Subcortical encoding of speech cues in children with attention deficit hyperactivity disorder

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Highlights

- Children with ADHD have a common dysfunction in the temporal processing of click and speech stimuli.
- They have weaker synchronization of neuronal response to find the onset and offset of speech stimulus.
- They have no apparent deficit in components the sustained frequency following response.

Abstract

Objective: There is little information about processing of nonspeech and speech stimuli at the subcortical level in individuals with attention deficit hyperactivity disorder (ADHD). The auditory brainstem response (ABR) provides information about the function of the auditory brainstem pathways. We aim to investigate the subcortical function in neural encoding of click and speech stimuli in children with ADHD.

Methods: The subjects include 50 children with ADHD and 34 typically developing (TD) children between the ages of 8 and 12 years. Click ABR (cABR) and speech ABR (sABR) with 40 ms synthetic /da/ syllable stimulus were recorded.

Results: Latencies of cABR in waves of III and V and duration of V-Vn (P < 0.027), and latencies of sABR in waves A, D, E, F and O and duration of V-A (P < 0.034) were significantly longer in children with ADHD than in TD children. There were no apparent differences in components the sustained frequency following response (FFR).

Conclusions: We conclude that children with ADHD have deficits in temporal neural encoding of both nonspeech and speech stimuli.

Significance: There is a common dysfunction in the processing of click and speech stimuli at the brainstem level in children with suspected ADHD.

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1. Introduction

Attention deficit hyperactivity disorder (ADHD) is a chronic and pervasive childhood disorder characterized by a developmentally inappropriate activity level, impulsiveness, low tolerance levels, difficulties in organizing or completing tasks, distractibility, and inability to sustain attention and concentrate (AAP, 2000). Impairments in functional domains, such as the ability to perform specific
tasks, educational development, interaction with parents and other family members, and the ability to establish and maintain solid relationship with peers, are the most common symptoms of ADHD (Cormier, 2008). According to DSM-IV-TR, there are two main subtypes of ADHD and each of them include nine specific symptoms. Its diagnosis requires the report of at least six symptoms in each subtype by either the child parents or his/her teachers (AAP, 2000). ADHD is one of the most common childhood disorders, with 2–9% prevalence worldwide (Froehlich et al., 2007). This disorder is present in one-third to one-half of the children referred for mental health services (Farace et al., 2003). In parts of Iran, the prevalence of ADHD is between 9.7% and 15.25% in elementary schools (Amiri et al., 2010; Ghanizadeh, 2008; Talaei et al., 2010), and 12.3% among preschool children (Abdekhodaei et al., 2012), indicating a much higher prevalence than in other countries.

Many children are diagnosed with a learning disability (LD) or attention deficit disorder (ADD) every year. Previous studies have shown that many of the children diagnosed with LD and/or ADD have difficulties with the neural processing of click stimuli (Lahat et al., 1995; Puente et al., 2002) or acoustical structures of complex stimuli, such as speech in auditory brainstem response (ABR) recording (Cunningham et al., 2001; King et al., 2002). This inability to process auditory information, particularly speech stimuli, may lead to several different diagnoses (Brandt and Rosen, 1980; Llinas, 1988; Tallal and Stark, 1981). Most of these children are diagnosed at school age as after progressing past the critical age of language development, they exhibit delays in many skills including communication. Many of the structural and functional neuroimaging studies of ADHD, along with neuropsychological tests in some cases, abnormalities in cortical, basal ganglia, and cerebellar brain regions have been consistently demonstrated (Koziol and Budding, 2012); however, little information is available regarding subcortical processing of speech and nonspeech stimuli specifically on children with ADHD.

The brainstem is highly involved in synchronization of neuronal responses, and its deficits on the areas involved in the processing of auditory stimuli manifest with changes in absolute latency, interpeak latency (IPL), and/or amplitude of waves in recording ABR with nonspeech stimuli such as click stimulus. Click ABR (cABR) is composed of seven waves, with peaks and troughs that can be used to estimate the auditory thresholds. It has been also applied to otoneurologically assess possible lesions along the auditory nerve and auditory brainstem pathways (Burkard and Don, 2007; Hall, 2007; Roeser et al., 2007).

An auditory deficit in the brainstem is not always shown in cABR. In fact, many studies using click stimuli, have reported no differences in the auditory brainstem response of LD and typically developing (TD) children (Gronvold et al., 1988; Jerger et al., 1987; Lauter and Wood, 1993; Mason and Mellor, 1984; McNally and Stein, 1997; Purdy et al., 2002; Tait et al., 1983). Nevertheless, some studies on children with attention deficits have described differences between LD and TD children in response to click stimuli (Lahat et al., 1995; Puente et al., 2002). For instance, Lahat et al. (1995) reported an increase in latency for waves III and V and in the IPLs I–III and I–V in 114 children diagnosed with ADHD compared with TD children. In addition, a study by Puente et al. (2002) on 18 ADHD young adults revealed a longer latency period for waves III and V and larger IPLs for I–III and I–V. With respect to the neural generators of wave III (pons) and wave V (midbrain) (Näätänen, 1992), the delays in these waves and the increased transmission times may indicate an auditory brainstem dysfunction in ADHD. Such dysfunction may lead to attenuation in the cortical representations and ultimately a poor performance, particularly in adverse listening conditions (Gomes et al., 2012). A recent study considering boys with ADHD and TD children based on the mismatch negativity (MMN) paradigm, responses to standards and four deviants (hard/easy frequency, hard/easy duration), the children’s ability to both automatically and actively discriminate each deviant was assessed. No significant differences were found in either automatic or active discrimination tasks between the groups; however, for both groups, performance was poorer for duration than for frequency deviants. In this study, the observed deficits in active discrimination paradigms were attributed to deficits in subjective perception or usage of temporal information (Gomes et al., 2013). Similar to these results, in Gomes et al. (2012) study, children with ADHD showed smaller amplitudes of the T-complex include a series of peaks in the latency range of 70–160 ms (McCallum and Curry, 1980; Wolpaw and Penry, 1975). This complex is elicited by passive listening to tone bursts stimuli and consists of a small negative peak (Na: 70–80 ms), a positive peak (Ta ~ 100 ms), followed by a larger negative peak (Tb: 140–160 ms). The Ta component matures early (Tonnquist-Uhlen, 2003) and is relatively insensitive to attention, which is thought to reflect the processing of basic stimuli. Overall, these results suggest that deficits in auditory discrimination tasks in children with ADHD may be attributable to a reduced inflow of information early in the processing stream (Gomes et al., 2012).

The use of more complex auditory stimuli such as speech sounds or music, known to represent a bigger challenge to the brain, has been widely applied over the last two decades (Banai et al., 2007). Auditory brainstem response to the /da/ synthetic syllable (referred to as speech ABR, sABR) has two general response classes, the so-called source class and filter class. The source class includes waves D, E, and F, which represent the vocal fold vibrations (transient response), with the distances between them having an exact relation with the F0 wavelength of speech (sustained response). The filter class group includes waves V, A, C, and O (transient response). Waves V and A represent the onset of sound at the brainstem (lateral lemniscus/inferior colliculus), wave C is a response to the onset of vowels (the separation of tongue from roof of mouth), and wave O is believed to signal the end of the sound. In the source class, there are small high-frequency fluctuations between waves E and D that are concordant with the first formant (F1) stimulus (sustained response). F2 frequency and higher formants in the /da/ stimulus are out of the frequency range for the brainstem response (Kraus and Nicol, 2005; Johnson et al., 2005). Despite some findings related to the neural processing of simple acoustic signals, such as the click at the brainstem level of individuals with ADHD, little is known about the brainstem response to complex auditory signals-like speech.

Several studies have revealed that the sABR is an objective and noninvasive electrophysiological test, useful to examine auditory brainstem function in processing complex stimuli-like speech in a broad range of developmental and educational disorders (Skoe and Kraus, 2010). Although cABR has reported of no differences between LD and TD children, many studies have shown that a sizeable subgroup of LD children show abnormal timing of their ABRs to speech sounds (Banai et al., 2009; Cunningham et al., 2001; King et al., 2002; Wible et al., 2004). Set against this background, and provided that the comorbidity of ADHD and LD ranges from 10% to 90% (Semrud-Clikeman et al., 1992), we hypothesized a deficit in subcortical temporal processing of both nonspeech and speech stimuli in children with ADHD compared with TD children. Therefore, the present study focuses specifically on children with ADHD and investigates their auditory brainstem response to both click and /da/ synthetic syllable stimuli in comparison with TD children. Our study uniquely addresses this disorder in sABR and can provide useful information regarding the processing of click and speech stimuli in the subcortex of these children. In addition, we discuss independence or switching in neural encoding of these two stimuli.
2. Methods

2.1. Participants

Fifty children with ADHD (34 boys, mean age: 9.99 ± 1.92 years) and 34 TD children (20 boys, mean age: 9.92 ± 1.51 years), ranging in age from 8 to 12 years, were investigated in Newsha Hearing Center. Seven other children were also assessed but were excluded from the study due to inappropriate cooperation, missing data, or muscle artifact contamination. Children with a history of neurological problems, medical diseases, major affective disorder, or schizophrenia and those under systemic treatment were excluded from the study. All children had an IQ ≥ 85 on the Wechsler Intelligence Scale for Children-Revised (WISC-R) (Wechsler, 1997). Pure-tone hearing thresholds in both ears were equal to or better than 25 dB HL in octave band frequencies ranging from 250 to 8000 Hz (ANSI S3.6-2004). Pure-tone hearing thresholds were comparable between the two groups, and the average of pure-tone hearing thresholds were 4.57 ± 2.88 dB HL in children with ADHD and 4.75 ± 2.12 dB HL in TD children. Results of acoustic reflexes, middle ear tympanometry (ear canal volume: 0.9–2.0 cm³, static compliance: 0.3–1.5 mmHg, and sound pressure level: ±50 dapa) (Shanks and Shohet, 2009), and word discrimination scores (WDSs) were within normal limits. Children with ADHD were referred by teachers, parents, or therapists and had behavioral and/or reading problems. ADHD was diagnosed based on a report of six or more symptoms of the inattention and impulsiveness/hyperactivity sub-groups according to DSM-IV ADHD (DuPaul et al., 1998). The onset of symptoms had to have occurred before the age of 7 years and persisted for more than 6 months. Moreover, these symptoms had to have been observed over two or more positions and could not have resulted from other mental health or learning disorders. The children's medical records were reviewed by a child neuropsychiatrist to rule out the possibility of any neuropsychological, physical or psychiatric problems in addition to ADHD diagnosis. Control children were identified from among classmates of children with ADHD. According to teacher reports and academic records, they had an educational level commensurate with age and no history of using special education services. Their parents had to report less than 4 symptoms in both parts of inattention and impulsiveness/hyperactivity of DSM-IV ADHD (Gomes et al., 2012). All children were right-handed and monolingual Persian speakers. This study was approved by the Ethics Committee of the Iran University of Medical Sciences.

2.2. Stimuli and recording Parameters

Tests of click-evoked Auditory Brainstem Response (cABR) and speech ABR (sABR) were conducted for all subjects and analyzed using the Bio-logic Navigator Pro System (Bio-logic Systems Corporation, Natus Medical Inc., Mundelein, IL). cABR was obtained before recording sABR. Silver-silver chloride electrodes were placed on the right mastoid, forehead, and at Cz. These acted as reference, ground, and active electrodes, respectively. Contact impedances were all <5 kΩ and within 1.5 kΩ of each other. Stimuli were presented through unshielded insert earphones (ER-3A, Etymotic Research, Elk Grove Village, IL). cABR was recorded by 100 µs click stimulus with alternate polarity at the rate of 11.1/sec at 80 dB SPL. Individual traces over 15.0 µV were removed online. Two blocks of 2000 artifact-free sweeps were collected for each subject.

The sABR test stimulus used was the synthesized syllable /da/ for the duration of 40-ms as used in previous studies and obtained from the Auditory Neuroscience Lab of Nina Kraus and colleagues at Northwestern University. The stimulus consisted of an initial noise burst and formant transition between a consonant and a steady state vowel (Johnson et al., 2005). Stimuli were presented using the custom stimulus option in the standard Bio-logic AEP software (version 7.0.0) at a rate of 10.9/sec. Stimulus intensity level was 80 dB SPL, as measured using a 2 cm³ DB-0138 coupler, Bruel and Kjaer Type 2203 sound level meter, and 1-inch microphone. The electrodes were arranged as for cABR. Responses were collected online by 100–200 Hz band pass filter using 1024 digital sampling points over an 85.33-ms epoch. Two blocks of 2000 artifact-free sweeps were recorded in the right ear.

Subjects were seated in a comfortable reclining chair in relaxed position with closed eyes during electrophysiological tests. These tests were conducted in a double-walled sound-treated booth with standard noise level (ANSI S3, 1-1999, R2008) and dimmed lights.

2.3. Data processing: cABR and sABR

All waves of both cABR and sABR were identified and marked manually by two expert audiologists separately. Except for one case, there was complete agreement between them. cABR waves of two replications were visually marked as waves I, III, V, and Vn (a negative trough after wave V). Also, in analysis of sABR waves, 7 waves were identified and marked, including two onset waves of A and V, a consonant–vowel transition wave C, an offset wave O, and three sustained frequency following response (FFR) waves D, E and F. sABR onset waves A and V are similar to cABR waves V and Vn (Song et al., 2006), and they are marked according to the cABR method (Hall, 2007). Therefore, wave V was considered as the biggest peak near 6 ms just before the negative slope, and a trough was also marked after the negative slope in its time expected latency as wave A. According to child norms reported in previous studies, waves C, D, E, F and O were labeled in their expected latencies as the deepest troughs. The normal values for these waves are C ~ 18.0 ms, D ~ 22.0 ms, E ~ 10 ms after wave D, F ~ 10 ms after wave E, and O around 48.0 ms (Banai et al., 2007). If there were two points with equal amplitudes within a trough, the point with shorter latency was marked, and if a peak had a plateau shape, the center of the plateau was labeled. In the one case of disagreement between the two experts in marking, a wave that was considered unreliable was excluded from the analysis. Waves with amplitudes smaller than the average of a baseline were marked as unreliable, and were excluded from the analysis. In addition, the neural response to the onset of stimulation was measured by calculating V–A inter-peak latency, V–A peak to trough amplitude, and slope of the V–A complex.

Magnitude and correlation between the sustained part of sABR or FFR and the stimulus in the both children with ADHD and in TD children were further analyzed in MATLAB. FFR is an interval of approximately 10–40 ms after the presentation of a stimulus. Frequency encoding was evaluated by fast Fourier transform (FFT) analysis (11.4–40.6 ms) in waves C, D, E and F. The amplitudes of three frequency ranges in accordance with stimulus fundamental frequency (F0 amp: 103–121 Hz), the first formant (F1 amp: 454–719 Hz), and a higher frequency region (HF amp: 721–1155 Hz) within the auditory brainstem response (Liu et al., 2006) were also analyzed. Stimulus-to-response correlation (SR corr) or the level of similarity of response to stimulus, and stimulus-to-response lag (SR lag) or the delay between the presentation of a stimulus to the onset of response (Vander Werf and Burns, 2011) were calculated. Root-mean square (RMS) values were calculated to assess signal energy for both the whole signal and the silence period before determining averages. Then, SNR was obtained as the ratio (in dB) between RMS on the whole sABR (0–190 ms) and RMS on the preaveraging silence (40-0 ms) (Akhoun et al., 2008).
2.4. Statistical analysis

Normal distribution of data was assessed by the Kolmogorov–Smirnov test. Multivariate one-way analysis of variance (MANOVA) was conducted to compare children with ADHD and TD children in terms of latency and amplitude of cABR and sABR waves, RMS amplitude, F0 and its harmonics, latency, amplitude and slope of V-A complex, SR corr and SR lag. Pearson’s correlation test was used to determine the relation between duration of V-Vn complex in cABR with duration of V-A in sABR. All statistical analyses were done using SPSS Statistics 18.0 at significance level of 0.05.

3. Results

3.1. Comparison of cABR findings between the two groups

Fig. 1 shows grand mean waveforms for the cABR in the both groups. Latencies of cABR in waves of III and V and duration of V-Vn complex were significantly longer in children with ADHD than in TD children. The mean and standard deviation (SD) of cABR wave latencies and V-Vn duration in the two groups, along with p values of statistical analysis are shown in Table 1. There was no significant difference between the two groups in wave inter-peak latencies and amplitudes.

3.2. Comparison of sABR findings between the two groups

Grand mean waveforms for the sABR are shown for children with ADHD and TD children in Fig. 2. It is noteworthy that waves C and O were not identified in some children of both groups. Wave C was observed in 66.0% (33 individuals) of the ADHD group and 64.70% (22 individuals) of the TD group, and wave O was seen in 76.0% (38 individuals) of the ADHD group and 76.48% (26 individuals) of the TD group, despite the good identification of other sABR waves. Latencies of sABR in waves A, D, E, F and O, duration of V-A complex, and SR lag were significantly longer in children with ADHD than in TD children. At the bottom of Fig. 2, the difference on the grand mean waveforms for the sABR of both groups including the rising phase of waves A, D, E and F, and the negative-going difference deflection of wave C is shown.

Fig. 3 shows enlarged onset and offset portions of the sABR grand means for the both children with ADHD and the TD children. The SNR value was significantly lower in children with ADHD than in TD children too. Table 2 shows the mean and SD of sABR wave latencies, V-A duration, SR lag, prestimulus RMS amp, and SNR in both groups, along with p values of statistical analysis. No significant differences were found in the amplitude of frequency following response in narrow frequency regions for the stimulus F0, F1 and HF. Finally, a significant correlation was found between the duration of V-Vn and V-A complexes in both children with ADHD (r = 0.403, p = 0.040) and TD children (r = 0.398, p = 0.042).

4. Discussion

In the present study, brainstem function in processing auditory stimuli using click and /da/ speech stimuli were investigated. In response to the click stimulus, children with ADHD showed a significant delay in the absolute latency of waves III and V, as well as in the duration of the V-Vn complex. Previously found that deficits in neural timing of the cABR waves have been observed in children with ADHD (Lahat et al., 1995; Puente et al., 2002), although such deficits are not found in children that in generally diagnosed with a learning disorder (Grontved et al., 1988; Jerger et al., 1987; Lauter and Wood, 1993; Mason and Mellor, 1984; McAnally and Stein, 1997; Purdy et al., 2002; Tait et al., 1983). According to cABR results in other neurological disorders, such as auditory neuropathy spectrum disorder (ANSD), small changes in the timing of responses to individual stimuli (clicks) can lead to missing averaged cABR signals. But, peaks of late auditory evoked potentials, such as auditory middle latency response (AMLR) and auditory late response (ALR) are less sensitive to fine changes in the timing of response to discrete stimuli (Durston, 2003; Jafari et al., 2009; Rance et al., 2004). The possible origins of wave III are the cochlear nuclei and the caudal portion of the auditory pons. The lateral lemniscus and inferior colliculus areas of the high brainstem are the potential sources of late waves of cABR (V and Vn) (Hornickel et al., 2009; Kraus and Chandrasekaran, 2010). Thus, it can be concluded that children with ADHD present considerable delay in response to click stimuli in those waves of cABR that originate from parts of middle and high brainstem levels than TD. However, this finding would need to be verified in future studies on this population.

To investigate the brainstem response to speech stimuli of children with ADHD, sABR was recorded by /da/ synthetic speech syllable. The latencies of all sABR waves were longer in children with ADHD than in TD children. The A, D, E, F, and O waves in children with ADHD were significantly different to those of TD children. Also, the most consistent differences on the grand mean waveforms for the sABR of both groups were positive, and clearly mark the rising phase of components A, D, E and F, indicative of delayed peaks in ADHD that overlap the corresponding control peaks. The only negative-going difference deflection was from a missing wave C in ADHD. Previous studies in LD children have reported an increase in wave V latency in the presence of noise (Cunningham et al., 2001), and increases in the latencies of waves A, C, and F in
silence (King et al., 2002). According to these previous findings and the results of the present study, in the filter class of sABR response, longer latencies of onset wave A and offset wave O may be regarded as a possible impact of the weaker synchronization of neuronal responses to find the beginning (onset) and ending (offset) of speech stimulus in children with ADHD. In the source class of sABR response, longer latencies of transient FFR components including waves E, D, and F may also be considered as a delay of the ADHD group to comprehend transient elements of FFR. They may be also weaker in discriminating between consonants.

In sABR, the V-A complex represents the synchronization of the neuronal response to the onset of a stimulus (Kraus and Nicol, 2005; Johnson et al., 2005). In our study, the analysis of the V-A complex showed a longer duration, shorter amplitude, and...
Fig. 3. Enlarged onset and offset portions of the grand means for the sABR. Top: the onset waves V and A with the gray line representing children with ADHD and the black line representing the TD children. Bottom: the offset component, wave O, is shown in the same manner.

Table 2
Mean values of sABR measures for children with ADHD and TD children.

<table>
<thead>
<tr>
<th>Latencies (ms)</th>
<th>TD children</th>
<th>Children with ADHD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
</tr>
<tr>
<td>V</td>
<td>5.920</td>
<td>0.190</td>
<td>34</td>
</tr>
<tr>
<td>A</td>
<td>6.749</td>
<td>0.151</td>
<td>34</td>
</tr>
<tr>
<td>C</td>
<td>17.366</td>
<td>0.334</td>
<td>22</td>
</tr>
<tr>
<td>D</td>
<td>21.278</td>
<td>0.124</td>
<td>33</td>
</tr>
<tr>
<td>E</td>
<td>30.047</td>
<td>0.108</td>
<td>31</td>
</tr>
<tr>
<td>F</td>
<td>38.690</td>
<td>0.090</td>
<td>34</td>
</tr>
<tr>
<td>O</td>
<td>46.788</td>
<td>0.453</td>
<td>26</td>
</tr>
</tbody>
</table>

Other sABR measures
<table>
<thead>
<tr>
<th>V-A duration (ms)</th>
<th>TD children</th>
<th>Children with ADHD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
</tr>
<tr>
<td>V</td>
<td>0.773</td>
<td>0.113</td>
<td>34</td>
</tr>
<tr>
<td>SR lag (ms)</td>
<td>8.029</td>
<td>0.446</td>
<td>34</td>
</tr>
<tr>
<td>RMS amp (µV)</td>
<td>0.124</td>
<td>0.036</td>
<td>34</td>
</tr>
<tr>
<td>Pre-stimulus RMS amp (µV)</td>
<td>0.047</td>
<td>0.016</td>
<td>34</td>
</tr>
<tr>
<td>SNR</td>
<td>3.799</td>
<td>1.208</td>
<td>34</td>
</tr>
</tbody>
</table>

Statistical results from MANOVA analysis performed for latency and other sABR measures.
N, numbers of ears.
* Statistically significant at p < 0.05.
shallower depth in children with ADHD compared with TD children; however, only the V-A duration was significantly different between ADHD and TD children. These results might indicate a weaker neuronal synchronization and a weaker representation of the beginning of speech stimulus in children with ADHD. On the other hand, there was a significant difference in the V-Vn duration in cABR, indicating that children with ADHD have some level of impairment in responding to both click and speech stimuli, possibly due to slight similarities in processing them at the subcortical level (Banai et al., 2007). A significant positive relation was obtained between the V-Vn duration in cABR and the V-A duration in sABR in both groups. This relation has been previously reported in normal individuals (Song et al., 2012), but it has been suggested that this relation is reduced in cases with prolonged onset of sABR (Banai et al., 2007). In our study and as expected, this relation was observed in both groups, considering the prolonged durations in both cABR and sABR tests. Although the ABRs that click and speech stimuli evoke differ, based on the acoustic characteristics of the evoking stimuli and the acoustic characteristics of the speech syllable /da/ used to measure the sABR, speech stimuli may be more challenging than click stimulus to the auditory system of children with ADHD. In fact, it seems that the neural encoding of click and speech stimuli is not entirely independent, and there are some common points for encoding them temporally (Banai et al., 2007). This notion should be further tested in future studies.

Previous research has also revealed that subcortical auditory processing does not have a typical hardware design, but it has a plastic and adaptable nature which arises from learning effects and cognitive capabilities (Skoe and Kraus, 2010). According to event-related potentials (ERPs), individuals with ADHD have longer latencies in late auditory evoked potentials, which are interpreted as a disruption in their cortical inhibitory control (Anjana et al., 2010; Fisher et al., 2011; Sndereccka et al., 2012; Tsai et al., 2012). In general, we can conclude that the timing deficits observed with ADHD are a combination of both bottom-up and top-down regulated processes. In other words, auditory processing in the subcortical neural pathways can be disrupted at the level of the response generators (putatively the midbrain), due to abnormal inputs from more peripheral auditory structures (bottom-up accounts) or due to abnormal modulations from more central structures via descending pathways (a top-down account) (Banai et al., 2009).

In the present study, signal-to-noise ratio (SNR) was obtained as the mean amplitude of the response divided by the mean amplitude of the pre-stimulus activity (Krizman et al., 2012). This value was significantly lower in children with ADHD than in TD children. According to the SNR results and the similarity of the RMS amplitude values calculated for both groups, this difference occurs due to the higher amplitude of pre-stimulus activity or internal physiological noise in children with ADHD. There is a possible relation between this finding and the weakness of auditory selective attention (Gomes et al., 2012) in these children. Gomes et al. (2012) reported a significantly smaller Taa, elicited by both the attended and unattended standards from the children with ADHD as compared to those from the TD children. They concluded that deficits in auditory selective attention in children with ADHD may be attributable to reduced information early in the processing stream. In this regard, the amplitude of pre-stimulus activity (internal physiological noise) in the children with ADHD than TD shown in our study may have an inappropriate influence on the basic stimulus processing, and consequently it may affect the results of the auditory attended tasks. However, given the lack of direct measurements on auditory attention in this study, further investigation would be required to test this hypothesis.

Moreover, the correlation measures showed no difference between the two groups in SR correlation. In other words, the response could imitate and follow the stimulus equally in both groups. However, SR lag was markedly higher in children with ADHD than in TD children. This finding means that there was a latency difference between the two groups. Similar findings have been reported in older adults compared with younger adults with normal hearing (Vander Werff and Burns, 2011).

In the spectral analysis of sABR waves, no significant difference was observed between the two groups with regard to amplitude magnitudes of the three frequency ranges of F0, F1, and HF. This finding is consistent with the results from Cunningham et al. (2001) based on nine children with LD, six of which were also clinically diagnosed with attention deficit disorder (LD/ADD), and the study by King et al. (2002) on 54 children with LD formally diagnosed with a learning disability or attention disorder. Accordingly, we can conclude that children with ADHD do not differ significantly from TD children in the amplitude of sustained FFR in both filter (F1) and source (F0) responses. Future studies in children with attention disorders in degraded auditory situations should provide more information in this field.

In this study, cABR and sABR were recorded in silence to investigate the impacts of ADHD on speech processing at the subcortical level. Recording sABR in the presence of noise, or using psychoacoustic and/or speech recognition tests in the presence of noise, and comparing the electrophysiological and behavioral findings can provide more detailed information in this regard. In addition, we tried to select children with ADHD according to our inclusion criteria and the preliminary tests precisely, but the possible comorbidity of ADHD with LD and/or reading problems is another limitation of the present study. On the other hand, we did not systematically conduct central auditory tests to rule out the possible comorbidity of ADHD with central auditory processing disorder (C)APD. (C)APD has been defined as a deficit in the perceptual processing of auditory stimuli in the central nervous system (CNS) and the neurobiological activity underlying that processing (Bellis and Ross, 2011). The clinical utility of visual analogs of central auditory tests in the differential diagnosis of (C)APD has been tested in a study on children diagnosed with (C)APD or ADHD and TD children on three diagnostic tests of central auditory function (dichotic digits, frequency patterns, and duration patterns tests) and their corresponding visual analogs. Results in children with supramodal disorders such as ADHD supported the “non-modular” model of the central auditory nervous system (Bellis and Ross, 2011), which would predict the presence of comorbid deficits in other sensory modalities on tasks that rely on shared neuroanatomical substrates (Musiek et al., 2005).

5. Conclusion

In the present study, delayed III and V wave latencies and longer V-Vn duration in cABR and a delay in the temporal encoding of each filter and source class of sABR responses were observed in children with ADHD compared with TD children. Based on these results, children with ADHD have a common dysfunction in the processing of nonspeech and speech stimuli at the brainstem level. Our results, together with findings from previous studies, suggest an influence of both top-down and bottom-up neural pathways on the observed deficits in temporal encoding of speech and nonspeech stimuli in ADHD. These findings can provide novel avenues for future studies in this area and to learn more about bottom-up processing of auditory stimuli in children with ADHD.

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References


