Click ABR Characteristics in Children with Temporal Processing Deficits

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Temporal processing deficits are one characteristic of a (central) auditory processing disorder [(C)APD]. Combining behavioral and electrophysiologic methods in the (C)APD battery is valuable. This investigation focuses on auditory brainstem response (ABR) measures in a group of children with specific temporal processing deficits and an age-matched control group. No significant differences in ABR waveform latency were found, but there were significant amplitude differences between control and experimental groups. The ABR in an interaural time delay (ITD) paradigm did not demonstrate differences between groups. While group differences in this study were limited, they nonetheless support the value of electrophysiological measures in (C)APD assessment.

Abbreviations: ABR = auditory brainstem response, (C)APD = central auditory processing disorder, ITD= interaural time delay MLD= masking level difference, PPST=Pitch Pattern Sequence Test

Introduction

(Central) auditory processing disorders [(C)APDs] have received considerable attention over the past few decades. (C)APD is not a new entity in audiology. For many years, professionals have been aware that some individuals with normal results on tests of peripheral function report difficulty understanding speech. Recent attention has focused on controversies surrounding the operational definition of (C)APD, the heterogeneous nature of (C)APD, and an appropriate test battery for (C)APD assessment. This renewed interest in (C)APD has generated a clinical demand for improved diagnostic methods.

Temporal processing refers to the time aspects of an auditory or acoustic signal. Phillips (1995) defines temporal processing in several ways including determination of a sound source or "spatial percept," determination of the pitch of a sound, and the perceptual segregation of two successive acoustic events. Temporal processing is important in the discrimination of duration and variations in pitch, which are critical to following the prosody of speech and music perception (Phillips, 1995).

Poor temporal processing is one of the characteristics of (C)APD. Efficient temporal processing is a key component of auditory function (Chermak and Musiek, 1997). Temporal processes are critical in a number of auditory functions "including auditory discrimination, binaural interaction, pattern recognition, localization/lateralization, monaural low-redundancy speech recognition, and binaural integration" (Show et al., 2000, p. 67).

Tests of Temporal Processing

The underlying physiological neural mechanisms for temporal processing may be assessed by behavioral and electrophysiological means. Several behavioral

tests "stress" the auditory system by degrading the acoustic environment or signal by introducing background or speech noise or by filtering the signal. Behavioral tests may require multiple auditory processes such as attention, memory, and perception (Jirsa and Clonz, 1990). Further, behavioral tests may be confounded by learning, attention, fatigue, hearing sensitivity, intelligence, developmental age, motivation, motor skills, language experience, and language impairments (Jerger and Musiek, 2000).

Although temporal processes are critical in a number of auditory behaviors, there are limited clinical tests used to assess temporal processing abilities. These tests are based on the assumption that important acoustic signals, such as speech vary over time. If a person is to extract meaning from these acoustic signals, the listener must be able to detect very small and rapid time variations. Temporal processing deficits may be evident on tests of temporal resolution, such as gap detection tests, or on temporal patterning tests. Temporal processing deficits may also result in poor performance on monaural low-redundancy speech tests, especially time compressed speech tests.

Gap Detection

Gap detection reflects the ability of the auditory system to detect a brief silent interval in noise. This test requires temporal fusion of the auditory system. Investigators have found larger auditory fusion thresholds in children with language, learning, and reading disorders (McCroskey & Kidder, 1980; Isaacs, Horn, Keith, & McGrath, 1982). Gap detection thresholds systematically decrease with increasing age from three to nine years (McCroskey & Keith, 1996). Gap detection thresholds remain stable throughout adulthood until the fifth decade of life, and then increase with age (McCroskey & Keith, 1996).

Time Compressed Speech

Compressed speech alters the temporal and frequency characteristics of the signal. Historically, the first compressed speech tests were accomplished by having the speaker read the passage faster or by increasing the playback speed of the tape recorder. Soon after, electromechanical alterations and later digital computer editing of natural speech were used to distort the temporal and frequency components of speech. This test of reduced temporal redundancy is sensitive to dysfunction at all levels of the central auditory pathway (Pinheiro & Musiek, 1985; Thompson & Abel, 1992a, 1992b).

Discrimination scores of time-compressed speech in school-aged children also improve with age (Beasley & Maki, 1976). Allen (1997) reports that temporal auditory discrimination and detection is often more variable in school-age children than adults. Certainly, it is evident that there are improvements in temporal related auditory tasks with age.

Masking Level Difference

The Masking Level Difference (MLD) is a widely used test of temporal processing and binaural interaction. The MLD compares the threshold of two binaural signals: either a low-frequency tone (500 Hz) or speech embedded in noise. The thresholds for the signals are measured in noise while the noise is in-phase (homophasic- No) and out-of- phase (antiphasic- Nπ) with the signal, or while the signal is in phase (homophasic- So) and out-of-phase (antiphasic Sπ) with the noise (Hirsh, 1948; Olsen, Noffsinger, & Carhart, 1976; Olsen, Noffsinger, & Kurdziel, 1975). In most cases, there is a release of masking, or improvement in threshold, either when the noise or signal is out-of-phase between the two ears. This release of masking occurs because the listener perceptually can separate the signal from the competing noise. The stimulus appears to originate from a different source while out-of-phase. The MLD is mediated by the lower brainstem. The MLD has been shown to be abnormal in patients with brainstem lesions (Olsen et al, 1976; Lynn, Gilroy, 1977); whereas, cortical lesions have shown no effect on the MLD (Cullen & Thompson, 1974).

There are limited data reporting MLDs in children. Sweetow & Redell (1978) found a reduced MLD in children with auditory perceptual difficulties. However, Wayras & Battin (1985) did not report a reduced MLD in learning disabled children but attributed this finding to the wide heterogeneity of learning disabled children. Roush & Tait (1984) also found normal MLDs in children with APD.

Temporal Pattern Tests

Pinheiro (1977) first reported the use of the Pitch Pattern Sequence Test (PPST) to assess pattern perception and temporal sequencing skills. The stimuli consist of a low frequency tone and a high frequency tone. This test is "not designed to assess fine temporal acuity per se but rather to assess the listener's ability to perceive a pattern of auditory events occurring over time" (Bellis & Ferre, 1999, p. 321). Pinheiro (1977) found a significant deficit in the ability of dyslexic children and a control group of normal children. The PPST is sensitive to cortical lesions. Information on laterality, as well as inter-hemispheric transfer via the corpsus callosum, can also be obtained.

The Duration Pattern Test (Pinheiro & Musiek, 1985) is similar to the Pitch Pattern Test. The frequency of the stimulus tones are the same, however, the duration of one of the tones is different from the

other two. The listener must respond to the correct sequence of "long" (500 msec) and "short" (250 msec) tones. This test is also sensitive to cortical lesions. Information about laterality and inter-hemispheric transfer can also be obtained.

Electrophysiologic Recordings

In electrophysiologic recordings of the central and peripheral neural auditory pathway, the early latency Auditory Brainstem Response (ABR) may objectively assess neural functions that are believed to be involved in early neural coding for temporal processes. The ABR reflects synchronous firing of neurons of cranial nerve VIII and brainstem structures. This electrophysiologic recording provides information about the integrity of the peripheral and brainstem auditory pathways that are involved in auditory processing and the requisite capabilities of the auditory system to encode information.

The inclusion of electrophysiological measures is recommended by the Working Group on Auditory Processing Disorders (2005) when there is a questionable neurologic disorder, to assess auditory neuropathy or auditory dys-synchrony (AN/AD), or in difficult to test children. Electrophysiological tests in the (C)APD evaluation may aid in the diagnosis or in the validation of the results of the behavioral test battery (Bellis, 2003; Chermak and Musiek, 1997). Electrophysiological recordings were also recommended by the Bruton Conference on auditory processing disorders (Jerger and Musiek, 2000).

Previous research investigations reporting electrophysiologic recordings and (C)APD have been conflicting. Sohmer and Student (1978) reported abnormal ABR latency results in 16 subjects with minimal brain dysfunction. Subjects placed in this category had traits of hyperactivity, learning difficulty and coordination defects. Additionally, the Sohmer & Student investigation reported ABR latency abnormalities in other broad-spectrum disorders such as autism and mental retardation.

Worthington (1981) reported no differences in the ABR latencies between controls and children with (C)APD. This lack of difference is in contrast to the investigation by Worthington et al. (1981), which reported abnormal ABR latencies in 8 out of 18 subjects with severe developmental and or/ language delays. Conductive hearing loss accounted for an additional five abnormalities. The other three abnormalities related to interaural asymmetries which were greater than .3 msec. Subject selection criteria for these studies were not reported.

Protti (1983) reported increased ABR latencies in 2 of 13 subjects with (C)APD. Again, the type of (C)APD, or how the diagnosis of (C)APD was made, was not specified in this paper. However, Protti's work supports inclusion of electrophysiological measurements in the assessment of (C)APD.

Hall & Mueller (1997) reviewed ABR recordings for 102 pediatric patients with (C)APD and found abnormal findings in approximately 10% of these subjects. They reported a greater percentage of abnormalities for the left auditory pathway, than for the right auditory pathway. They did not comment on this finding. Information about the subject's age or specific type of (C)APD also was not reported.

Mason & Mellor (1984) reported latency and amplitude measurements in eight children diagnosed with a language disorder and six children with motor speech disorders. No significant group differences in latency were reported. The amplitudes of the ABR were smaller in the language delay and motor speech group than the normal group. It is important to remember that the ABR is recorded from surface electrodes, making it a "far-field" recording. The amplitudes of the ABR recording will depend upon the conductivity of the tissue and the distance of the electrode from the generator site. It is worth noting that each group's mean amplitude measures were within normal limits. It is also important to note that ABR amplitude is more variable than peak latency (Lauter et al., 1993). Inherent noise conditions may affect the amplitude of the ABR. In addition, other factors such as head size, the thickness of the skull, and electrode placement will affect the amplitude of the ABR.

Test stimuli typically used to elicit the ABR, which consist of clicks, filtered clicks, tone pips, and tone bursts, rather than speech-like stimuli, may be a contributing factor in distinguishing children with (C)APD. Early latency ABR responses merely reflect the auditory mechanism's ability to recognize a signal, not the processing functions reflected by the late potentials (Brugge, 1975).

Binaural ABRs

Binaural stimulation in ABR recordings was initially used to enhance wave peaks. However, other investigators believed that diagnostic information, such as the localization of possible brainstem disorders, could be obtained from the binaural recording (Levine, 1981). Binaural stimulation causes changes in ABR recordings such as 1) an increase in the amplitude of the waveforms, 2) a decrease in the latency of the ABR wave peaks, and 3) morphological changes in the wave form peaks occurring approximately 4 msec post-stimulation (Blegvad, 1975; Davis, 1976). The binaural ABR is not a summation of the monaural recordings, but reflects central neural interaction in the superior

olivary complex and in the inferior colliculus (Arslan et al, 1981). From animal recordings, these nuclei are responsible for time-encoding processes (Erulkar, 1976; Sample & Aikin, 1979).

Introduction of an ITD binaural click has previously been employed to investigate lateralization. The introduction of an ITD click will change the perception of the fused binaural click. Arslan et al. (1981) investigated the binaural auditory brainstem response with interaural time delays of the binaural stimulus. These investigators reported morphological changes in the latency range of 3.5 to 6.5 msec when the ITD was greater than 2 msec.

Study Rationale

While previous investigations have shown that the ABR is not sensitive to (C)APD, some studies have shown that some subjects with (C)APD do have abnormal ABRs (Sohmer & Student, 1978; Worthington et al, 1981; Protti, 1983; Mason & Mellor 1984; Hall and Mueller, 1997). The purpose of this study was to investigate ABR characteristics in a group of (C)APD children with specific temporal processing deficits. Specific temporal deficits were identified by behavioral assessment. Although most behavioral temporal processing tests are more sensitive to central lesions, temporal encoding occurs initially in the peripheral auditory system and is represented throughout the central auditory nervous system. This investigation is based upon the premise that specific temporal processing deficits may arise from a disruption in the early firing patterns of the VIII nerve and auditory brainstem nuclei, and thus, individuals with temporal processing disorders may show differences in auditory brainstem response recordings. We recorded ABRs using standard and temporally altered click stimuli in a group of children with behaviorally identified problems of auditory temporal processing and compared these results to a matched group of children with no auditory processing disorders.

Methods

Subjects

The majority of investigations of (C)APD have not described the specific auditory deficits or characteristics of their subjects. This may have led to some of the conflicting results in both behavioral and electrophysiological measures in children with (C)APD. This study will report findings in a sub-group of children with (C)APD for whom we tried to carefully define specific temporal processing deficits.

The subjects for this research were 24 experimental and 24 control male subjects between the ages of 7 and 12 years of age. Only male subjects were included because of the gender effect on wave latency in the electrophysiologic recordings (Cox et al., 1981). All subjects gave informed assent and had parental or legal guardian consent, as approved by the Louisiana State University Health Sciences Center Institutional Review Board. All subjects had normal peripheral hearing as assessed by normal pure-tone audiometric thresholds from 500 to 4000 Hz < 15 dB HL (re: ANSI, 1989) and normal middle-ear pressure and static admittance as evidenced by normal (type A) tympanograms. All subjects were native English speakers. All subjects were paid a small stipend for participation in this study. All behavioral and electrophysiological measures were collected by one of the authors (AH). Data collection was completed in one or two sessions. At least two breaks were given during the behavioral assessment and another before beginning the electrophysiological assessment.

Behavioral and electrophysiological data were collected on 24 males who had been diagnosed with (C)APD. These subjects were self-referred to the Louisiana State University Health Sciences Center Speech and Hearing Clinic for a (C)APD assesment. The experimental subjects had abnormal temporal processing skills as assessed by behavioral tests in the (C)APD behavioral test battery. Criterion for abnormal performance on the behavioral tests was defined as a score at least 2 standard deviations below normative data on four of five selected tests of behavioral tests of temporal processing. Parents and/or guardians of potential subjects were informed about this prospective investigation and consented to additional testing as described in the later section. Subjects with the possibility of attention deficit hyperactivity disorder, as reported by a medical diagnosis, or parent's report, were excluded from this investigation. Academic difficulties experienced by these subjects included reading and language-based learning disability.

Additional inclusion criteria for this study included normal language scores on the Peabody Picture Vocabulary Test III (Third Edition) (PPVT-III) and two subtests of the OWLS. The PPVT-III is designed as a measure of an individual's receptive vocabulary. In addition, it is an achievement test of the level of a person's vocabulary acquisition. The Listening Comprehension subtest of the OWLS is designed to measure the understanding of spoken language. The Oral Expression Scale is designed to measure the understanding and use of spoken language.

Twenty-four age-matched males comprised the control group, recruited from families and friends of the LSU Health Sciences Center Department of Communication Disorders faculty and staff. Members

of the control group had normal temporal processing, as indicated by normal performance on behavioral tests of temporal processing. They also had normal scores on the PPVT-III and the two subtests of the Oral and Written Language Scales (OWLS). In addition, the parent or legal guardian of the control subjects reported that there were no academic, language, learning, reading, attention, or hearing concerns.

Additional demographic information from both groups was obtained. The educational level of the mother and father was obtained and grouped into five categories: 1) did not finish high school, 2) finished high school, 3) some college, 4) college graduate, and 5) post-graduate degree. Information about the type of school each subject attended was also obtained. The type of the school each subject attends was obtained and grouped into four categories: 1) public school, 2) private school, 3) parochial school, and 4) home-schooled. This demographic data ensured that groups were similar in socio-economic status.

Behavorial Tests

Behavioral tests of auditory processing were completed in order to appropriately include or exclude subjects from the experimental and control groups. Thus the behavioral measures are considered baseline and grouping measures, while the electrophysiologic measures (described below) are the experimental measures in this study. Behavioral tests were administered in a sound treated room. With the exception of the masking level difference (MLD), all behavioral tests were recorded on compact disks available from Auditec of St. Louis. The clinical audiometer, Interacoustics 40, was calibrated to the 1000 Hz calibration tone on each individual CD before administering the behavioral tests. The recorded stimuli were presented at 55 dB HL and delivered through EAR 3A insert earphones. The presentation order for the behavioral tests was counterbalanced to eliminate order effects.

Masking Level Difference

The Masking Level Difference (MLD) was derived by measuring the masked threshold for a 500 Hz tone. Thresholds were obtained for SoNo (homophasic) and SπNo (antiphasic) conditions. The 500 Hz pure tone signal was generated using the Interacoustics 40 audiometer. The narrow band noise, also generated by the Interacoustics 40 audiometer, had a 146 Hz band of noise centered at 500 Hz with a 12 dB per octave roll-off. The 500 Hz signal was set to 70 dB HL. Signal attenuation of the narrowband noise was in 1 dB steps. Thresholds were obtained by averaging the level of the noise that masked the 70 dB, 500 Hz signal in four ascending and four descending trials for a total of eight trials in SoNo and SπNo conditions. The MLD was defined as the difference in threshold between homophasic and antiphasic stimuli. The MLD was considered abnormal if it was less than 10 dB (Sweetow and Reddell, 1978; Roush and Tait, 1984).

Frequency Pattern Test

The Pitch Pattern Test, or Frequency Pattern Test, which requires auditory discrimination, temporal ordering and pattern recognition, was administered. This test consists of 120 pattern sequences made up of three tone bursts, two are the same frequency and one is different. The pure tones were 1122 and 880 Hz. The subject repeated the pattern by verbalizing the pattern of the tones. Thirty monaural trials were presented at 55 dB HL. This test was scored based on the percentage correct.

Duration Pattern Test

The Duration Pattern test is very similar to the Pitch Pattern Test. This test also requires temporal ordering and pattern recognition. The tones do not vary in frequency, but vary in duration as being either long (500) ms or short (200) ms. Thirty monaural trials were presented at 55 dBHL. The subject repeated the pattern by verbalizing "long or short". The test was scored based on the percent correct.

Discrimination of Time Compressed Speech

Time compression alters the temporal characteristics of speech by reducing the duration of the signal without affecting the frequency characteristics (Fairbanks, Everitt, & Jaeger, 1954). Time compressed (45%) NU-6 word lists were presented monaurally at 55 dB HL. Test scores were reported as percent correct.

Gap Detection

Gap detection thresholds were obtained using the Random Gap Detection Test. This test requires temporal resolution of the auditory system. The Random Gap Detection Test is a revision of the Auditory Fusion Test-Revised. This test consists of a calibration tone, a practice subtest and four subtests at 500, 1000, 2000, and 4000 Hz. Each pure tone is seventeen msec in duration. Stimuli with inter-stimulus intervals (gaps) of 0, 2, 5, 10, 20, 25, 30, and 40 milliseconds were randomly presented. Stimuli were presented binaurally at 55 dBHL. The gap detection threshold was the lowest interval where the subject consistently identified two tones, rather than one tone. A composite gap detection threshold was obtained by averaging the gap detection thresholds at 500, 1000, 2000, and 4000 Hz. Composite thresholds greater than 20 msec indicate temporal processing deficits that could interfere with speech perception and phoneme recognition (McCroskey and Keith, 1996).

Electrophysiologic Recordings

Electrophysiologic recordings were obtained while the subject rested comfortably in a chair and watched silent videos (animated videos with captioning) or played a hand-held video game with no audible sound.

Stimulus

Test stimuli were generated using the Tucker Davis Workstation System III. Test stimuli consisted of 100 μsec condensation clicks with a rate of 11.1 /sec, presented at 70 dB nHL via insert ER3A earphones. Two stimulation sequences consisting of 2000 click presentations were recorded for each test condition for a total of 4000 presentations. The protocol consisted of two recordings each of right, left and binaural (diotic) stimulations of 2000 clicks per run.

In order to further assess temporal effects in the ABR, responses were obtained to dichotic stimuli in which the right stimulus was delayed relative to the left stimulus by an interaural time delay (ITD) interval of 0.1, 0.4, 0.9, and 1.9 ms. Conditions were counterbalanced across subjects to reduce order effects.

Recordings

Recordings were made with five surface electrodes attached to the skin at the vertex (positive), each ipsilateral mastoid (negative), nape of the neck, and ground placed at the forehead. Electrode impedance was below 5 kΩ. Three channel recordings were obtained: 1) vertex to ipsilateral earlobe, 2) vertex to contralateral ear, and 3) vertex to nape of neck (Cz-Oz). The response was averaged over a 12 msec window. The response was amplified and filtered (bandpass 10-3000 Hz). A 10 Hz low-frequency filter was chosen to enhance wave V amplitude. Artifact rejection was employed. Peak-to-following trough amplitude and latency of Waves I, III, and V were measured for each subject in the ipsilateral and mid-line channels.

Results

An important consideration before beginning this investigation was to recruit children for the control and experimental groups that were similar in age and socioeconomic level. The control group had a mean age of 8 years and 6 months. The experimental group has a mean age of 8 years and 8 months. An analysis of variance indicated no significant differences in age between the two groups [$F(1, 46)=.143$, $p=.707$]. A Chi Square analysis indicated no significant differences between the education level of the mother *[$x^2 = 1.66, 3, p=.645$]*, educational level of the father, *[$x^2 = 2.462, 4, p=.651$]*, or the type of school the subject attends *[$x^2 = 1.667, 3, p=.644$]*. Therefore, there were no statistical differences between the two groups in demographic composition.

Another important consideration for this study was to recruit and test similar experimental and control subjects who had normal receptive vocabulary as evidence by their standard scores on the PPVT-III. Both groups had clinically "normal" scores; the experimental group had a mean score of 102.33 and the control group had a mean score of 115.29. There was a significant difference between the groups, even though each individual subject was "clinically normal [$F(1,46) =15.396$, $p=.001$].

Behavioral Tests of Temporal Processing

A nonparametric statistic (Chi Square) was used to examine group differences because the homogeneity of variance assumption was not met. For statistical comparisons, the behavioral tests for temporal processing are interpreted as either normal or abnormal. (Again, for the behavioral test to be considered 'abnormal', the score must be at least two standard deviations below published norms.) A Chi Square analysis, shown in Table 1, indicates

Table 1. Chi Square analysis, mean scores, standard deviations, for the control and experimental groups for the behavioral tests of temporal processing.

			EXPERIMENTAL		Number of Experimental	CONTROL	
TEST	χ^2	*p*	Group Mean	St. Dev	Abnormalities	Group Mean	St. Dev
Time Compressed Speech Right	9.36	0.002	62%	20.43	21	91%	5.74
Time Compressed Speech Left	19.05	0.001	63%	20.59	21	93%	5.62
Pitch Pattern Right	40.33	0.001	20%	19.49	23	73%	27.94
Pitch Pattern Left	27	0.001	26%	25.5	22	71%	28.56
Duration Pattern Right	27.19	0.001	14%	19.63	23	71%	27.42
Duration Pattern Left	16.45	0.001	21%	25.7	20	68%	26.56
Masking Level Difference	12.63	0.001	8 dB	2.76	19	11 dB	1.3
Random Gap Detection	31.45	0.001	16 msec	14.39	9	8 msec	3.2

Table 2. Latency measures for Waves I, IIII, and V for right, left, and binaural modes of stimulation.

	Left			Right			Binaural		
	I	**III**	**V**	**I**	**III**	**V**	**I**	**III**	**V**
Experimental	1.69	3.82	5.86	1.67	3.84	5.84	1.68	3.81	5.84
St. Dev	0.08	0.17	0.18	0.12	0.16	0.23	0.09	0.14	0.19
Control	1.69	3.85	5.85	1.70	3.87	5.85	1.69	3.90	5.82
St. Dev	0.10	0.17	0.25	0.11	0.12	0.16	0.09	0.26	0.15

significant differences between the control and experimental groups for each of the behavioral tests. This finding suggests that the two groups differ in their temporal processing. An analysis of variance indicated a statistical difference between the groups in the behavioral tests of temporal processing. Listed in Table 1 are the mean, standard deviation, and p value for each behavioral test, as well as the number of abnormal test results for the experimental group.

Electrophysiologic Measures

Latency

No significant differences in ABR peak latency for Waves I, III, or V were found between the control and experimental groups [F (2, 27) =1.25, p=.303]. In addition, no significant latency differences for Waves I, III, and V were found between the right, left, or binaural modes of stimulation [F (2, 2), = 1.639, p=.208]. Group means and standard deviations for latency measures of Waves I, III, and V for right, left, and binaural stimulation are shown in Table 2.

Amplitude

The control group had higher peak-to-peak amplitude measurements for ABR waves I, III, and V than the experimental group, and differences were significant for Waves I and III. These significant differences occurred for all stimulation modes: right, left, and binaural (see Table 3). Significantly greater amplitudes were obtained for binaural than monaural stimulation for both groups [F (2, 27 = 8.105, p=.001]. Peak-to-peak amplitude measures for Waves I, III, and V are displayed in Table 3.

Group-mean amplitude measures for the Cz-ipsilateral ear lobe trace for the right, left, and binaural stimulation modes for Waves I and III are displayed in Figures 1 and 2, respectively. As noted above, amplitude is greater for binaural stimulation for both groups for Waves I, III, and V, and amplitudes are greater in the control than experimental group.

Binaural ITD

Latency and amplitude measurements for binaural wave V with an ITD of 0, 0.1, 0.4, 0.9, and 1.9 msec for the midline electrode montage recordings are displayed in Figures 3 and 4, respectively. In addition, an example of a midline recording for each binaural ITD for one control subject is shown in Figure 5.

Wave V latency increased and amplitude decreased with an increase in the ITD for both groups. A repeated measures analysis of variance indicated no significant differences in latency between the control and experimental groups [F (4,42) = .814, p=.523], although the experimental group has slightly longer wave V latencies.

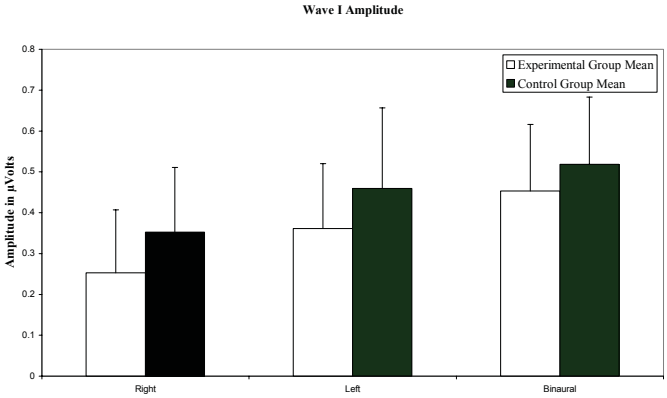
A significant difference was observed for the 0.9 msec ITD amplitude measure between the experimental and control groups [F (4, 42) = 2.209, p= .001].

Table 3. Amplitude measures and statistical differences for Waves I, III, and V for right, left, and binaural modes of stimulation.

	Left			Right			Binaural		
	I'	**III'**	**V'**	**I'**	**III'**	**V'**	**I'**	**III'**	**V'**
Experimental	0.36	0.22	0.47	0.25	0.21	0.53	0.45	0.31	0.74
St. Dev.	0.16	0.1	0.21	0.15	0.11	0.22	0.21	0.16	0.22
Control	0.46	0.38	0.55	0.35	0.33	0.58	0.52	0.44	0.8
St. Dev.	0.2	0.2	0.17	0.18	0.18	0.17	0.16	0.22	0.23
p	0.005	0.004	0.056	0.02	0.006	0.115	0.039	0.003	0.173

Discussion

Figure 1. Group means and standard deviations for Wave I amplitude for right, left and binaural stimulation.



The objective of the present study was to evaluate ABR measures in a group of children with a specific temporal processing disorder. Because the brainstem auditory centers are involved in early encoding of timing parameters, and these centers are involved in generation of the ABR, we reasoned that early electrophysiologic recordings in children with temporal processing deficits may differ from normal children.

One of the difficulties in reviewing published investigations of (C)APD is the frequent, inadequate definition of the study participants. The temporal processing deficits of the subjects in this investigation are clearly defined by the differences in the specific behavioral measurements of temporal processing.

Electrophysiological Measures

Measures of ABR latency showed no significant differences in the latency of ABR waves I, III, and V between the experimental and control groups. There were also no significant differences in the wave V latency between the midline and Cz-ipsilateral recording sites. This is consistent with previous investigations which report no latency differences in the ABR recording from various recording sites (Hall, 1992; Hashimoto et al, 1981). In addition, there were no significant differences in latency in the mode of stimulation, right, left or binaural. This is consistent with previous investigations of monaural versus binaural stimulation (Dobie & Norton, 1980; Hosford-Dunn, Mendelson & Salamy, 1981).

Wave I and III latencies and Waves I, III, and V amplitudes were within normal clinical limits for all control and experimental subjects (Musiek, Josey, & Glassock, 1986). Wave V latencies were within normal limits (Musiek et al., 1986) for all but two experimental subjects. Careful inspection of individual ABR waveform latency data indicates that two experimental subjects had Wave V latencies that were two standard deviations greater than the experimental group mean latency value. Here, the electrophysiological data adds objective evidence to support the diagnosis of a central auditory processing disorder with a possible neurophysiological etiology in each of these two cases. It is also noted that both of these experimental subjects had a positive history of middle ear infections, as evidenced by having had pressure equalization tubes. In addition, both reported infant jaundice. Additional information of other abnormal or neurological findings was not mentioned in the case history. Other experimental subjects who had both infant jaundice and a history of middle ear infections had ABR recordings that were within normal limits.

The control group had greater amplitudes for all waves, but significantly greater for waves I and III in all modes of stimulation (right, left, and binaural). These results are similar to Mason & Mellor (1984) who found smaller ABR amplitudes in the language delay and motor speech group. This amplitude difference may be attributed to better neural synchrony in the control group subjects.

A significant difference between groups in wave V amplitude for the 0.9 ITD condition was shown. A gradual decrease of .27 µV in amplitude was observed as the ITD increased from 0-.4 msec in the control group. This is similar to .17 µV decrease in amplitude as the ITD increased from .1 to .4 msec in the experimental group. An abrupt decrease in amplitude was observed as the ITD increased from 0.4 to 0.9 msec. Around 1 msec, the image is no longer fused; therefore, the amplitude reduction at 0.9 msec ITD is exhibited. The control group had a decrease of .23 µV in wave V amplitude, while the experimental group

Figure 2. Group means and standard deviations for Wave III amplitude for right, left and binaural stimulation

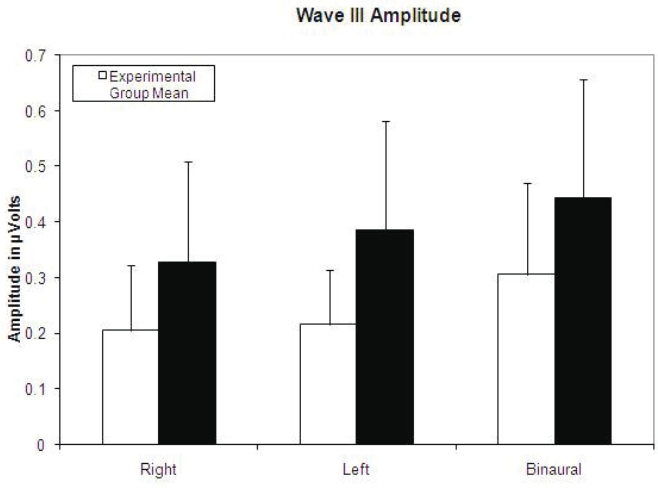
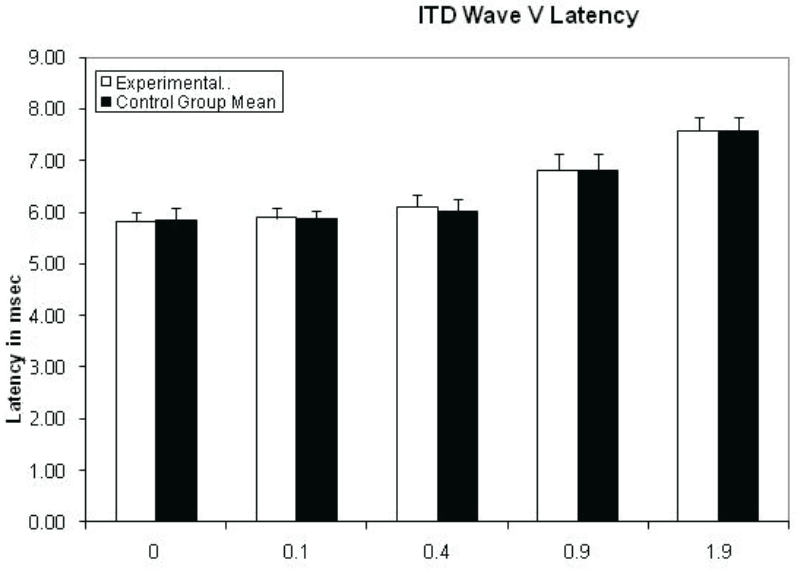


Figure 3. Group means and standard deviations for Wave V latency mid-line recording at each ITD condition.



had a decrease of .44 µV in wave V amplitude.

The finding of limited differences between groups on the ABR may be related to the specific stimuli and paradigms used or to the possibility that the temporal processing deficits in these subjects arise at more central levels. Recent work by Kraus and colleagues has reported that about one third of individuals with language-based learning problems have reduced temporal synchrony at the upper brainstem level (Banai, Nicol, Zecker & Kraus, 2005; Cunningham, Nicol, Zecker, Bradlow, & Kraus, 2001; King, Warrier, Hayer, & Kraus, 2002; Wible, Nicol, & Kraus, 2004). Electrophysiologic recordings to a speech ABR may be more useful in distinguishing temporal processing deficits at the level of the brainstem.

The results of this investigation are similar to the findings of Arslan et al. (1981) who reported morphological changes in the ABR recording when the ITD was greater than 2 msec.

As the ITD increased, the Wave V latency increased and the amplitude decreased for both groups. There were no significant differences between the control and experimental groups in wave V latency as a function of ITD.

Summary

This investigation reported electrophysiological data on a group of children with temporal processing deficits and an age-matched control group. Although there were no group differences in ABR latency, significant group amplitude differences were observed. These amplitude differences may be attributed to better neural synchrony for the control group. While amplitude measures for the experimental group were not abnormal based upon current clinical norms; nonetheless, there were statistical differences between the two groups.

This investigation does not negate the importance of including electrophysiological recordings as part of the (C)APD battery. In fact, two experimental subjects had abnormal ABR wave V latencies (Hood and Berlin, 1986). These two subjects did have a

Figure 4. Group means and standard deviations for Wave V amplitude at each ITD condition.

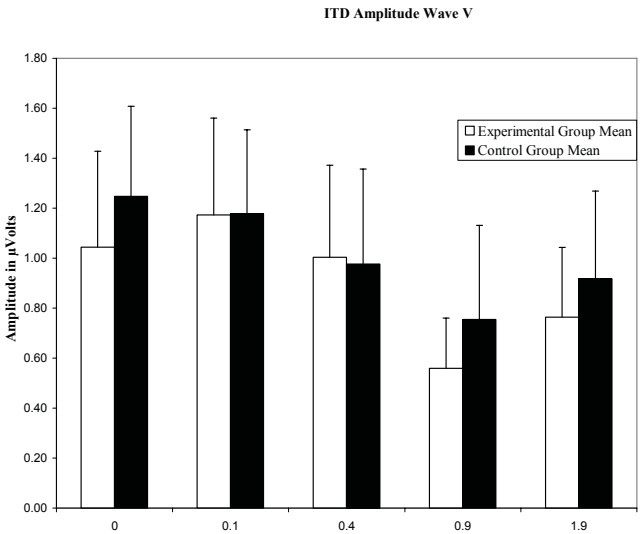
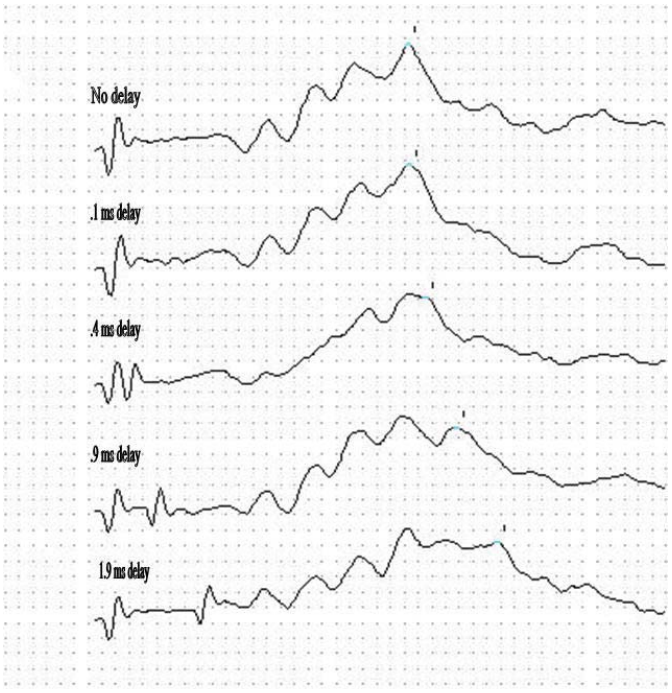


Figure 5. An example of one subject's midline binaural ITD recording. A cursor is placed on wave V.



positive history of otitis media; however, they did not perform poorer than other experimental subjects on the behavioral measures.

The ABR provides powerful information about the neurophysiological integrity of the peripheral and brainstem auditory nervous system and is useful in differentiating central auditory disorders (C)APD from auditory dys-snchrony/auditory neuropathy. Future investigations of temporal processing deficits using electrophysiological measures that include speech and other complex stimuli in ABR and other cortical potential paradigms may help clarify these relationships. Although this investigation did not show statistical differences in the ABR latency, there were significant amplitude differences for waves I and III. A normal ABR may be used implicate that temporal processing deficits in this individual result from asynchronies beyond the brainstem. An abnormal ABR may suggest the possibility of dys-synchrony at the level of the brainstem.

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