cultural issues and use of medications come into consideration (Jerger and Musiek, 2000). Additionally, in cases where an ADHD, MR, or PDD occur co-morbidly with APD, time constraints are weighed even more heavily. To this extent, any modifications to the current APD battery that will reduce the number of redundant tests will result in more time-efficient assessments. Given the number of temporal processes and the variety of approaches to assessing temporal processing, this is one key area where careful selection of auditory processing tests is of great potential impact.

The goal of this study is to examine the relationships and the differences among two commercially available and two experimental tests of temporal resolution. The two commercially available tests are the Auditory Fusion Test-Revised (McCroskey and Keith, 1996) and the Random Gap Detection Test (Keith, 2000). The two experimental tests are the Binaural Fusion Test (Musiek, 2000) and the Gap in Noise Test (Musiek, 2003). If the four tests are shown to correlate in their results, the audiologist would then be directed to use that test with the greatest sensitivity and specificity, assuming that information is available. The results of this study will provide useful information to the clinician who is involved in the lengthy processes of assessing auditory processing disorders. Knowledge of whether or not strong correlates exist between two tests within the same test battery will enable clinicians to continue to make accurate APD diagnoses in a more time-efficient manner. If on the other hand the results of this study do not show a correlation, further research would need to be performed to determine the true nature of what each test is evaluating.

APD Assessment

For the differential diagnosis of APD a minimal test battery recommendation was made in 2000, at the Consensus Conference on the Diagnosis of Auditory Processing Disorders, also known as the Bruton Conference. The recommendations included behavioral tests, electroacoustic tests, electrophysiologic tests, and a detailed case history. The case history is suggested to provide the clinician with information regarding the patient's birth experience, current health, speech and language development, familial history, academic achievement, social development, cultural and linguistic background and auditory behavior (ASHA, 1996). The minimal audiologic test battery recommended at the Bruton Conference of 2000, as outlined by Jerger and Musiek, is as follows:

Basic Audiologic Test Battery: These tests are utilized to assess the peripheral auditory system, including conductive and sensory mechanism and the extra-axial and intra-axial brainstem. Peripheral auditory dysfunction can mimic or exacerbate APD type behavioral manifestations.

1. Pure tone Audiometry: Essential for assessing presence and degree of peripheral hearing loss.
2. Performance-Intensity Functions for Word Recognition: Essential for the exploration of word recognition over a wide range of speech levels, and for inter-aural comparisons. Reduced word recognition at increased presentation (i.e., intensity levels) indicates "roll-over" which suggests retrocochlear or 8^{th} nerve involvement.
3. Immittance Audiometry: Tympanometry (Metz, 1946) and Acoustic Reflex (Terkildsen, 1957) testing identifies middle ear pathologies and the integrity of the reflex arc, 8^{th} nerve and lower brainstem, and provides information regarding the presence of hearing loss as well.
4. Otoacoustic Emissions (OAE): OAEs reflect the integrity of the cochlear outer hair cells (Kemp, 1978).
5. Auditory Brainstem Response (ABR): ABRs reflect the function and integrity of the 8^{th} nerve and brainstem (Jewett, Romano and Williston, 1970).
6. Auditory Middle Latency Response (AMLR): AMLRs reflect the auditory perceptual function in the auditory thalamus and the primary auditory cortex (Geisler, Frishkopf and Rosenblith, 1958).

Auditory Processing Tests: Following the peripheral evaluation, the auditory processing test battery is administered to determine the status of the central auditory nervous system.

1. Frequency or Duration Pattern Sequence Tests: A key measure of auditory temporal (order or sequence) processing. Examples of such tests include the Pitch Pattern Test (Pinheiro and Ptacek, 1971) and the Duration Pattern Test (Pinheiro and Musiek, 1985).
2. Temporal Gap Detection: A key measure of auditory temporal resolution or discrimination. Commercially available temporal gap detection tests include the Random Gap Detection Test (Keith, 2000) and the Auditory Fusion Test-Revised (McCroskey and Keith, 1996).
3. A Dichotic Test: An indicator of a binaural (integration and separation) processing and interhemispheric transfer via the corpus callosum. The Staggerd Spondaic Word Test (Katz, 1962), Dichotic Word Test (Kimura, 1961a), and the Dichotic Sentence Identification Test (Fifer, Jerger, Berlin, Tobey and Campbell, 1983) are all examples of possible tests to use in this category.

Chermak (2001) recommends the inclusion of a monaural low-redundancy test in the test battery to investigate an individual's ability to comprehend degraded auditory stimuli or auditory stimuli in noise. She notes that filtered or compressed speech and speech in competition tests are possible options to implement. Chermak argues that including a monaural-low redundancy test alongside dichotic tests and tests of interhemispheric transfer (i.e., pitch and duration patterns tests) allow differentiation of probable hemispheric versus corpus callosal site of disruption or lesion.

Beyond the comprehensive audiologic evaluation, a multi-disciplinary team approach has also been suggested for the differential diagnosis of APD (Jerger and

Musiek, 2000; Bellis and Beck, 2000; Chermak, 2001). In cases of those individuals who present with symptomatology associated with both APD and other disorders, professionals from various fields are needed to collaborate for an accurate diagnosis. This multi-disciplinary team approach to differentially diagnosing APD will enable several important questions to be answered.

1. Does the disorder exist only in the auditory modality, or does a similar deficit exist across multiple modalities?
2. Does this individual have a processing problem specifically in the auditory domain, or is the auditory processing problem secondary to a more global cognitive deficit?
3. Are the behavioral manifestations causally related to an underlying language disorder, or are they the result of a language disorder that is secondary to APD?

Key professionals recommended to partake in the multi-disciplinary team as outlined in the 2000 Bruton Conference include Speech-Language Pathologists (SLP) and Psychologists (Jerger and Musiek, 2000). The SLP can identify language issues that might affect auditory processing performance, while a psychologist will be able to help in determining the cognitive and psychoeducational levels of a patient, including attention and executive control, and academic achievement. Together, with all data collected and analyzed, three possible accurate diagnoses can be made:

1. A differential diagnosis of APD.
2. A co-morbid diagnosis of APD with a concomitant disorder.
3. A diagnosis of an underlying disorder that is not APD, but one that presents with auditory processing difficulties among other deficits.

Temporal Processing

Temporal processing refers to time-related aspects of acoustic processing. It encompasses a wide range of auditory skills including: temporal resolution (i.e., gap detection, fusion), masking (i.e., backward and forward masking), temporal integration, and temporal ordering (i.e., temporal sequencing) (ASHA, 1996), as well as localization and pitch perception. These auditory skills are seen in a wide range of listening behaviors including: rhythm perception, periodicity pitch discrimination, segregation of auditory figure and ground, perception of a gap between two successive acoustic stimuli, and duration discrimination (Phillips, 2002). Problems arise when deficits in any one or more of the temporal auditory skills are required to decode time related aspects of speech. The manifestation of temporal processing deficits is thought to result in the typical speech comprehension problems associated with APD (Gordon-Salant and Fitzgibbons, 1993).

Studies that have administered temporal processing tests to individuals with central auditory nervous system pathologies have been used to demonstrate that normal temporal processing is dependent on normal central auditory nervous systems. Studies that show reduced temporal processing abilities in patients with brain lesion compared to normal populations allow us to confirm that temporal processing is indeed a central function. Downie, Jakobson, Frisk, and Ushycky (2002) administered a temporal order judgment task to children who had been born with extremely low birth weights who experienced mild, severe, or no periventricular brain injuries. The children were tested at ages 8 years 10 months to 14 years 5 months. The results indicated significantly lower (poorer) temporal order judgment scores for those children with brain injuries relative to those who did not experience brain injuries. The known presence of a central lesion along with the significantly poor results from the temporal order judgment task suggest that these children may possibly carry a diagnosis of auditory processing disorder and its associated problems. In another lesion study, Musiek and Pinheiro (1987) studied the specificity of the Frequency Pattern Test, another temporal processing test, on its ability to rule out cerebral, brainstem, and cochlear lesions. The Frequency Pattern Test, which is similar to the tone order judgment task, demonstrated high specificity for detecting cerebral lesions when compared to normative data. This is interpreted to suggest normal central function is necessary for successful completion of this task.

Strengthening the evidence of temporal processing as a central auditory nervous system function, Baran, Bothfeld and Musiek (2004) administered a battery of central auditory tests on a 46 years old woman who suffered a cerebrovascular accident (CVA) with damage involving a large portion of the primary auditory area of the left hemisphere. Threshold testing post-CVA revealed normal hearing sensitivity bilaterally; however, auditory complaints included: difficulty hearing in the presence of background noise, difficulty understanding in the presence of multiple speakers, and difficulty comprehending speech of people who speak fast. Performance on the Duration Patterns Test and the Auditory Fusion Test-Revised resulted in poor temporal processing function. The scores on the Duration Patterns Test indicated severe dysfunction in this task in both ears. The scores on the Auditory Fusion Test-Revised indicated poor temporal resolution ability bilaterally, with significantly poorer temporal resolution function in the right ear.

The relationship between temporal processing abilities and speech perception as explained in the literature suggests that these abilities may in fact be the basis of auditory processing in regards specifically to speech perception (Musiek, Shinn and Hare, 2002). The difficulty in processing speech in the presence of temporal processing deficits is that timing related cues are key to the formulation and resolution of the speech signal (Keith, 2000; Tallal, 1978). Phoneme differentiation, syllabic rhythm, varying rates of speech, and perception of pitch as related to the varying rates of vocal fold vibration are a few examples of timing related tasks that require intact temporal processing systems in order to comprehend speech (Phillips, 2002). In other words, intact temporal processing is thought to be required at all levels of language: phonemic, morphologic, and syntactic. An example of a temporal processing dependent element of speech includes comparisons between voiced and voiceless consonants such as /b/ versus /p/. In this example, the slight difference in voice onset time may not be processed clearly, and results in incorrect comprehension (Tallal, Miller, Bedi, Byma, Wang, Nagarajan, Schreiner, Jenkins and Merzenich 1996). Another example is seen in natural pauses between syllables: "They saw the snowdrift." versus "They saw the snow drift." Once again, incorrect processing of the time duration between various pauses throughout speech may result in inaccurate comprehension (Chermak, 2001). At the syntactic level, an example of a temporal processing dependent sentence is: "Look out the door!" versus "Look out! The door!" (Lucker and Wood, 2000).

Much research has investigated the possibility of a correlation between temporal processing deficits and various language based skills and disorders, including, reading development, phonological awareness, and dyslexia (McCroskey and Keith, 1996; Merzenich, Jenkins, Johnston, Schreiner, Miller and Tallal, 1996; Tallal, 1978; Tallal et al., 1996; Walker, Shinn, Cranford, Givens and Holbert, 2002). Many of these published articles have focused on attempting to demonstrate that a group of children with disorders generally perform significantly poorer on temporal processing based tasks as compared to a normal group.

McCroskey and Kidder (1980) studied to see if an auditory fusion test could demonstrate potential differences between normal children and children with learning disabilities, and children with reading disabilities in regards to their temporal resolution. Results from the study indicated that normal children perceived auditory fusion thresholds at significantly shorter time intervals than their reading disordered and learning disabled counterparts, suggesting that temporal resolution problems could possibly be causally related to reading and language disorders.

Rey, De Martino, Espesser, and Habib (2002) investigated the hypothesis that a general temporal processing deficit is the cause of the phonological disorders observed in children with dyslexia. The researchers utilized a series of experiments that looked at temporal order judgments of consonants /p/ and /s/, in various combinations with vowels. Subjects included a group with dyslexia and a normal, control group. In the consonant-consonant-vowel (CCV) condition, the group with dyslexia performed significantly poorer than the control group. In a comparison of a VCCV structure versus a VCVCV structure, considered less phonologically complex, the group with dyslexia showed no significant improvement in scores. The control group also showed no significant improvement over the two conditions; however, they also scored significantly better in both conditions as compared to the group with dyslexia. This was interpreted to suggest that phonological complexity is not a cause of the phonological disorders observed in dyslexic children. In a third experiment, the researchers presented a VCCV stimulus to subjects in two conditions: in the first condition the consonant cluster in the VCCV stimulus was represented at a normal speed, and in the second condition the consonant cluster in the VCCV stimuli was artificially slowed in duration. The group with dyslexia improved significantly on the temporal consonant order judgment tasks in the slowed speech condition when compared to their order judgments in the normal consonant cluster speed condition. Thus, the researchers concluded that a general temporal processing deficit could explain the phonological deficits seen in dyslexic children.

Researchers have also tackled the problem of correlating temporal processing with speech, language and reading skills by attempting to demonstrate that temporal based training does improve a disordered group's performance to normal or near-normal levels. In a study by Tallal, et al. (1996), a speech processing algorithm that extended the speech signal by 50% and enhanced fast transitional speech elements by increasing their intensity was used to help train language-learning impaired children over a six week period. A comparison of the pre- and post-test results on standardized speech, language, and auditory temporal processing tests indicated that after treatment the group with language-learning impairments demonstrated significant improvements in their speech discrimination and language comprehension skills by about two years. In another 1996 publication authored by Merzenich et al., language-learning impaired children were provided training through the use of engaging computer games that focused on temporal ordering and perceptual identification tasks using both speech and non-speech stimuli. Training was provided for a duration of twenty minutes over nineteen to twenty-eight training sessions over a span of four weeks. Results from the study demonstrated a marked improvement in the abilities of the children with language-learning impairements to recognize brief and fast sequences of non-speech and speech stimuli. The researchers concluded from their study that the children with language-learning impairements do have temporal processing deficits and that training can ameliorate those deficits.

Though a body of research has shown a positive correlation between temporal processing deficits and speech, language and reading disorders, a series of published articles have also demonstrated that no correlation exists. Nitrouer (1999) studied the hypothesis that temporal processing deficits underlie phonological processing problems. In a study of one hundred ten children divided into two groups of children with normal and poor reading skills, Nitrouer tested both groups on their abilities to sequence non-speech tones presented at varying rates and on their abilities to make phonetic decisions based on brief transitional parts of speech signals. She concluded that there was no evidence to support her hypothesis as the results demonstrated that the children with reading impairements were equally able to sequence the rapidly presented non-speech stimuli as their normal counterparts. In a similar study, Watson and Miller (1993) investigated the possibility of a relationship between one's auditory processing abilities and one's phonological abilities, given the latter's seemingly causal relation to the development of reading skills. Their research revealed that there was no significant relationship between temporal processing and phonological abilities. In a more recent study, Bretherton and Holmes (2003) investigated the relationship between auditory temporal processing of non-speech sounds and phonological awareness ability in children with reading disabilities. Forty-two children with reading disabilities were tested using Tallal's tone-order judgment task, as well as tests of their ability to process speech sounds and visual symbols, and on phonological awareness and reading. Tallal's Tone-

Order Judgment task required participants to indicate the order in which a pair of tones is perceived. Participants' responses were one of four possible tone pair presentations: High-High, Low-Low, High-Low, and Low-High. Results suggested there is no evidence that auditory temporal processing is an underlying problem in poor phonological awareness and in turn neither would a temporal processing problem contribute to reading disorders. Breier, Gray, Fletcher, Foorman, and Klaas (2002) reported that when children with and without reading disorders were tested with temporal order judgment tasks, the group with reading disorders performed worse relative to the group without reading disorders on speech tasks, but not on non-speech tasks. Their research suggests that the children with reading disorders have deficits in phoneme perception rather than an underlying temporal processing disorder. In another study by Schulte-Korne, Deimel, Bartling, and Remschmidt (1998), no evidence was seen to support the theory that a relationship between reading disabilities/dyslexia and temporal resolution abilities exists.

Hautus, Setchell, Waldie, and Kirk (2003) found that auditory temporal processing defined by gap-detection in noise abilities, were significantly deficient in a population of children with dyslexia aged six to nine years as compared to age-matched controls. The investigators administered the same task to older subjects (ten to eleven years, twelve to thirteen years, and twenty-three to twenty-five years) and observed that no significant differences were noted between the impaired and the control groups' abilities to perceive gaps in noise. They interpreted the results to suggest that temporal processing abilities might be an antecedent to language-related perceptual problems that continue on after the initial deficit resolves. Clearly, the debate over the role of auditory temporal processing in one’s phonological awareness and reading and language abilities continues and the need for further research is necessary.

Assessment of Temporal Resolution

The accurate identification of temporal processing deficits, specifically in the area of temporal resolution, requires the inclusion of sensitive and specific tests in the APD test battery. Currently, there are two commercially available clinical tests that assess the minimum time interval required to discriminate or resolve acoustic events: the Auditory Fusion Test-Revised (AFTR) and the Random Gap Detection Test (RGDT). Other variations have been incorporated in several experimental temporal resolution tests, including the Binaural Fusion Test (BFT) and the Gap In Noise Test (GIN). Each test attempts to evaluate one’s temporal resolution abilities, however, notable differences exist in their characteristics and methods of assessment, as shown in Table 1. One characteristic that differentiates temporal resolution tests is the concept of “fusion detection” versus “gap detection.”

The gap detection threshold represents the smallest silent interval in a stimulus that a listener can detect (Lister, Besing, and Koehnke, 2002). In contrast, the fusion threshold represents the smallest silent interval in a stimulus that a listener does not detect. Fusion and gap detection tasks are similar in that they both seek to measure temporal discrimination or temporal resolution. However, fusion and gap tasks take different approaches to reach their intended goal. Gap detection tasks generally require subjects to listen to stimuli presented with varying inter-stimulus intervals and indicate when they detect two distinct stimuli**.** Fusion detection tasks, in contrast, require subjects to indicate when two stimuli fuse as one, and hence the threshold of “fusion” is obtained.

TABLE 1. A comparison of temporal resolution tests.

	AFTR	RGDT	BFT	GIN
Test Developer	McCroskey & Keith	Keith	Musiek	Musiek
Year Published or Recorded	1996	2000	2002	2003
Fusion vs. Gap Detection	Fusion	Gap Detection	Fusion	Gap Detection
Presentation Mode	Binaural *	Binaural	Dichotic	Monaural
Presentation Level	50 dB SL, Re: PTA	55 dB HL	55 dB HL	50 dB SL, Re: PTA
Stimuli	Tone Pairs	Tone & Click Pairs	Noise Pairs	Gaps in 6 s Noise
Range of Inter-pulse Interval (IPI) or Gap Duration	2-300 ms	2-40 ms	5-100 ms	2-20 ms
Smallest IPI Step Size	2 ms	2 ms	5 ms	2 ms
Age Appropriate Norms: Mean/ Standard Deviation#	8-9 ms/3-4 ms	6.0 - 7.8 ms/ 2.5 - 5.3 ms^	None Available	4.9 ms/1 ms+
Response Mode	Verbal	Verbal	Verbal	Nonverbal/Motoric
Response Task	Count 1 or 2	Count 1 or 2	Count 1 or 2	Press button when gap is heard
Measure	Shortest IPI that results in the perception of one tone	Shortest IPI that results in the perception of two tones/clicks	Shortest IPI that results in the perception of one noise	Shortest IPI that results in the detection of a silent gap
Total Test Time	13-16 min**	10 min 6 min (tones only)	10 min	20 min
Sections	3	4	1	1
Test Lists	1	1	3	4
Number of Gap/Fusion Trials per List	126 Subtest 2 72 Subtest 3	63	54	60
Commercially Available	Yes	Yes	No	No

* AFTR can be administered monaurally; however, normative data has been reported only for binaural administration.

Range reported where participants' ages span more than one norm group.

^ Norms for tones only; no normative data available for RGDT clicks.

+ Normative data based on adult performance.

** Subtest 1 + 2 = 16 min; subtest 1 + 3 = 13 min.

According to Keith (2000), “fusion detection” and “gap detection” are sometimes used interchangeably to describe the same process, even though they describe two different concepts. It is not certain whether the two tasks reflect the same underlying process or neurology; however, it is thought that discontinuity of spike potentials and/or neural adaptation might underlie one or both tasks (Phillips, 1999). Eggermont (1995) postulated that the neural correlate for an auditory fusion threshold is the reduction in neural activity after the presentation of the second click is completed. He further postulated that the auditory fusion threshold in humans should occur for gap durations below two to three msec, since the average gap detection threshold is known to occur at approximately two to three msec (Eggermont, 1995). Mickey and Middlebrooks (2001) contended that the neurophysiology of the perception of two distinct acoustic stimuli as one fused stimulus is a continuation of spike potentials, similar to the neurophysiologic response of a single acoustic stimulus.

Whether a fusion or a gap detection task is used to assess temporal resolution, the shorter the time interval between two presenting sounds that one is able to detect, the better their temporal resolution ability. Temporal resolution thresholds were shown to be dependent upon variables including intensity of presentations, frequency, bandwidth, and channel type (Phillips, 1999). Phillips (1999) suggested that for narrow band stimuli higher frequency signals allow for shorter gap detection thresholds than lower frequency signals and that gap detection thresholds were shorter for narrow band noise stimuli with larger bandwidths than for smaller bandwidths. Within-channel test designs where the leading stimulus and the trailing stimulus are the same were shown to have shorter gap detection thresholds than for between-channel test designs, which are considered to be more representative of speech (Phillips, Taylor, Hall, Carr and Mossop, 1997). For subjects with normal hearing, three msec was required between two presented stimuli to perceive two sounds instead of one (Muchnik, Hildesheimer, Rubinstein, Sadeh, Shegter and Shibolet, 1985). Gap detection thresholds were seen in normal populations down to two to three msec (Plomp, 1964; Penner, 1977; Phillips, Hall, Harrington, and Taylor, 1998). Normative data for the RGDT and the AFTR suggests that any perception of a gap threshold or fusion threshold below twenty msec is considered normal. The cut off score of twenty msec was chosen as it represents two standard deviations above the mean (McCroskey and Keith, 1996; Keith 2000).

Emanuel (2002) looked at the common practices used in the evaluation of auditory processing disorders by fifty audiologists and found that more than sixty percent of respondents administered a frequency patterns test to target temporal processing abilities (i.e., temporal recognition, temporal sequencing), but few indicated the administration of any temporal resolution (i.e., temporal discrimination) tests. This, despite the recommendations made at the Bruton Conference that a test of temporal resolution should be administered (Jerger and Musiek, 2000). Of those that responded to her survey and did test for temporal resolution abilities, twenty-eight percent used the AFTR. Less than twenty percent used some form of a gap detection task.

Auditory Fusion Test-Revised (AFTR)

The AFTR, by Robert L. McCroskey and Robert W. Keith (1996), is essentially a digitized version of the WAFT. The AFTR measures the shortest separation (in milliseconds) between two auditory stimuli that results in a subject to perceive a single stimulus rather than two separate stimuli. This duration is identified as the Auditory

Fusion Threshold (AFT^{hreshold}) and is measured in milliseconds (msec). In the AFTR, the tone pairs are presented in ascending and descending runs relative to inter-pulse interval (IPI) durations, both in monaural or binaural presentations.

The test consists of 3 subtests. Subtest 1 is a screening test with 500 Hz tone pairs ascending from a 0 to 300 msec IPI. Standard subtest 2 contains five frequencies: 500 Hz, 1000 Hz, 4000 Hz, 250 Hz, and 2000 Hz**.** Each frequency is presented with 18 corresponding frequency pairs with successively larger and smaller IPI. The IPI of each tone pair ascends from 0 msec to 40 msec and then descends back down to 0 msec. Expanded subtest 3 contains 18 pairs of tones at each of the three frequencies: 1000 Hz, 4000 Hz, and 250 Hz. The IPI of each tone pair ascends from 40msec to 300msec and then descends back down to 30 msec. The expanded subtest 3 is only utilized when two consecutive two-tone pulses are not reported until a 60 msec inter-pulse interval or greater during subtest 1. If the listener reports two consecutive two-tone pulses under a 60 msec IPI during subtest 1, then the standard subtest 2 is administered. Each subtest is administered in both the monaural condition (left and right) and the binaural condition at a presentation level of 50 dB SL, reference pure tone average (PTA) (M[c]Croskey and Keith, 1996).

The auditory fusion threshold is determined by a two-step calculation. For each frequency run, an auditory fusion threshold is determined by averaging the last ascending IPI that is perceived as a single fused stimulus before consecutive IPI are perceived as two distinct stimuli, with the first of two consecutive descending IPIs that are perceived as a single fused stimulus. Next, all frequency specific auditory fusion thresholds are averaged to determine the final auditory fusion threshold.

No reliability studies have been done on the AFTR; however, limited studies of validity have been published. (Reliability refers to the extent that a test's score remains stable over a period of time when tested and re-tested on the same group of subjects. Validity refers to the extent a test measures what it was designed to measure. Both reliability and validity studies are necessary in order for one to assume with confidence that a given measure does in fact measure what it is testing.) M^{c}Croskey and Keith utilized predictive validity to determine whether the AFTR does in fact measure the AFT^{hreshold}. Predictive validity is the degree to which the scores on two tests taken at different times are correlated. Predictive validity is used to examine how well scores on one test predict accurately findings on already established tests. For example, if a new temperature thermometer was developed, in order for it to have predictive validity, it must be able to predict accurately the temperature reading of an already proven temperature thermometer currently in use when measuring an individual's temperature. The predictive validity of the AFTR was demonstrated by its ability to accurately predict individuals with poor temporal processing abilities by comparing itself to its predecessor, the Wichita Auditory Fusion Test (WAFT) of 1975 (M^{c}Croskey and Keith, 1996). McCroskey and Kidder (1980) studied the validity of the WAFT by testing 135 children divided into groups of normal children and children with reading and learning disorders**.** They found that children with reading and language disorders present with temporal resolution deficits, which they believe confirmed the hypothesis that the auditory fusion threshold is an effective tool in identifying individuals with temporal resolution problems. Isaac, Horn, Keith, and McGrath (1982) confirmed the results of McCroskey and Kidder's study. Issacs et al. (1982) reported that the children in the group with language and learning disabilities had significantly larger auditory fusion thresholds than the control group. However, no studies of validity have yet shown that the auditory fusion threshold paradigm identifies temporal resolution deficits in individuals diagnosed with APD.

<u>Random Gap Detection Test (RGDT)</u>

The RGDT, developed by Robert W. Keith is a revision of the AFTR (Keith, 2000). Keith's concern with the predictability of the successively larger and smaller IPIs of the AFTR contributed to the development of the RGDT, which, as the name suggests randomizes the presentations of the two-tone stimuli and their corresponding IPIs. Similar to the AFTR, the RGDT is designed to measure temporal resolution; however the method by which this is determined is slightly different. In the AFTR, the level of the AFT^{hreshold} is determined. In the RGDT, by contrast, the level of the random gap detection threshold (RGDT^{hreshold}) is determined. The subject's task is to respond to whether one or two distinct tones/clicks were heard and it is at the smallest interval that a subject consistently identifies two tones/clicks (rather than one tone as is the case for the AFT^{hreshold}) that the RGDT^{hreshold} is determined. This is the level of the gap detection.

Interestingly, no explanation has been made as to why Keith altered the fusion detection paradigm in the AFTR to the gap detection paradigm in the RGDT, the successor to the AFTR. Response tasks for both tests require subjects to listen and verbally respond to the number of separate stimuli they perceived; however, the measure extracted from the AFTR is purportedly one of fusion and the measure extracted from the RGDT is purportedly gap detection.

The RGDT is further differentiated with the AFTR by its use of both click and tonal stimuli. The tonal stimuli used in both the AFTR and the RGDT is beneficial in its ability to determine an individual's frequency specific temporal resolution abilities as well as its ability to help in testing individuals who present with peripheral hearing loss. Tonal stimuli may enable, even individuals with peripheral hearing losses, to have their temporal resolution abilities tested without possible contamination or influence of a peripheral hearing loss. The assumption of course is that these individuals must have at least one of the frequencies at normal to near normal hearing acuity. The click stimuli utilized in the RGDT are beneficial in that clicks are spectrally complex, enabling testing of individuals regardless of the presence or absence of most configurations of peripheral hearing losses. This may in fact be an excellent screening tool for auditory processing abilities as was suggested in the Bruton Conference of 2000 (Jerger and Musiek, 2000).

The RGDT consists of 4 subtests. Subtest 1 is utilized as the screener and consists of nine 500 Hz tone pairs with IPIs that increase in ascending order from 0 msec to 40 msec. Subtest 2 contains four frequencies: 500 Hz, 1000 Hz, 2000Hz, and 4000 Hz. Each frequency is presented in nine-tone pair combinations with IPIs randomly assigned between 0 msec to 40 msec. Subtest 3 is a practice test for two click stimuli with IPIs increasing in ascending order from 0 msec to 40 msec. Subtest 4 presents click pairs with IPIs randomly assigned between 0 msec to 40 msec. In contrast to the AFTR, each subtest is presented in the binaural only condition at a presentation level of 55 dB HL. The random gap detection threshold is calculated by averaging the sum of all the gap detection thresholds for each stimulus as determined by the shortest IPI that is perceived as two distinct stimuli.

No studies of the reliability of the RGDT exist; however, some limited studies of validity have been done. The validity of the RGDT's ability to correctly identify individuals with temporal resolution difficulties was established by examining its predictive validity, using the AFTR as the criterion measure. Keith (2000) reported that gap detection thresholds obtained on the RGDT for tonal stimuli were comparable to fusion thresholds reported for the AFTR, as published by McCroskey and Kidder (1980).

Binaural Fusion Test (BFT)

The BFT is an experimental fusion test developed by Frank E. Musiek (2002). It is designed to identify temporal resolution deficits and binaural interaction problems by utilizing a series of noise burst pairs with randomly assigned IPIs. The BFT requires subjects to attend to stimuli presented to both ears, and respond by counting whether one or two noise bursts were heard. The noise burst pairs are presented dichotically, in contrast to the RGDT and the binaural portion of the AFTR where the stimuli are presented diotically. The BFT differs from the GIN in that the BFT is a binaural, dichotic task that tests for a fusion threshold, whereas the GIN is a monaural gap in noise detection test. In the BFT, each noise burst from each pair is presented asynchronously between each ear. For example, if the initial noise burst is presented in the left ear then the subsequent noise burst, after the IPI, would be presented in the right ear. This modification results in a more complex task and may enable the experimenter to determine not only if there is a temporal resolution dysfunction, but also opens the possibility of exploring a binaural interaction deficit. Binaural interaction is an auditory skill that enables individuals to take different stimuli from both ears and combine them to produce a meaningful auditory percept (Plakke, Orchik and Beasley, 1981). In real world conditions, this ability to merge disparate information from both ears is seen when acoustic information to each ear differs in timing and intensity due to the head shadow effect and spatial separation of the ears (Perrott and Nelson, 1969). In order to separate out possible deficits in temporal resolution and binaural interaction, further testing utilizing binaural interaction specific tests would be required. Tests of binaural interaction include masking level difference and tests of localization/lateralization.

The BFT consists of 3 forms. Each form has 54 trials and randomizes its IPIs and noise burst presentations differently. One of the three available forms can be used as a training/practice section to help in training the subject to the task. The initial presentation (left or right) of each dichotic pair of noise bursts are also randomized to reduce any predictability effects. The IPIs utilized range from 0 msec to 100 msec and are presented at 55 dB HL. The binaural fusion threshold is determined by the shortest IPI that is perceived four out of six times.

No data is available regarding the validity and reliability of this experimental test.

<u>Gap Detection in Noise Test (GIN)</u>

The GIN test is another experimental temporal resolution test developed by Frank E. Musiek (Shinn, Jirsa, Baran and Musiek, 2004). Gap detection thresholds are the focus of the GIN, however, in this test protocol the presentation stimuli surrounding the IPIs are no longer tone or click pulses. Instead, a constant white noise presented for a duration of 6 seconds is utilized. Interspersed within the six-second white noise are random gaps, ranging in duration from 2 msec to 20 msec with each gap trial occurring six times within each test list. The GIN test consists of a practice section, and 4 forms (variants of the randomized stimuli). Currently, only adult normative data exists. The mean gap detection duration for adults is 4.9 msec, with a standard deviation of 1 msec (Shinn, Jirsa, Baran and Musiek, 2004). The GIN is administered in both monaural conditions at a presentation level of 55 dB SL, reference to PTA. The gap in noise threshold is determined by the shortest gap that is perceived to be present four times out of six presentations.

A notable difference between the GIN and the 3 temporal resolution tests previously described is the response tasks required from subjects. In the administration of the AFTR, RGDT, and the BFT, subjects are required to respond verbally by indicating whether one or two presentations are heard. The GIN on the other hand, requires subjects to respond by clicking a button when a gap in the six second continuous white noise is detected. By not requiring a response involving speech or language production, the absence of the language-processing component in the GIN, as compared to the 3 other tests, suggests the GIN is less cognitively demanding and may, therefore results in reduced response times. It has not been shown that either response task is preferable for temporal resolution testing; however, it is assumed that each tests provides sufficient time between stimulus presentations for subjects to process the auditory information and respond accordingly and as such, should not affect this study's ability to compare tests.

The validity of the GIN as a clinical measure of temporal resolution was examined by comparing the performance of eighteen patients with confirmed neurological lesions of the central auditory nervous system (CANS) with fifty subjects with normal hearing (Shinn et al., 2004). The GIN scores of the patients with CANS lesions were statistically larger than the scores of the normal subjects. The GIN demonstrated a sensitivity of approximately seventy to eighty percent to CANS lesions. The GIN was also shown to present strong equivalent forms reliability (Shinn, personal communication, 2004).

Research Purpose

This study addressed the following questions:

1. What is the concurrent validity (i.e., correlation) of the AFTR, RGDT, BFT, and GIN temporal resolution tests when administered to children with normal hearing?
2. Are there any differences in the mean AFTR, RGDT, BFT, and GIN temporal resolution scores obtained by children with normal hearing?
3. Are there any significant statistical or clinical differences in the mean AFTR, RGDT, BFT, and GIN temporal resolution scores obtained by children with normal hearing?

CHAPTER TWO

METHOD

Participants

The participants of this study included a group of ten children with normal hearing ranging in age from 7 years through to 11 years and one child age 13 who demonstrated auditory processing deficits as indicated by an APD evaluation at the Child Development and Rehabilitation Center (CDRC) at the Oregon Health and Science University in Portland, Oregon at the age of 11 years. The child who was evaluated at CDRC was determined to have a deficit in one are of auditory processing, and was not diagnosed as disordered. The ten participants with normal hearing were selected based on the following criteria: must not demonstrate any auditory processing deficits, must not display any behaviors that may suggest the presence of hearing impairment or APD, must perform well academically, and must demonstrate normal hearing acuity bilaterally, as determined by thresholds better than 15 dB HL. This information was obtained in a case history format prior to the beginning of testing. Parents were asked to describe their child in terms of any concerns with hearing, documented auditory processing deficits, history of otitis media, family history of hearing loss, and academic performance.

Only the parents of participant seven described having some possible concerns with their child's hearing. Subsequent testing revealed participant seven to have normal hearing acuity bilaterally. Only participant eleven was described as having documented auditory processing deficits, although he was not diagnosed as having an auditory processing disorder. Participants eleven and five were described as having a significant history of otitis media. Subsequent middle ear studies demonstrated normal middle ear function on the day of testing. Parents of all participants denied any family history of hearing loss, and all participants were considered by their parents to be performing at the subjective level of "good" or better academically on a scale ranging from excellent to poor. Participants' demographic information is displayed in Table 2.

TABLE 2. Participant demographic information.

Participant	Age	Sex	Concerns with Hearing	Normal or AP Deficits	History of Otitis Media	Family History of Hearing Loss	Academic Performance
1	7.05	M	None	Normal	None	None	Excellent
2	9.07	M	None	Normal	None	None	Excellent
3	11.01	F	None	Normal	None	None	Excellent
4	11.07	F	None	Normal	None	None	Excellent
5	7.02	M	None	Normal	Yes	None	Good
6	7.03	F	None	Normal	None	None	Good
7	9.11	M	Some	Normal	None	None	Good
8	7.04	F	None	Normal	None	None	Excellent
9	7.10	M	None	Normal	None	None	Good
10	8.09	M	None	Normal	None	None	Good
11	13.03	M	None	AP Deficits	Yes	None	Good

The one participant demonstrating auditory processing deficits (participant eleven) was tested three years prior to this study (at age 10 years) and found to present significant difficulties in binaural integration as indicated by his performance of two standard deviations below the mean on the Competing Words portion of the SCAN-C. He obtained a raw score of 30 and a percentile rank of 5 on the Competing Words portion of the SCAN-C. Auditory memory deficits were also noted as indicated by his poor recall ability on repetition tasks. On the Filtered Words subtest of the SCAN-C, the participant performed within two standard deviations above the mean. He obtained a raw score was 35 and a percentile rank was 63 for the Filtered Words subtest. On the Auditory Figure Ground subtest of the SCAN-C, a score greater than one standard deviation above the mean was obtained. His raw score was 37 and his percentile rank was 75 on that subtest. In the Competing Sentences subtest of the SCAN-C, the participant obtained a raw score of 13, which is greater than one standard deviation below the mean; however, still placing him within the normal limits for that task. His percentile rank for that subtest was 9. Participant eleven’s composite standard score was 90, placing him at a percentile rank of 25, but less than one standard deviation below the mean. On the Staggered Spondaic Word Test, the participant demonstrated slightly elevated scores in all conditions; however, his performance was still within two standard deviations of the mean. His raw scores for the Staggered Spondaic Word test were: Right Non-Competing = 2, Right Competing = 3, Left Competing = 8, and Left Non-Competing = 2. On the Random Gap Detection Test, the participant was able to detect a gap down to a duration of 6 msec, which placed him within two standard deviations above the mean. On the Pitch Pattern test the participant obtained a raw score of 100% in both ears, which was well above the cut-off criteria of 78%. During his APD assessment, participant eleven demonstrated normal hearing acuity, normal middle ear function and normal word recognition bilaterally.

Protocols for the CDRC Audiology Department include both a comprehensive peripheral evaluation, as well as a battery of tests for the APD evaluation. The comprehensive peripheral evaluation includes: puretone air and bone conduction thresholds, speech recognition thresholds, word reception scores, tympanometry, and acoustic reflex testing. The APD battery includes: the SCAN-C, the Dichotic Digits Test, the Staggered Spondaic Word Test, the Pitch Pattern Sequence Test, the Duration Pattern Sequence Test, and the Random Gap Detection Test.

Equipment

Immittance testing: tympanometry and acoustic reflex testing was performed using the GSI-33 immittance bridge calibrated to ANSI S3.390 1987 specifications. All pure tone and speech testing were performed using the InterAcoustics-AC40 audiometer calibrated to ANSI S3.6 1996 specifications. Last calibration was completed on 10-03-2003. Each instrument was subjected to biologic checks daily prior to testing. Participants were presented the auditory stimuli through Eartone 3A insert earphones. During the temporal resolution testing, the AFTR, RGDT, BFT and the GIN were played back on the CD player (Sony CDP-CE215) or the tape player (Nakamichi DR-3). All testing was conducted in a sound-treated booth (InterAcoustics RE-143), which met the ANSI S3.1 1991 requirements for permissible ambient noise levels.

Procedures

Peripheral Hearing Evaluation**:** Each participant was administered a pure tone hearing test at all octave frequencies between .250 KHz and 8KHz. Immittance measures were also obtained, including tympanometry and an acoustic reflex test to rule out the presence of middle ear disorder. Each participant was required to demonstrate normal peripheral hearing sensitivity as defined as pure tone thresholds no poorer than 15 dB HL for all octave frequencies between .25 KHz and 8 KHz, bilaterally, and ipsilateral and contralateral acoustic reflexes present at expected sensation levels and hearing levels, for octave frequencies between .5 KHz and 4 KHz**,** bilaterally. Participants were also required to demonstrate normal middle ear function by way of tympanometry defined as static acoustic admittance of no less than .3 mmho, and tympanometric width no greater than 200 daPa, as delineated in American Speech-Language-Hearing Association's

(1997) revised guidelines for screening for middle ear disorders in children. Rest breaks were provided throughout this portion of the testing period as requested by the subjects to minimize subject fatigue.

Temporal Resolution Testing**:** The participants from the group with normal hearing and the one APD participant were administered the four Temporal Resolution tests in a randomized order in an attempt to avoid practice/learning effects. Auditory Fusion Test-Revised (AFTR), the Random Gap Detection Test (RGDT), the Binaural Fusion Test (BFT), and the Gap in Noise test (GIN) were the tests administered. Rest breaks were provided, as requested by participants, between tests and between subtests (as permitted by the test manuals) to minimize participant fatigue. A practice trial was included for each test for test familiarization purposes.

Auditory Fusion Test-Revised (AFTR): The AFTR involves three sections as described in the previous chapter. Stimuli were presented at 50 dB SL, with reference to the pure tone average of 500 Hz, 1000 Hz, and 2000 Hz as directed in the user's manual. Each subject was provided with the same instruction:

> "You are going to hear some tones that sound like beeps. There will either be one or two sounds presented at one time. Please indicate whether you have heard one sound or two sounds by saying "one" or "two." For example, if you hear 'beep' how many sounds do you hear? Sometimes the sounds will be very close together and you may not be sure whether you heard one or two. Take a guess. It's okay. Do you have any questions?"

Random Gap Detection Test (RGDT): The RGDT involves 4 sections as described in the previous chapter. Stimuli were presented at 55 dB HL as directed in the user's manual. Each subject was provided with the same instructions:

> "You are going to hear some tones that sound like beeps. There will either be one or two sounds presented at one time. Please indicate whether you have heard one sound or two sounds by saying "one" or "two." For example, if you hear 'beep' how many sounds do you hear? Sometimes the sounds will be very close together and you may not be sure whether you heard one or two. Take a guess. It's okay. Do you have any questions?"

Binaural Fusion Test (BFT): The BFT involves 3 sections as described in the previous chapter. Stimuli were presented at 55 dB HL to provide each subject with sufficient intensity in order to accurately perform the test. No recommendations to the presentation level have been made to date; however, an intensity of 55 dB HL is consistent with other temporal resolution test presentation levels. Each subject was provided with the same instructions:

> "You are going to hear some tones that sound like beeps. There will either be one or two sounds presented at one time. Please indicate whether you have heard one sound or two sounds by saying "one" or "two." For example, if you hear 'beep' how many sounds do you hear? Sometimes the sounds will be very close together and you may not be sure whether you heard one or two. Take a guess. It's okay. Do you have any questions?"

Gap in Noise Test (GIN): The GIN involves four test lists as describe in the chapter 1. Stimuli were presented at 50 dB SL reference their pure tone average of 500 Hz, 1000 Hz, and 2000 Hz in both monaural conditions as directed in the user's manual. Each subject was provided that same instructions:

> "You are going to hear a noise and within the noise there will be pauses, or short periods of silence where the noise is absent. The pauses will vary in length with some of them being very small. Sometimes there will not be any pauses. Whenever you hear a pause, press the button. Do you have any questions?"

Data Analysis

Means, standard deviations, and ranges were calculated for participants' performance on the four temporal resolution tests. Pearson's correlation coefficients (r) were calculated to examine relationships of pairs of temporal resolution measures. A repeated measures analysis of variance (ANOVA) was run to compare the means of the six measures of temporal resolution. A Newman-Keuls' multiple-range test was run to determine which means were significantly different from each other. Data obtained from the participant with auditory processing deficits were presented for comparison.

CHAPTER THREE

RESULTS

Four tests of temporal resolution were administered to ten children with normal hearing and to one child with auditory processing (i.e., binaural integration) deficits. Six different measures were extracted from the four temporal resolution tests. The RGDT provided two measures: the average binaural gap detection threshold for tonal stimuli and the average gap detection threshold for click stimuli. The GIN provided a monaural gap in noise threshold measure for left and right ears. The BFT and the AFTR each provided a single measure, an average binaural fusion threshold, diotic for the AFTR and dichotic for the BFT. The raw scores for each participant on each of the six temporal resolution measures are shown in Table 3 and in Figure 1.

TABLE 3. Raw scores, means and standard deviations for ten participants with normal hearing on four tests and six measures of temporal resolution.

			Duration (msec)			
Participants	RGDTT	RGDTC	BFT	GINR	GINL	AFTR
1	7.50	20.00	0.00	5.00	4.00	4.75
2	3.50	10.00	0.00	6.00	5.00	2.25
3	6.40	5.00	0.00	3.00	4.00	0.83
4	5.94	10.00	10.00	5.00	6.00	1.08
5	1.40	3.50	0.00	3.00	3.00	0.75
6	6.00	3.50	0.00	4.00	6.00	2.42
7	3.20	3.50	0.00	6.00	5.00	1.17
8	5.40	10.00	0.00	4.00	5.00	2.83
9	3.60	12.50	0.00	5.00	5.00	1.50
10	4.80	6.00	0.00	5.00	6.00	2.83
11	6.40	7.50	0.00	5.00	8.00	0.67
Means*	4.77	8.40	1.00	4.60	4.90	2.04
Std. Dev.*	1.83	5.25	3.16	1.07	0.99	1.24

RGDTT = Random Gap Detection Test for Tones; RGDTC = Random Gap Detection Test for Clicks; BFT = Binaural Fusion Test; GINR = Gap in Noise for the Right ear; GINL = Gap in Noise for the Left ear; AFTR = Auditory Fusion Test-Revised.

***** Means and standard deviations do not include data from participant 11 who presented auditory processing (binaural integration) deficits.

The scores for the child with auditory processing deficits (participant 11) on each of the six measures of temporal resolution is extracted from Table 3 (and Figure 1) and displayed individually in Table 4.

TABLE 4. Raw scores for the participant with auditory processing deficits (participant eleven) on four tests and six measures of temporal resolution.

	Duration (msec)					
Participant	RGDTT	RGDTC	BFT	GINR	GINL	AFTR
11	6.40	7.50	0.00	5.00	8.00	0.67

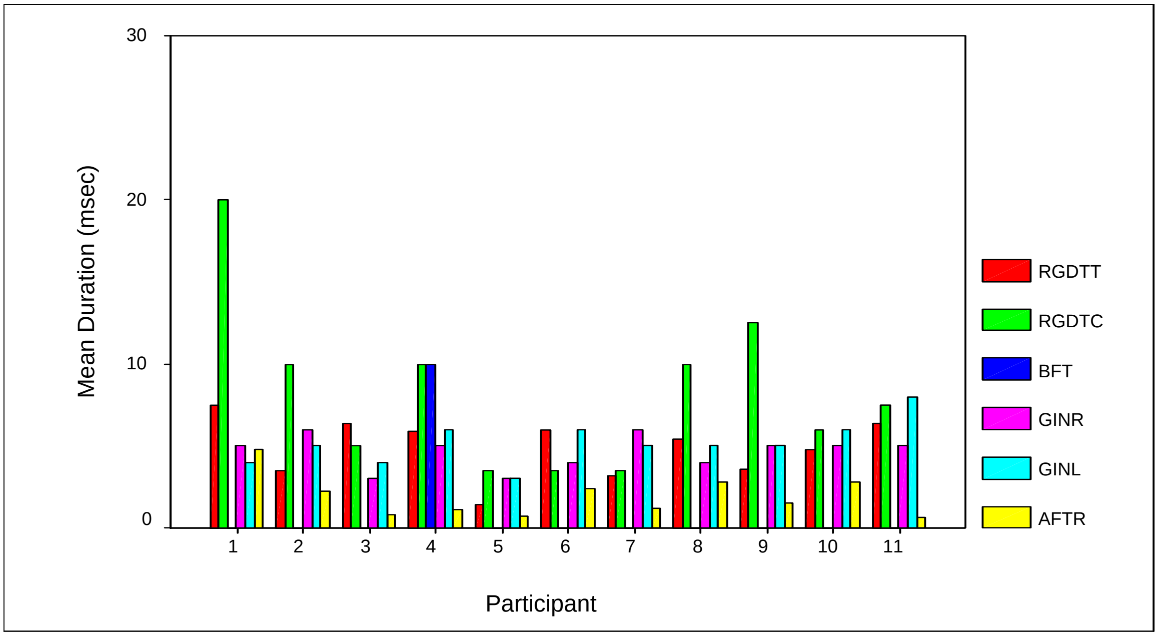

FIGURE 1. Fusion or gap duration scores (in milliseconds) for all participants on six measures of temporal resolution. RGDTT = Random Gap Detection Test for Tones; RGDTC = Random Gap Detection Test for Clicks; BFT = Binaural Fusion Test; GINR = Gap in Noise for the Right ear; GINL = Gap in Noise for the Left ear; AFTR = Auditory Fusion Test-Revised.

The means, standard deviations and ranges for each of the six measures derived from ten participants with normal hearing are found in Table 5. Figure 2 displays the means and standard deviations for each of the six measures derived from ten participants with normal hearing.

TABLE 5. Means, standard deviations, and ranges for ten participants with normal hearing for six measures of temporal resolution.

	N	Minimum	Maximum	Mean	Std. Dev.
RGDTT	10	1.40	7.50	4.7740	1.83160
RGDTC	10	3.50	20.00	8.4000	5.25357
BFT	10	0.00	10.00	1.0000	3.16228
GINR	10	3.00	6.00	4.6000	1.07497
GINL	10	3.00	6.00	4.9000	0.99443
AFTR	10	0.75	4.75	2.0410	1.24182

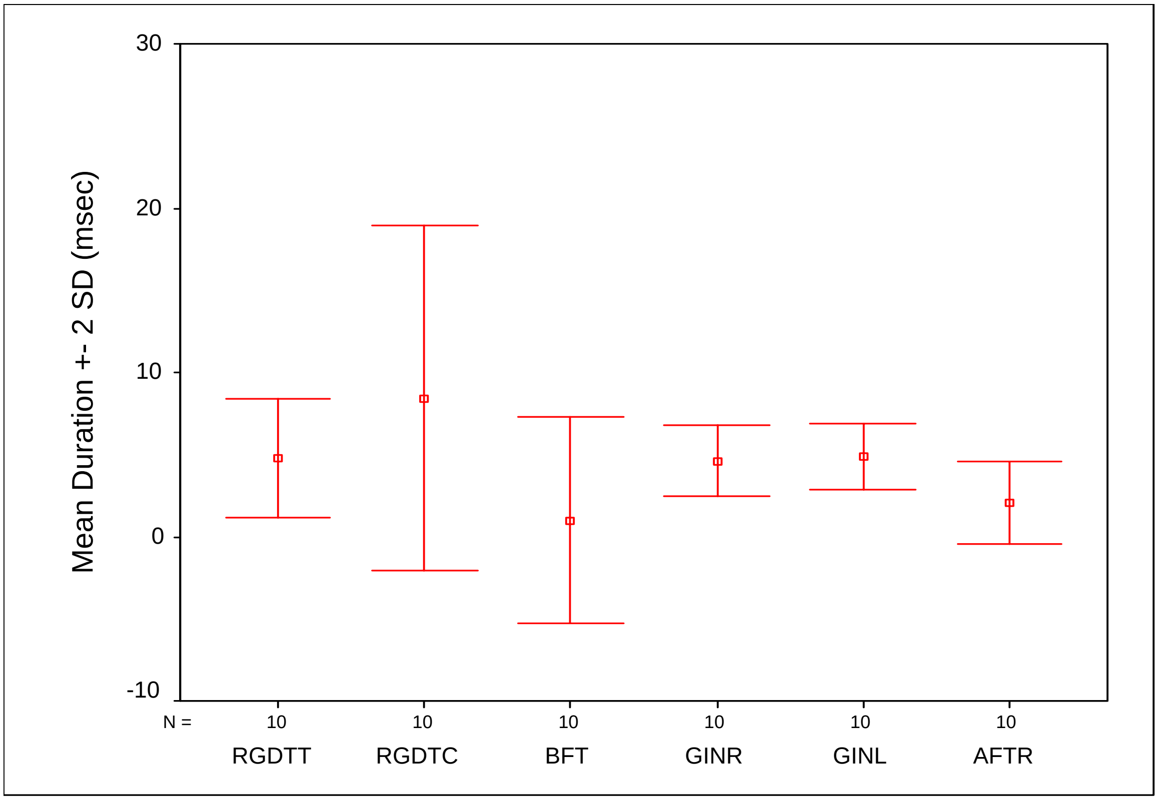

FIGURE 2. Means and standard deviations for each of the six measures of temporal resolution obtained from ten participants with normal hearing. RGDTT = Random Gap Detection Test for Tones; RGDTC = Random Gap Detection Test for Clicks; BFT = Binaural Fusion Test; GINR = Gap in Noise for the Right ear; GINL = Gap in Noise for the Left ear; AFTR = Auditory Fusion Test-Revised.

Frequency specific gap and fusion thresholds were obtained on the AFTR and the RGDT. The scores and means from each of the participants with normal hearing for all frequencies from both the AFTR and the RGDT are found in Table 6.

TABLE 6. Temporal resolution scores per frequency on the AFTR and the RGDT for ten participants with normal hearing.

	AFTR					RGDT			
Participant	250	500	1000	2000	4000	500	1000	2000	4000
1	5	5	5	5	3.5	10	10	5	5
2	2	2.5	1	2	3.5	2	10	10	5
3	0	2.5	0	0	0	2	5	10	5
4	1	0	1	3.5	1	2	2	5	5
5	2.5	0	1	0	1	5	5	2	5
6	2.5	0	5	3.5	3.5	5	5	5	10
7	5	1	0	0	0	5	2	2	2
8	0	1	5	5	5	2	5	5	5
9	1	1	2.5	2.5	1	2	2	2	2
10	2.5	2.5	2	2.5	5	2	5	2	5
Means	2.15	1.55	2.25	2.40	2.35	3.70	5.10	3.80	4.90

Pearson correlation coefficients (two-tailed) were calculated to examine relationships across the six measures of temporal resolution. An alpha level of .05 was used to establish significance. Table 7 displays the Pearson correlation coefficients for ten participants with normal hearing.

TABLE 7. Pearson correlation coefficients for six measures of temporal resolution for ten participants with normal hearing.

		RGDTT	RGDTC	BFT	GINR	GINL	AFTR
RGDTT	r	1	.465	.224	-.068	.294	.555
		.	.176	.534	.852	.410	.096
RGDTC	r		1	.107	.327	-.078	**.685**
			.	.769	.357	.811	**.029**
BFT	r			1	.131	.389	-.272
				.	.719	.267	.447
GINR	r				1	.478	.264
					.	.162	.461
GINL	r					1	.116
						.	.749

A significant ($p < 0.05$) correlation based on the scores of ten participants with normal hearing indicated a high degree of association between RGDTC and the AFTR ($r = 0.685$), two measures of binaural temporal resolution (see category 4, Table 8)**.** A scatter plot with a linear-regression line is displayed in Figure 3.

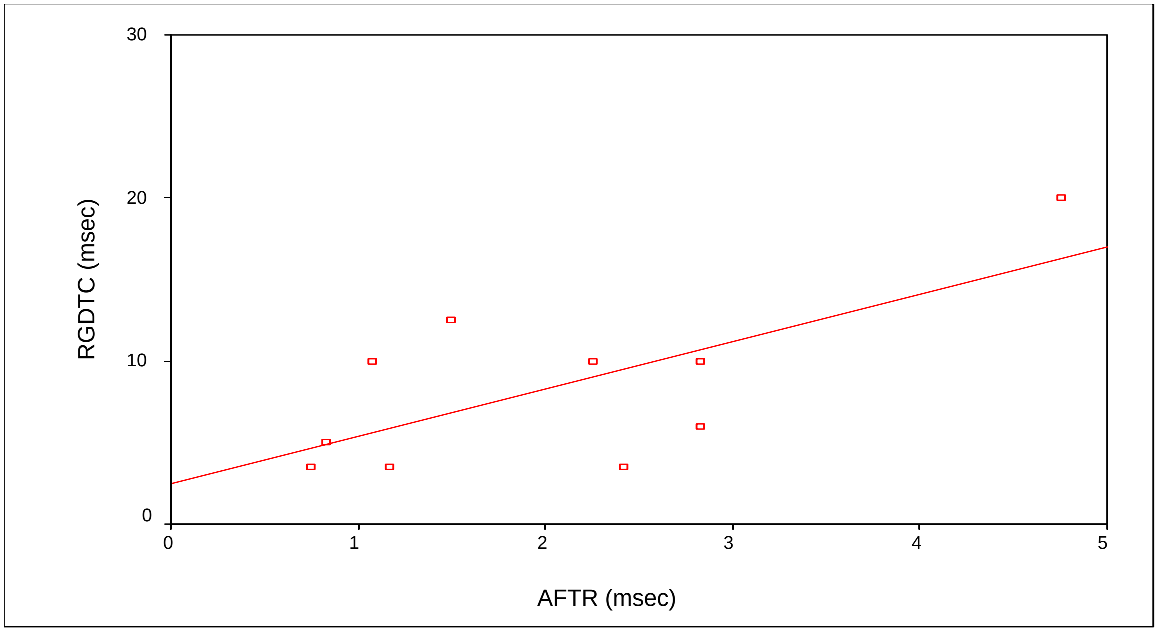

FIGURE 3. Scatter plot of the relationship between RGDTC and the AFTR derived from ten participants with normal hearing.

From the six measures of temporal resolution, six distinct categories of measures can be established. Measures within each category share a certain characteristic. Consequently, some of these categories of common characteristics are thought to cause means of measure within the categories to be similar. The categories include: 1) all measures; 2) measures of fusion; 3) measures of gap detection; 4) measures derived from binaural presentation; 5) measures derived from monaural presentation; and 6) measures derived from binaural presentation with tonal stimuli. Table 8 displays the six categories of temporal resolution measures.

TABLE 8. Six categories of temporal resolution measures.

	Category	Measure
1	All Six Measures	RGDTT, RGDTC, BFT, GINR, GINL, AFTR
2	Measures of Fusion	BFT, AFTR
3	Measures of Gap Detection	RGDTT, RGDTC, GINR, GINL
4	Binaural Presentation Mode	RGDTC, RGDTT, AFTR, BFT
5	Monaural Presentation Mode	GINR, GINL
6	Binaural Presentation Mode Tonal Stimuli	RGDTT, AFTR

A repeated measures, one-way analysis of variance (ANOVA) was run to compare the means of the six measures of temporal resolution, as found in category 1. Results of the analysis are found in Table 9. A main effect for treatment indicated that the six means of temporal resolution are significantly different from each other ($p < .001$).

TABLE 9. Analysis of variance based on means of six measures of temporal resolution from ten participants with normal hearing.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	p
Total	736.54	59			
Subjects	117.00	9			
Treatment	334.77	5	66.95	10.58	< .001
Error	284.78	45	6.33		

Table 10 displays the results of a Newman-Keuls' multiple-range test was used to determine which pairs of the six means of temporal resolution were significantly different ($p < .05$). Significant statistical differences were observed for eight of the fifteen possible pairs of temporal resolution means, as indicated by the difference between means value being greater than the minimum critical difference value.

TABLE 10. Newman-Keuls' multiple-range test based on means from ten participants with normal hearing.

Significant Difference in Means			Non-significant Difference in Means		
Measures	Difference between Means	Minimum Critical Difference	Measures	Difference between Means	Minimum Critical Difference
BFT - GINR	3.60	3.27	BFT - AFTR	1.04	2.72
BFT - RGDTT	3.77	3.60	AFTR - GINR	2.56	2.72
BFT - GINL	3.90	3.84	AFTR - RGDTT	2.73	3.27
BFT - RGDTC	7.40	4.02	GINR - RGDTT	0.17	2.72
AFTR - RGDTC	6.36	3.84	GINR - GINL	0.30	3.27
GINR - RGDTC	3.80	3.60	AFTR -GINL	2.86	3.60
RGDTT-RGDTC	3.63	3.27	RGDTT - GINL	0.13	2.72
GINL - RGDTC	3.50	2.72			

Of the six categories depicted in Table 8, measures within three of the categories [i.e., category 2 measures of binaural fusion (BFT and AFTR), category 5 measures of monaural gap detection (GINR and GINL), and category 6 measures of binaural presentation mode (i.e., fusion and gap detection) for tonal stimuli (AFTR and RGDTT)] were not significantly different. Non-significant mean differences were also seen between AFTR and GINR and between AFTR and GINL (categories 2 and 4 measures of fusion and binaural presentation, and categories 3 and 5 measures of gap detection and monaural presentation). Non-significant mean differences were observed also for GINR and RGDTT and for GINL and RGDTT, monaural and binaural measures of gap detection.

Significant mean differences were observed between measures within category 3 (i.e., RGDTT and RGDTC, GINR and RGDTC, and GINL and RGDTC), and within category 4 (i.e. BFT and RGDTT, BFT and RGDTC, AFTR and RGDTC, RGDTT and RGDTC). Significant mean differences were also observed across categories of binaural fusion and monaural gap detection (i.e., BFT and GINR and BFT and GINL).

CHAPTER FOUR

DISCUSSION

The performance of ten participants with normal hearing, ranging in age from 7 years to 11 years, and one participant age 13 years with auditory processing (i.e., binaural integration) deficits was compared across four tests and six measures of temporal resolution. All participants performed within the normal range on all temporal resolution tests according to clinical norms; however, statistical differences between test means suggest that these measures of temporal resolution may not be tapping identical temporal processes. Statistical mean differences (as well as the one significant correlation) are discussed relative to differences in presentation mode (i.e. monaural v. binaural/diotic v. binaural/dichotic), stimuli (i.e., tones, clicks, or noise), inter-pulse (i.e., gap) interval, response mode (i.e., verbal v. nonverbal), response task (i.e., verbal counting v. nonverbal motoric), and measure derived (i.e., shortest inter-pulse interval that results in perception of one tone or noise, or perception of two tones or clicks, or perception of a silent gap in noise). Clinical implications, including recommendations regarding test selection for evaluation of temporal processing in pediatric subjects, are provided.

All participants on each of the six measures of temporal resolution performed within the normal range according to the clinical norms. However, some concerns arise when analyzing data from clinical tests that do not have sufficient, or only have limited reliability and validity data, as is the case for the four tests of temporal resolution being studied. Questions arise regarding the validity of the results obtained when utilizing such tests. The consistency between the published normative data and the results obtained in this study suggest that these tests present some basic minimum degree of reliability.

Two different presentation levels were used across the four tests of temporal resolution, providing the potential for presentation level to be a factor that could have caused statistically significant differences in the means of the six measures. Presentation level is known to inversely affect the duration of gap and fusion thresholds, where greater intensity levels result in smaller gap or fusion scores (Fitzgibbons, 1983). However, due to the inclusion criteria stating that participants were required to demonstrate hearing thresholds better than 15 dB HL, at most a variability of plus or minus 5 dB HL could have occurred across the presentation levels of each test. This variability is thought to be insignificant, and therefore, presentation level was not expected to have been responsible for any of the significant differences in the means.

Only one pair of measures (i.e., RGDTC and AFTR) was found to correlate significantly. Finding a significant correlation between two tests that differed on the important dimension of stimulus type (click v. tone) may be more a function of two mathematical aspects of correlation coefficients rather than a function of test association. Indeed, these aspects may also explain why only one of fifteen correlations was statistically significant. Larger values are needed to reach statistical significance with smaller sample sizes (N=10 in this study) and more homogeneous (i.e., narrow range) scores produce smaller correlation coefficients. A larger sample size, potentially generating more diverse performance across subjects, may have resulted in more significant correlations across tests. The stimulus difference between RGDTC and AFTR may have led to more variation in participants' performance, which led to a significant correlation. This argument is strengthened by the finding that RGDTC scores showed the greatest range of all tests/measures (Table 5).

Significant mean differences were not anticipated for temporal resolution measures derived from tests with the same presentation mode, presentation level, stimuli, inter-pulse (gap) interval, response mode, response task, and type of measure of temporal resolution. The greater the difference between tests/measures in these dimensions, the more likely participants' performance was expected to differ on these tests. Of the seven dimensions differentiating the tests/measures, four are most salient: presentation mode, stimulus type, response mode, and response task. Given that five of eight significant paired comparisons involved the RGDTC, which used click stimuli, and 4 of the 8 involved the BFT, which used noise stimuli, it would appear that stimulus type might be the largest source of variance across tests. In fact, mean performance on the RGDTC was 8.4 msec, nearly twice the mean measure of temporal resolution obtained for any other measure. The smallest estimate of temporal resolution was obtained on the BFT, with a mean of 1.0 msec. Similarly, four of the eight significant paired comparisons involved the GIN (GINR or GINL) implicating its unique stimulus (i.e., gaps in ongoing noise) and possibly its unique response mode (i.e., nonverbal button pushing) as major sources of variance in performance.

Stimulus type is known to cause performance differences across tests/measures, although Keith (2000) reported pilot data for the RGDT indicating comparable gap thresholds for click and tonal stimuli. Other studies suggest that temporal resolution improves with wider bandwidth stimuli (Eddins, Hall and Grose, 1992; Moore, Peters, Glasberg, 1993), increasing tonal frequency (Moore, 1985), and with increasing center frequency of the noise (Fitzgibbons, 1983). Phillips, Taylor, Hall, Carr, and Mossop (1997) reported that gap detection thresholds supported by the apical regions of the cochlea (i.e., low frequencies) have significantly longer gap detection thresholds than their basal region counterparts. Studies have also shown that higher frequency (> 0.5-1.0 kHz) stimuli permit better temporal resolution than lower frequency stimuli (Hall, Grose and Joy, 1996). (However, the frequency specific gap (RGDT) and fusion thresholds (AFTR) obtained in this study from the ten participants with normal hearing did not vary across frequency in the expected manner.) Buunen and Valkenburg (1979) reported a temporal resolution constant of 25 msec for detection of a single gap in noise. Within-channel gap detection thresholds obtained using wideband noise range from 2.7-4.4 ms (Phillips et al., 1998). No studies have been found that compared temporal resolution between tones and clicks; however, it is assumed from the information above that the click stimuli, with its broader bandwidth**,** would result in better temporal resolution scores than tonal stimuli. Following this same assumption, pairs of measures with different stimulus types (i.e., tone, narrow band noise, or click) were expected to have significantly different means. This was confirmed by the Newman-Keuls' comparisons where six of eight comparisons yielding significant mean differences (i.e., all but BFT and GINR and BFT and GINL**)** differed in stimulus type. Further, those measures of temporal resolution derived from noise resulted generally in shorter mean gap/fusion durations than the tonal or click stimuli, and the click stimuli consistently resulted in shorter mean gap durations than tonal stimuli. The AFTR is an anomaly to the above statement, as the mean of the AFTR was obtained down to 2.04 msec. However, the substantially lower mean fusion threshold obtained on the AFTR is attributed to the predictive nature of the test's ascending and descending format, which may lead to perseveration in responses. The GIN and the BFT, as mentioned earlier, share the same narrow band noise stimulus, and therefore, were expected to result in non-significant differences in their mean scores; however, the significant difference between the GIN and the BFT means might be due to differences in their presentation modes (i.e., the BFT used a dichotic presentation mode and the GIN used a monaural presentation mode), their response modes (i.e., the BFT used a verbal response mode and the GIN used a nonverbal response mode), and their differing response tasks (i.e., the BFT used a counting response task and the GIN used a button pressing response task).

All significant differences revealed through Newman-Keuls' comparisons could be explained on the basis of the four factors of presentation mode, stimulus type, response mode, and/or response task (Table 10). For example, the GIN and the BFT both use noise stimuli; however, the GIN is a monaural test of temporal resolution using a nonverbal response, and the BFT is a binaural/dichotic test of temporal resolution and uses a verbal response mode. Moreover, the specific characteristics of the narrow band noise used in the BFT and the GIN are not described in published reports; however, the narrow band noises in both the BFT and the GIN do share the same center frequency (Musiek, personal communication, 2004). In addition, the BFT can be described as a between-channel temporal resolution task and the GIN is a within-channel temporal resolution task. Between-channel gap detection tasks have been shown to have significantly higher (poorer) gap detection thresholds because the underlying perceptual operation requires a comparison of activity in different perceptual channels rather than simply detecting discontinuity within a given perceptual channel (Phillips, 1998, 1999). However, the BFT provided the best temporal resolution abilities with a mean threshold obtained down to 1 msec. No obvious explanation for this unexpected finding can be proposed.

Of the seven non-significant comparisons, two were anticipated (i.e., GINR ad GINL and AFTR and RGDTT) given the shared stimulus type, presentation mode, response mode and response task. It was unexpected to find non-significant mean differences between AFTR and GINR, AFTR and GINL, RGDTT and GINL, and RGDTT and GINR since these tests/measures difference across the key dimensions of stimulus type, presentation mode, response mode and response task. The non-significant difference between BFT and AFTR may have resulted from the shared binaural mode of presentation, response mode, and response task, despite the difference in stimulus.

The non-significant difference between the AFTR and GINR, GINL, and BFT may be a reflection of the predictive nature of the ascending and descending format of the AFTR, which may have caused artificially improved temporal resolution on the AFTR. The non-significant mean difference between the RGDTT and the GIN may also reflect the fact that these are both measures of gap detection (v. fusion).

Participant with Auditory Processing Deficit

The scores obtained for the one participant (participant eleven) with documented auditory processing deficits (i.e., binaural integration) were within 1 SD of the mean of the ten participants with normal hearing, with the exception of the score obtained on the AFTR and the GINL. Participant eleven's performance on the AFTR was greater than 1 SD below the mean, indicating a shorter (better) fusion threshold; however, his performance on the GINL was greater than 3 SD above the mean, indicating *poorer* temporal resolution. Participant eleven's better performance on the AFTR may be attributed to the AFTR's ascending/descending staircase methodology, which may make this test easier for subjects. However, according to the clinical norms available for the AFTR, and the RGDT, participant eleven performed well within the range considered to indicate normal temporal resolution function. Participant eleven's performance on GINL when compared to the available normative data was greater than 3 SD from the mean; however, the available norms were obtained from adults and therefore comparisons using these norms against pediatric populations must be interpreted with caution. Participant eleven demonstrated normal temporal resolution function on all other measures, and therefore is considered not to be deficient in this process.

Participant eleven's score on the left and right ears of the GIN were considerably different (i.e., 5 msec for the right ear and 8 msec for the left ear). The score for the left ear on the GIN was substantially poorer than for the right ear and fell 3 SD's below the published mean for the GIN. This is thought to be related to the classic right ear advantage found on dichotic tests, a phenomenon that is understood to occur when language-based functions are processed mainly in the left hemisphere (Devlin, Raley, Tunbridge, Lanary, Floyer-Lea, Narain, Cohen, Behrens, Jezzard, Matthews, and Moore, 2003). Due to the significant crossing of the auditory pathway to the contralateral side in the central auditory nervous system, the right ear has been seen to perform better than the left ear for language-based tasks presented in a dichotic mode. Even though the GIN was not presented dichotically, the substantial differences in participant eleven's left and right ear scores may be the result of the primacy for the left hemisphere for temporal processing (Binder, Frost, Hammeke, Bellgowan, Springer, Kaufman, Possing, 2000), and hence the right ear performance exceeding the left ear performance on the GIN.

Interestingly, out of the eleven participants, six participants demonstrated superior performance of the right ear on the GIN.

Participant eleven's normal performance on the four tests of temporal resolution was expected as no deficits in temporal resolution were observed at age eleven when he was evaluated for APD. However, it is questioned whether his temporal resolution abilities may have been disordered at an earlier age and recovered by age eleven years as was suggested in the study by Hautus et. al, (2003). This participant's auditory processing difficulties included: following directions presented verbally, understanding questions presented verbally, understanding in noise, and following multi-step directions. Verbal comprehension and understanding in noise have been suggested to be associated with temporal processing. Hautus et. al. study in 2003, suggested that poor temporal resolution present at an early age may have produced other disorders and that those disorders could remain after the temporal resolution dysfunction resolved itself. It is thought that this may have been the case with participant eleven.

Participant Four

Participant four's performance on the BFT was considerably poorer than the other participants, as indicated by a score of 10 msec compared to the mean of 0 msec for all other participants. However, this participant's performance on the other tests/measures was consistent with others and fell within 1 SD of the mean. This participant's performance on the BFT changed the group mean only slightly—from 0 msec to 1 msec. ANOVA and Newman-Keuls' analyses calculated with and without this participant's data revealed no differences in outcomes (see Appendix A for nine participant analysis).

BFT

The exceptionally small temporal resolution scores obtained on the BFT were somewhat unexpected considering its' dichotic presentation mode. According to Phillips (1999), between-channel temporal resolution tasks, where the leading and trailing stimuli are presented disparately, are thought to require longer duration times due to perceptual channel switching required of the central auditory nervous system. The BFT's dichotic presentation mode rendered it a between-channel test; however, the temporal resolution thresholds obtained were the shortest of all measures.

The format of the BFT may provide some explanation as to why such exceptional scores were obtained for this measure. Comparing the distribution of the stimulus durations between the BFT and the other five measures, a notable difference was seen. When arranged in ascending order, the distribution of the BFT stimuli according to inter-stimulus interval is: 0 msec, 5 msec, 10 msec, 20 msec, 30 msec, 40 msec, 60 msec, 80 msec, and 100 msec. The shortest detectable duration between two stimuli in the BFT is 5 msec, below that is the point of true fusion where only one noise is actually heard (i.e., 0 msec). In the AFTR and the RGDT, the shortest duration between two stimuli is 2 msec. The subsequent duration is 5 msec. In the GIN, the shortest gap in noise is 2 msec with subsequent gaps at 3 msec, 4 msec, and 5 msec. The 0 msec measure of temporal resolution obtained on the BFT by ten of the eleven participants may in fact be and artifact of its distribution of stimuli. The lack of an intervening inter-stimulus interval between the single noise (0 msec) and the 5 msec inter-stimulus interval, may have limited the BFT's sensitivity in detecting more finite abilities of temporal resolution.

GIN

Currently no clinical norms are available for children on the GIN. Comparisons of scores obtained from the participants were made using the available adult normative data. This kind of comparison creates the potential for incorrectly identifying children with temporal processing problems, as children typically perform poorer on tasks than adults. However, due to the fact that scores from all participants (with the exception of participant eleven's elevated left ear score) were well within two standard deviations of the adult normative mean, this concern is relegated insignificant

Clinical Implications

Statistically speaking, significant differences between the six measures and four tests of temporal resolution were revealed. However, in terms of clinical relevancy, the statistically significant differences between the measures provided little practical information**.** The purpose of tests of temporal resolution is to identify individuals with disordered temporal resolution function. The results from this study suggest that these four tests yield comparable results when administered to children with normal hearing, including normal temporal resolution function.

Nonetheless, there are differences among the four tests of temporal resolution regarding the ease of use and time required for administration. The AFTR and the GIN both required a substantial amount of time, averaging approximately 20 minutes to complete. In addition, the GIN tended to require an additional few minutes for instruction and practice due to its more complex nonverbal motoric response. Initially, the administration and scoring of the GIN was quite complicated, as it required the clinician to attend to several tasks at once (i.e., the V.U. meter, score sheet, response button indicator and stimuli); however, with practice the GIN became relatively easy to administer. The GIN did not require a verbal response from subjects, which eliminates a potentially confounding factor (Jerger and Musiek, 2000). The GIN is advantageous due to its inter-list equivalency, its monaural presentation mode, which may provide some laterality information, and its reported reliability and validity. The BFT and the RGDT on the other hand, required the least amount of time and were very straightforward in terms of their administration and scoring. The limitation of the BFT in regards to the absence of an intervening inter-stimulus interval between the 0 msec inter-stimulus interval and the 5 msec inter-stimulus interval is a limiting factor. The RGDT appeared to be the easiest and fastest temporal resolution test to administer and score and for subjects to follow. Not only was it easy and fast, it was shown in this study to effectively identify children with normal hearing with intact temporal resolution function. However, no normative data has been published for the RGDTC; hence, clinicians who choose to use the click section of the RGDT must collect their own norms before using this section. The RGDT is anticipated to save clinicians a substantial amount of time; the GIN may offer the greatest accuracy.

CHAPTER FIVE

CONCLUSION

The relationship between temporal processing and phonology, reading, and language development remains controversial. Nonetheless, the assessment of temporal processing is an integral part of the overall evaluation of auditory processing. The results of this study revealed a number of statistically significant differences between various pairs of temporal resolution measures, most of which can be explained on the basis of differences in test stimulus, presentation mode, response task, and/or response mode. From a clinical perspective, however, all four tests revealed normal temporal resolution abilities in children expected to have normal auditory processing skills, as well as in the one participant with identified auditory processing deficits, whose deficits were not in the area of temporal processing. Hence, all four tests appear to present good specificity. Based on ease of use, efficiency of administration, and availability of normative data, the tone portion of the Random Gap Detection Test (RGDT) may be an appropriate choice of the measures examined in this study for clinical assessment of temporal resolution. The Gap in Noise (GIN) Test is relatively easy to administer and perhaps superior to the RGDT since the GIN uses a nonverbal response mode/task, utilizes a monaural presentation mode, which may provide some laterality information**,** and as suggested by preliminary studies, may demonstrate good reliability and validity.

Due to the small sample size, however, additional research is needed to examine differences and relationships among the four tests examined in this study. Additional research is needed to determine the relative sensitivity and specificity of the four tests in pediatric and adult populations. Comparison of the sensitivity and specificity of the various temporal resolution tests when administered to a population with documented central nervous system lesions will allow audiologists to choose the most efficient test for clinical purposes. Future research should also examine the affects of stimulus differences on temporal resolution acuity and elucidation of the neurophysiology underlying temporal fusion and temporal gap detection tasks.

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APPENDIX A

ANALYSIS BASED ON NINE PARTICIPANTS

TABLE 11. Means, standard deviations, and ranges for the nine participants (excluding participant four) with normal hearing for six measures of temporal resolution.

	N	Minimum	Maximum	Mean	Std. Dev.
RGDTT	9	1.40	7.50	4.6444	1.89348
RGDTC	9	3.50	20.00	8.2222	5.54026
BFT	9	0.00	0.00	0.0000	0.00000
GINR	9	3.00	6.00	4.5556	1.13039
GINL	9	3.00	6.00	4.7778	0.97183
AFTR	9	0.75	4.75	2.1478	1.26752

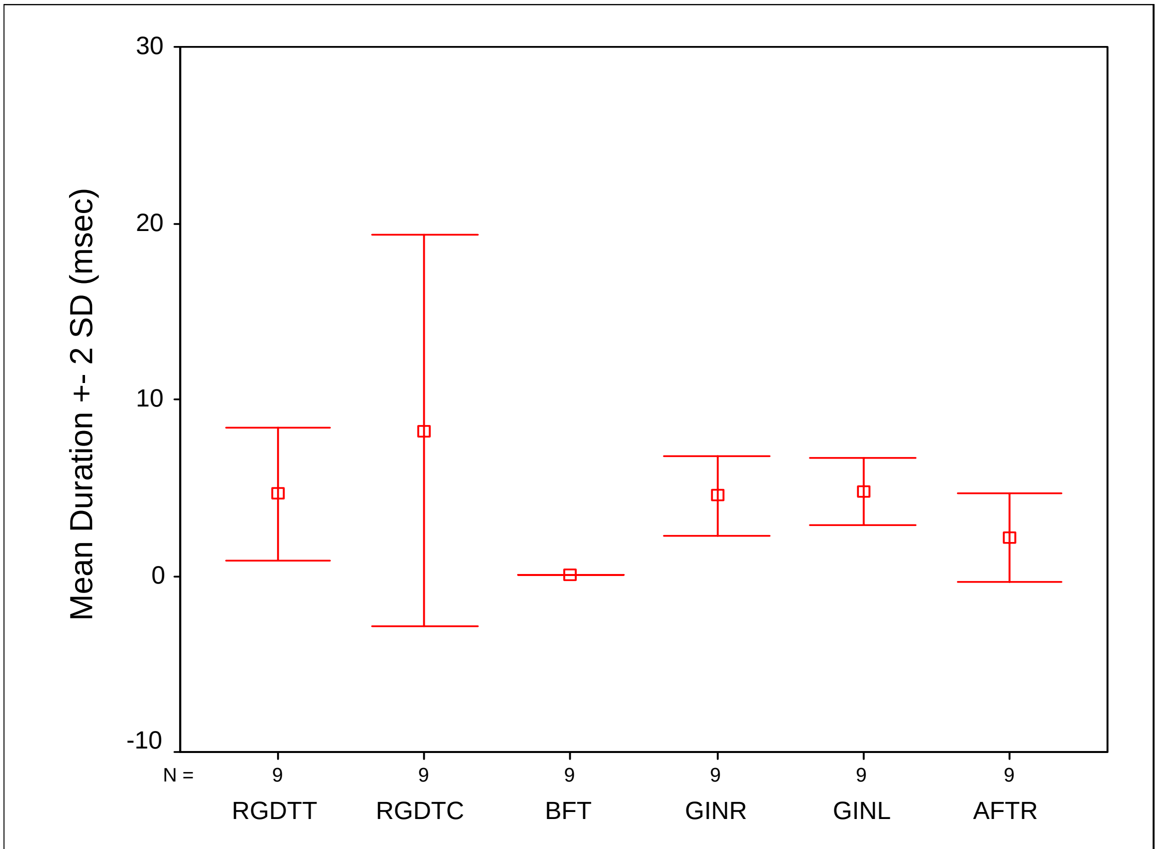

FIGURE 4. Means and standard deviations for each of six measures of temporal resolution obtained from nine participants with normal hearing (excluding participant four). RGDTT = Random Gap Detection Test for Tones; RGDTC = Random Gap Detection Test for Clicks; BFT = Binaural Fusion Test; GINR = Gap in Noise for the Right ear; GINL = Gap in Noise for the Left ear; AFTR = Auditory Fusion Test-Revised.

TABLE 12. Pearson correlation between the six measures with all participant data included excluding participants four and eleven.

		RGDTT	RGDTC	BFT	GINR	GINL	AFTR
RGDTT	r	1	.455	.	-.101	.230	.657
		.	.218	.	.797	.551	.055
RGDTC	r		1	.	.317	-.141	**.746**
			.	.	.406	.718	**.021**
BFT	r			1	.	.	.
				.	.	.	.
GINR	r				1	.468	.314
					.	.204	.410
GINL	r					1	.250
						.	.516

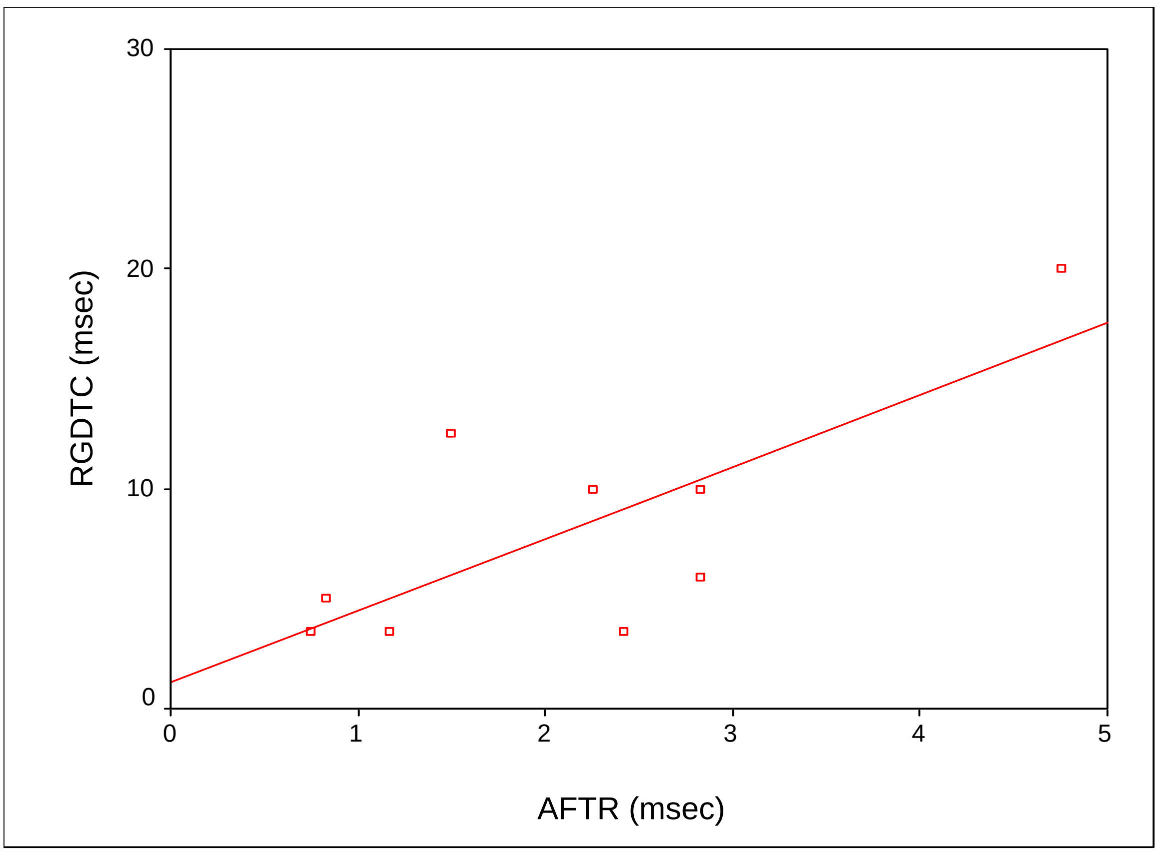

FIGURE 5. Scatter plot of the relationship between RGDTC and the AFTR derived from nine participants (excluding participant four) with normal hearing.

TABLE 13. Analysis of variance based on means of six measures of temporal resolution from nine participants with normal hearing excluding participant four.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	p
Total	651.97	53			
Subjects	88.96	8			
Treatment	347.10	5	69.42	12.86	<.001
Error	215.91	40	5.40		

TABLE 14. Newman-Keuls' multiple-range test based on nine participants with normal hearing excluding participant four.

Significant Difference in Means			Non-significant Difference in Means		
Measures	Difference between Means	Minimum Critical Difference	Measures	Difference between Means	Minimum Critical Difference
BFT - GINR	4.56	3.27	BFT - AFTR	2.15	2.72
BFT - RGDTT	4.64	3.60	AFTR - GINR	2.41	2.72
BFT - GINL	4.78	3.84	AFTR - RGDTT	2.50	3.27
BFT - RGDTC	8.22	4.02	GINR - RGDTT	0.09	2.72
AFTR - RGDTC	6.07	3.84	GINR - GINL	0.22	3.27
GINR - RGDTC	3.67	3.60	AFTR -GINL	2.63	3.60
RGDTT-RGDTC	3.58	3.27	RGDTT - GINL	0.13	2.72
GINL - RGDTC	3.44	2.72			