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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 ($P \leqslant 0.027$), and latencies of sABR in waves A, D, E, F and O and duration of V-A ($P \leqslant 0.034$) 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.

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

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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 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 (Faraone 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 (Abdekhodaie 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 (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). 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 was elicited by passive listening to tone bursts stimuli and consists of a small negative peak (Na: 70–80 ms), a positive peak (Ta $\sim$ 100 ms), followed by a larger negative peak (Tb: 140–160 ms). The Ta component matures early (Tonnquist-Uhlen et al., 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.