Electrophysiological and Behavioral Assessment of Temporal Processing Abilities in Children with Dyslexia

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Abstract

Temporal processing refers to the time aspects of an auditory or acoustic signal. Temporal processing may be defined in several ways including determination of a sound source or " spatial percept," or determination of the pitch of a sound, and the perceptual segregation of two successive acoustic events. Temporal processing deficits have also been associated with learning disabilities. The present study investigates the performance of children with dyslexia and children without learning problem on different behavioral and electrophysiological tests of temporal auditory. The second aim to investigate the relationship between speech-evoked ABR responses and behavioral tests of temporal auditory processing in children with dyslexia and children without learning problem. Performance of 15 children with dyslexia (mean age 10.1 years) and 10 normal children without learning problem (mean age 9.5 years) were studied using behavioral tests of auditory temporal processing and speech-evoked ABR. The results indicate that all the children with dyslexia had deficits in brainstem timing. They also found to have poor performance on behavioral tests of temporal auditory processing. The present study concludes that BioMARK may be put to clinical use to identify the temporal processing deficits in difficult-to-test population and in monitoring the temporal processing abilities in children with dyslexia, following auditory training.

Keywords: *Dyslexia, speech-evoked ABR, temporal processing*

Introduction

(Central) Auditory Processing refers to the perceptual processing of auditory information in the central nervous system (CNS) and the neurobiological activity that underlies processing and gives rise to electrophysiological auditory potentials. It includes the auditory mechanisms that underlie the following abilities or skills: sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition, including temporal integration, temporal discrimination (e.g. temporal gap detection), temporal ordering, and temporal masking; auditory performance in competing acoustic signals (including dichotic listening); and auditory performance with degraded acoustic signals (ASHA, 1996; Bellis, 2003; Chermak & Musiek, 1997). (Central) Auditory Processing Disorder (C)APD refers to difficulties in the perceptual processing of auditory information in the CNS as demonstrated by poor performance in one or more of the above skills.

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," or 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).

Temporal processing deficits have also been associated with learning disabilities. Several authors have demonstrated that impaired temporal processing may result in language disorders, speech processing disorders and reading disorders (Merzenich, Jenkins, Johnston, Schreiner, Miller & Tallal, 1996; Tallal, Miller & Fitch, 1993). These investigators hypothesized that impaired temporal processing disrupts the normal development of an efficient phonological system and these phonological difficulties may result in language and reading disorders. 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, Seikel, Chermak, & Berent, 2000). The underlying physiological neural mechanisms for temporal processing may be assessed by behavioral and electrophysiological means. 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 & Clontz, 1990).

Auditory-evoked potentials (AEPs) are commonly used to assess the temporal properties of the auditory system in a non-invasive fashion. Furthermore, AEPs have long been recognized as a reliable tool for providing objective information about the structural and functional integrity of the central auditory system (Hall, 1992; Kraus & McGee, 1992). Brainstem electrophysiological response elicited by speech stimuli may provide additional insight into the auditory processing abilities of some children with dyslexia. Speech-evoked ABR is a neurophysiologic response recorded to multiple presentations of a 40-ms synthetic /da/ syllable (Johnson,

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Nicol, & Kraus, 2005). The response manifests as a series of brief neural events that are time-locked to the onset, offset, and periodic information of the stimulus /da/. The response consists of two components: an onset response composed of Waves V, A, and C, and a sustained frequency-following response composed of Waves D, E, F, and O (Johnson et al., 2005).

Speech-evoked ABR has been used to investigate temporal processing deficits in children with language-based learning (including reading) disorders. Researchers have found that children with language-based learning disorders have abnormal speech-evoked brainstem responses (Banai, Nicol, Zecker, & Kraus, 2005; Banai et al., 2009). They concluded that the deficits observed may be due to a disruption at the brainstem level in timing and harmonic encoding.

Temporal processing may also be assessed behaviorally by tests of auditory temporal processing such as Masking Level Difference (MLD), Pitch Pattern Test, Duration Pattern Test, Random Auditory Gap Detection, and Time Compressed Speech Test. Behaviorally in the temporal processing ability of children at risk for APD will also be seen in results of electrophysiological tests (Musiek & Gollegly, 1988)

King, Lombardino, Crandell and Leonard (2003) investigated the performance of young adults with dyslexia on auditory processing tasks such as frequency pattern test (FPT) and duration pattern test (DPT) and found that 5 out of the 11subjects failed in both tests. Other studies have used different behavioral tasks such as same-different tasks (Tallal, 1980), identification of rapidly presented high-low frequency tones (Tallal, 1980; Farmer & Klein, 1993), or gap detection (Farmer & Klein, 1993) to investigate auditory processing in children and adults with reading disorders. They found significant difference in scores obtained by individuals with reading disorder and individuals without reading disorder. In contrast, Walker, Shinn, Cranford, Givens and Holbert (2002) found no significant differences in FPT scores between adults with dyslexia and a control group. These studies opine that children with learning disability have significant deficits in encoding of speech signal at brainstem as well as cortical level. They have poor performance on behavioral and electrophysiological tests of auditory processing.

There are various studies which reveal that a substantial proportion of children with auditory based learning problems such as dyslexia display abnormal encoding of speech signal as measured by the speech evoked auditory brainstem response (King, Warrier, Hayes, & Kraus, 2002; Warrier, Johnson, Hayes, Nicol, & Kraus, 2004; Banai et al., 2009;).

Furthermore, researchers have also investigated the performance of children with learning disability on behavioral tests of temporal auditory processing. (Farmer & Klein, 1993; King et al., 2003; Tallal, 1980).Hence, there is a need to check how the speech evoked auditory brainstem responses relate to the performance on behavioral tests of temporal auditory processing. Hence, the present study aimed to investigates the performance of children with dyslexia and children without learning problem on different behavioral tests of temporal auditory processing and speech-evoked ABR. It also aimed to investigate the relationship between speech-evoked ABR responses and behavioral tests of temporal auditory processing in children with dyslexia and children without learning problem.

Method

Participants

In the present study two groups was taken i.e. experimental group and control group. The experimental group consisted of 15 children with dyslexia (mean age 10.1 years) including 14 males and 1 female in the age range of 8 - 12 years. The diagnosis of dyslexia was made by an experienced speech and language pathologist/psychologist on the basis of following criteria. 1) scores below the normal range on the Early Reading Skills develop and standardized in Indian children by Loomba, (1995) and 2) Performance at least two grade levels lower than that expected of their chronological age on the scale, 'Appraisal of Kids with Specific Handicap in Arithmetic and Reading Activities' developed and standardized by Venkatesan (2002)

The control group consisted of 10 normal children without learning problem (mean age 9.5 years) including 7 males and 3 females in the age range of 8 - 12 years. All the participants in control group had good scholastic performance as per the detailed information gathered from the parents. All of them passed the screening checklist for auditory processing (SCAP) developed by Yathiraj and Mascarenhas (2004) indicating absent auditory processing disorder.

Those participants who had normal hearing sensitivity in the frequency range of 250 to 8000 Hz, normal click evoked ABR, normal middle ear function were included in both experimental and control group. The normal hearing was described as $\leq$ 15 dB HL for octaves frequencies from 250 to 8000 Hz and speech identification score (SIS) of $\geq$ 90% in both the ears. Participants who had peripheral hearing loss, clinically abnormal/absent click-evoked ABR, any middle ear pathology, limited intellectual capacity, and attention deficit hyperactivity disorder (ADHD) were excluded from the experimental as well as from the control group.

Materials and procedure

The testing was carried out in two phases. The first phase was a preliminary screening session which included auditory electrophysiological testing. The second phase consisted of a behavioral central auditory testing. All the behavioral as well as electrophysiological tests were carried out in the sound treated room where the noise level was as per the guidelines in ANSI S3.1 (1991).Informed consent was obtained from all participants and their parents.

The phase 1 consisted of a complete hearing screening, click-evoked ABR testing, and speech-evoked ABR testing. Screening Checklist for Auditory processing (SCAP) developed by Yathiraj and Mascarenhas (2004) was administered which consists of twelve questions having the symptoms of deficits in auditory processing (Auditory perceptual processing, Auditory memory and others). The scoring was done as 'Yes' or' No'. Each answer was marked "yes" carried one point and "no" carried zero point. Those children who scored less than 50% (< 6/12) in SCAP were considered for the study. Pure-tone thresholds were obtained using calibrated double channel clinical audiometer (Orbiter-922) with TDH-39 headphones at octave frequencies between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction through modified Hughson Westlake procedure (Carhart & Jerger, 1959). Immittance audiometry was carried out using a calibrated middle ear analyzer (GSI-tympstar) with a probe tone frequency of 226 Hz. Ipsilateral and contralateral acoustic reflexes thresholds were measured for 500, 1000, 2000, and 4000 Hz.

Electrophysiological testing which includes click and speech-evoked ABR was carried out using Biologic Navigator Pro EP system (version 7.0). Click evoked ABR testing was performed to verify normal transmission of auditory stimuli through the brainstem auditory pathway. For recording the click evoked and speech evoked ABR the clients were asked to sit on a reclining chair. The site of electrode placement was cleaned thoroughly with skin abrasive to reduce the skin-electrode impedance to less than 5 kΩ. Electrodes were placed with the help of skin conduction paste at Cz (non-inverting), with inverting electrode at the mastoid of test ear (M1) and the ground electrode at contralateral mastoid (M2). Responses were obtained for both ears to rarefaction click stimuli presented at 90 dB nHL with an online filter of 100 - 3000 Hz. Two thousand stimulus repetitions were collected at a rate of 11.1/sec. All participants in control as well as in experimental group had click-evoked ABR within the clinical norms.

Once the normal click-evoked ABR and normal hearing sensitivity was conformed, all participants underwent speech-evoked ABR testing. Electrodes (impedance < 5 kΩ) were placed with the help of skin conduction paste at Cz (non-inverting), with inverting electrode at the mastoid of test ear (M1) and the ground electrode at contralateral mastoid (M2). Responses were obtained for both ears to 40-ms speech like /da/ stimulus with alternating polarity. Stimuli were presented at 90 dB SPL with an online filter of 100 - 2000 Hz. Two thousand stimulus repetitions were collected at a rate of 10.9/sec.

Speech-evoked ABR composed of the transient and the sustained responses (also known as frequency following responses). Transient responses consists of peak V and A, whereas the sustained responses consist of peak D, E, F and O. In the present study both transient as well as sustained responses were evaluated. Two repeatable recordings were obtained in order to verify response replicability. Peaks were marked on the resultant waveform which was obtained after 'weighted-add' of two replicable waveform. In order to get spectral components of speech-evoked ABR, waveforms were first converted into "ASCII" formant using the software called 'AEP to ASCII' (version 1.6.0). ASCII formant data was then analyzed using the MATLAB platform and software 'BRAINSTEM TOOLBOX (Skoe & Kraus, 2010).

In phase 2, a test battery of three behavioral tests used in the diagnosis of temporal processing abilities in children with (C) APD was used. It includes Duration Pattern Test (Gauri, 2003), Pitch Pattern Sequence Test (Shivani, 2003) and Gap Detection Test (Shivaprakash, 2003). Test stimuli was routed from a personal computer (PC) with Intel Celeron processor through a two-channel clinical audiometer (Madsen OB-922) with TDH-39 headphones at an intensity level of 40 dB SL (re: PTA) binaurally. Initially 1 kHz calibration tone was presented to the subject's ear through TDH-39 earphone and V-U meter was adjusted to show "0" reading. Practice items were presented before the beginning of each test to ensure understanding of the task. Order of test administration within the behavioral central auditory test battery was counter balanced across participants to control for possible order effects. Listening breaks were given periodically throughout the testing session or as per the participant's request. The duration of the test session was approximately 60 to 90 minutes.

Statistical Analyses

Scores of behavioral as well as electrophysiological tests obtained from 10 normal children without learning problem and 15 children with dyslexia were analyzed using SPSS (version 19) software. Beside descriptive statistics, parametric test Multivariate Analysis of Variance (MANOVA) was used to compare the performance between the two groups. Further, in order to find the correlation between electrophysiological and behavioral tests, Karl Pearson correlation was used.

Results

The data collected from dyslexic children and children without learning problem were tabulated. Both descriptive and inferential statistical analysis was carried out

Table 1: Mean and SD values of amplitude of sustained responses of speech-evoked ABR of experimental and control group

Parameters	Control group (N = 20)		Experimental group (N = 30)		p Value
	Mean	S.D	Mean	S.D	
F0 (μV)	8.51	5.32	8.21	4.67	0.836
Fl (μV)	1.81	0.74	0.79	0.45	0.000***
F2 (μV)	0.58	0.08	0.02	0.15	0.000***

Note: $p< 0.05$; $p < 0.01$**; $p < 0.001$***; N = number of ears*

Table 2: Mean and standard deviation (SD) values of speech-evoked ABR parameters of control and experimental group

Parameters	Control group (N = 20)		Experimental group (N = 30)		p Value
	Mean	S.D	Mean	S.D	
Wave V (ms)	6.87	0.30	8.25	1.64	0.001**
Wave A (ms)	7.94	0.52	9.70	2.65	0.005**
Wave C (ms)	17.75	0.73	20.45	3.28	0.001**
Wave D (ms)	23.09	0.84	25.98	4.43	0.006**
Wave E (ms)	31.61	0.73	35.09	4.32	0.001**
Wave F (ms)	39.67	0.71	43.36	3.80	0.000***
Wave O (ms)	48.64	0.80	50.75	3.20	0.006**
V/A slope (μV/ms)	0.01	0.12	-0.03	0.05	0.592

Note: $p< 0.05$; $p < 0.01$**; $p < 0.001$*** ;N = number of ears*

for speech-evoked ABR as well as for the auditory temporal processing tests.

Results of Speech-evoked ABR

The speech-evoked ABR data was analyzed in terms of latency and amplitude. The waves V, A, C, D, E, F and O of speech-evoked ABR were identified and their latencies and amplitude were noted. Fast-Fourier Transform (FFT) was carried out to find the amplitude of F0, Fl and higher harmonics (F2) frequency components elicited by syllable /da/ of 40 msec.

Speech-evoked ABR could be recorded from all dyslexic children and children without learning problem. It was observed that the overall waveform morphology was poorer and increased (prolonged) in latency in dyslexic children (Figure 2) as compared to children without learning problem (Figure 1)

Visual inspection of individual data revealed that out of 30 ears wave C was absent in 3 ears (20%) and wave O was absent in 2 ear (13.3%) of the dyslexic children. However in children without learning problem all the waves were present. Results of MANOVA (Table 1) revealed that latencies of waves - were significantly prolonged in dyslexic children as compared to children without learning problem ($p < 0.05$). These findings suggest that dyslexicchildren showed abnormal encoding of speech signal at the brainstem level.

Results of MANOVA (Table 2) showed a significant reduction in amplitude of harmonics (Fl & F2) in dyslexic children as compared to the children without learning problem ($p < 0.001$). However, there was no significant difference in the amplitude of fundamental frequency (F0) between dyslexic children and children without

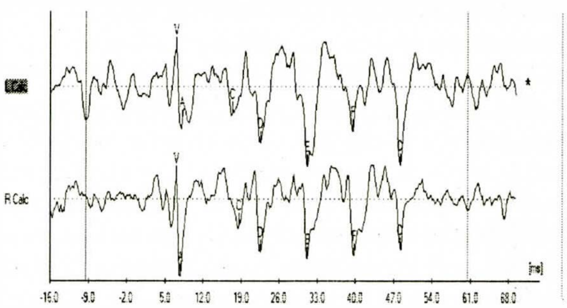

Figure 1: Sample waveform of speech-evoked ABR in children without learning problem.

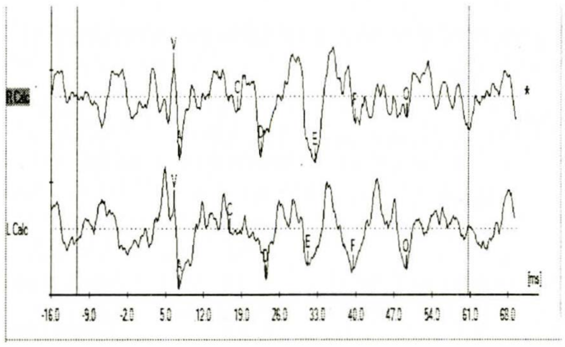

Figure 2: Sample waveform of speech-evoked ABR in dyslexic children.

learning problem ($p > 0.05$). These findings suggested that the spectral information within the F0 region of the response remain robust in the dyslexic children.

Results of Auditory Temporal Processing tests

For behavioral tests descriptive statistics which included means and standard deviation was carried out for both experimental and control groups. A parametric test, MANOVA was used to check if there were significant differences between means of the two groups.

Table 3 showed the mean scores of behavioral tests of temporal processing in children without learning problem and in dyslexic children. The scores of GDT, PPST, and DPT were significantly reduced in dyslexic children as compared to children without learning problem ($p < 0.05$). In dyslexic children, the mean gap detection threshold was 4.40 msec, whereas in children without learning problem, the mean gap detection threshold was found to be 11.23 msec, which was significantly higher in dyslexic children as compared to children without learning problem. This depicts the reduced temporal resolution ability in children with dyslexia.

Relationship between Speech-Evoked ABR and Behavioral Tests of Temporal Auditory Processing

Karl pearsons correlation was used to check if there were any correlation between speech-evoked ABR (wave V, V/A slope and spectral components of sustained portion i.e. F0, F1 and F2) and behavioral tests of temporal auditory processing- GDT, PPST, DPT in both dyslexic children as well as in children without learning problem.

Results of Karl pearsons correlation (Table 4) showed a significant negative correlation between transient response (wave V) of speech-evoked ABR and PPST scores in dyslexic children ($r = -0.587$, $p < 0.05$). This suggests that latency of wave V of speech-evoked ABR tend to be prolonging (abnormal) when there is decrease (poor) in PPST scores and vice-versa. Wave V was also found to be have a non-significant negative correlation with GDT scores ($r = -0.25$, $p >$

Table 3: Mean and SD values of behavioral tests scores of experimental and control group

	Control group (N = 10)		Experimental group (N = 15)		p Value
Parameters	Mean	S.D	Mean	S.D	
GDT	4.40	1.34	11.23	1.63	0.000***
PPST	23.40	1.17	16.26	3.10	0.000***
DPT	23.30	2.21	15.33	2.76	0.000***

Note: p< 0.05; p < 0.01**; p < 0.001***; N = number of ears*

Table 4: Correlation values of speech-evoked ABR's parameters (both transient & sustained responses) and behavioral tests scores of experimental group

Parameters	GDT		PPST		DPT	
	r value	p value	r value	p value	r value	p value
Wave V	- 0.25	0.37	- 0.08	0.02*	0.27	0.33
V/A slope	0.24	0.38	0.03	0.91	- 0.08	0.77
F0	- 0.29	0.28	- 0.53	0.07	0.39	0.14
F1	- 0.02	0.41	0.38	0.15	0.39	0.14
F2	- 0.27	0.33	0.39	0.14	0.55	0.65

Note:p< 0.05; p < 0.01**; p < 0.001***; r = correlation coefficient*

0.05) and non-significant positive correlation with DPT scores ($r = 0.27$, $p > 0.05$). Moreover, a well negative but non-significant negative correlation was also found between GDT and all transient and sustained responses of speech-evoked ABR except V/A slope, where the correlation was positive and non-significant ($p > 0.05$). However, in children without learning problem, no correlation was found between speech-evoked ABR and behavioral tests of temporal auditory processing.

Discussion

Latency and amplitude of Speech-evoked ABR in children with dyslexia

The results of present study are consistent with the previously published studies (Abrams, Nicol, Zecker & Kraus, 2006; Banai et al., 2005; Banai et al., 2009; Johnson et al., 2005; King et al., 2002; Russo et al., 2004; Wible , Nicol & Kraus, 2005), which have shown that children with learning disorders, such as dyslexia, have been found to exhibit delayed peak latencies for waves V, A, C, and O and a shallow slope for V/A slope indicating abnormal brainstem timing to speech signal.

However, in the present study no statistically significant difference was found in V/A slope between dyslexic children and children without learning problem ($p > 0.05$). This could be due to heterogeneous nature of dyslexia and small sample of dyslexic population taken in the present study. Billiet and Bellis (2011) found that children with normal brainstem timing who met the diagnostic criteria for (C)APD using behavioral measures did exhibit some abnormalities in the temporal, rather than spectral, elements for their speech-evoked ABR responses, although overall speech-evoked ABR scores were well within normal range.

Other studies (Banai et al., 2005; Banai et al., 2009) have shown that children with dyslexia have significantly reduced spectral information for speech-evoked ABR responses. It has also been found that not all children with dyslexia show deficits in temporal processing. There are some studies which failed to demonstrate any auditory temporal processing deficit in children with dyslexia (Bretherton & Holmes, 2003; Brier, Fletcher, Foorman, Klaas & Gray, 2003; Mody, Studdert-Kennedy & Brady, 1997; Schulte-Korne, Deimel, Bartling, & Remschmidt, 1999; Watson & Miller, 1993; Watson & Kidd, 2002; Ziegler, Pech-Georgel, George, & Lorenzi, 2009).

In the present study it has also been found that amplitude of harmonics (F1 & F2) was reduced in dyslexic with changes amplitude of fundamental frequency (F0) children. These findings are consistent with the findings of (Cunningham, Nicol, Zecker, Bradlow & Kraus, 2001, Wible, Nicol & Kraus, 2004). They found that in the presence of noise or rapid stimulation, spectral cues present in F1 remain robust but it diminished in F0 region in the children with learning disability. Thus it can be concluded that children with dyslexia demonstrate selective disruptions in brainstem encoding of the F1 and F2 characteristics of the speech signal, whereas F0 information remain relatively intact. Banai et al. (2009) reported that these deficits may be due to a disruption at the brainstem level in timing and harmonic encoding

Temporal auditory processing tests in children with dyslexia

Results of behavioral tests are consistent with the previously published studies (Baldeweg, Richardson, Watkins, Foale & Gruzilier, 1999; Dougherty, Cynader, Bjornson, Edgell & Giaschi, 1998; Schulte-KĂśrne et al., 1998). Results of these studies have shown that children with dyslexia have significant deficits in frequency discrimination task and the tone-in-noise detection task resulting in poor temporal resolution.

Ingelghem et al. (2001) also assessed temporal processing in individuals with dyslexia by means of two psychophysical threshold tests - Gap detection in broad band noise and Frequency Modulation (FM) detection. They concluded that the results of the temporal processing assessment were statistically poorer in dyslexic children as compared without learning problem. A possible neurophysiologic explanation for this observed deficit in auditory temporal resolution is that dyslexic readers have a prolonged refractive period in their neurological firing pattern. This may be the result of a slower transmission time of neural information (Stein & Walsh, 1997).

In the present study, we also found that dyslexic children had poor performance on temporal patterning/ordering tasks. These findings are consistent with the study done by Tallal (1980), in which it was found that children with dyslexia had poor performance on temporal tests (Sequencing Test, Rapid Perception test, and Same-Different Discrimination Test) performed by the group with reading and writing disorder as compared to children without reading and writing problem.

Hari and Keisila (1996) studied the temporal processing in dyslexic children with trains of binaural clicks which led to illusory movements at short click intervals. They found that children in control group, the illusion disappeared at intervals exceeding 90-120 ms, while in dyslexics it persisted up to intervals of 250-500 msec. They concluded that dyslexic children seem to have deficit in the temporal processing of rapid sequences. In the another study, Murphy and Schochat (2009) also studied auditory temporal processing in Brazilian children with dyslexia and reported that the group of children with dyslexia showed poor performance on the temporal auditory processing tests developed by Tallal and Piercy (1973).

The neural basis of the timing deficit is unclear. According to researchers (Llinas, 1993; Merzenich et al., 1996) one possibility is that the rate necessary for filling in and reading out the sensory buffers, is slower in dyslexics than in normal subjects. Such slowing is thought to be associated with decreased frequency and synchrony of intrinsic neuronal oscillations, both in the cortex and in the thalamocortical system.

Relationship between speech evoked ABR and different temporal processing tests

The correlation findings between speech-evoked ABR and behavioral tests score indicate that abnormal brainstem responses to speech stimuli may also be an indicator of poor responses at the cortical level. This can be explained by the study done by Nicol, and Kraus (2004). They found that broader V/A slopes were correlated with an increased vulnerability of the cortical response to the effects of background noise. In the another study, Banai et al. (2005) also found that children with language-based learning disorders who exhibited abnormal speech-evoked brainstem responses also had reduced speech-evoked mismatch negativity responses compared with children without learning problem.

Conclusions

To conclude, in the present study it has been found that the BioMARK was able to detect brainstem timing deficits in children with dyslexia. Hence BioMARK may be put to clinical use to identify the temporal processing deficits in difficult-to-test population and in monitoring the temporal processing abilities in children with dyslexia, following auditory training. Moreover, it has also been found that there is a relationship between brainstem timing and cortical processing as depicted by correlation findings between speech-evoked ABR and behavioral tests of temporal auditory processing. However, this relationship may not be present in all children with dyslexia and may not be seen for all tests of auditory processing as depicted by the findings of present study. Moreover, central auditory processing is not affected in all children with reading deficits and reading deficits are not exhibited by all children with (C)APD in comparison to children without learning problem. This demonstrates the heterogeneous nature of this disorder.

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