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Event-related potentials to pitch and rise time change in children with reading disabilities and typically reading children

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Abstract

Objective: The purpose of the present study was to investigate whether children with reading disabilities (RD) process rise time and pitch changes differently to control children as a function of the interval between two tones.
Methods: Children participated in passive oddball event-related potential (ERP) measurements using paired stimuli. Mismatch negativity (MMN), P3a and late discriminative negativity (LDN) responses to rise time and pitch changes were examined.
Results: Control children produced larger responses than children with RD to pitch change in the P3a component but only when the sounds in the pair were close to each other. Compared to children with RD, MMN was smaller and LDN larger in control children in response to rise time change when the sounds in the pair were further apart. The non-overlap in ERP measures between the groups was 40–50%.
Conclusions: Problems in rapid processing of pitch change were reflected in a component associated with attention switching while amplitude envelope processing problems were reflected in components associated with stimulus detection or discrimination.
Significance: Children with RD process both rise time and pitch changes differently from control children thus providing evidence for the nature of amplitude envelope processing and rapid auditory processing deficits in dyslexia.

Keywords: Auditory processing; Dyslexia; ERP; LDN; MMN; P3a

1. Introduction

Developmental dyslexia or specific reading disability (RD) is a developmental disability in learning to read and write despite adequate educational and socio-economic opportunities and normal general cognitive capacities. In terms of causality, dyslexia is widely acknowledged as a problem with phonological awareness (Bradley and Bryant, 1983; Brady and Shankweiler, 1991; Stanovich, 1998; Wagner and Torgesen, 1987). However, the cause of this phonological processing deficit has been the subject of discussion for decades (for reviews see Farmer and Klein, 1995; Ramus, 2003; Rosen, 2003). Several studies suggest that subtle problems in auditory processing could cause difficulties in speech perception; this would result in the establishment of 'fuzzy' phonological representations which, in turn, would lead to phonological processing deficits and dyslexia (for reviews see e.g. Farmer and Klein, 1995; Stein, 2001; Tallal and Gaab, 2006). However, not all studies have observed auditory processing deficits in individuals with dyslexia (e.g. Hill et al., 1999; Mody et al., 1997). Two approaches to the investigation of auditory problems in dyslexia are relevant to the present study: research on perception of (speech) rhythm and stress (Goswami et al., 2002) and rapid auditory processing (Tallal, 1980; Tallal et al., 1993).

The theoretical framework of main interest to the present study was proposed by Goswami and colleagues (2002). These authors based their hypothesis on findings that, in the development of speech perception, speech is first segmented into larger parts (e.g. syllables, rhymes) and only later develop to phonemic-level units. They suggested that

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children with dyslexia have difficulties in initially segmenting these larger speech elements and thus later will also develop deficits with phonemic level segments. In dyslexia, stress/rhythm processing deficit was thought to underlie this segmentation problem. Perceived stress in speech is at least in part due to changes in rise times of sounds. Other studies have shown that temporal cues provided by amplitude modulation are important cues for speech intelligibility (Drullman et al., 1994; Shannon et al., 1995). Goswami et al. (2002) tested the hypothesis of deficient stress/beat perception in children with dyslexia using amplitude modulated stimuli. The change in amplitude modulation in these stimuli was observed only at the beginning of each modulation cycle; that is, multiple rise times were varied in order to create the perception of a beat. A short rise time at the start of each modulation cycle creates the perception of a beat, whilst long rise times make the beat harder to perceive. Results showed that, in comparison to control children, children with dyslexia were less able to categorize amplitude modulated tones that varied in beat rise time (Goswami et al., 2002). Several studies have replicated the finding of atypical rise time processing in adults and children with dyslexia in comparison to typical readers (Hämäläinen et al., 2005; Muneaux et al., 2004; Richardson et al., 2004; Thomson et al., 2006). Using event-related potentials (ERPs), the interest of the current study was to ascertain at what stage of auditory processing the possible group differences in rise time perception can be observed. However, there are many other hypotheses concerning the nature of the auditory processing deficits in dyslexia and it is not known how the different hypotheses are linked to each other and whether the different auditory deficits could interact with each other. Thus, we were also interested in investigating the effects of rapid stimulus presentation on rise time processing.

One of the earliest hypotheses relating to auditory problems in dyslexia is associated with rapid rate processing. In the present study we were interested also in whether the rise times would be processed differently with rapid stimulus rates. Rapid auditory processing (RAP) problems were proposed by Tallal (1980) as underlying the phonological deficits in dyslexia. Identification of the temporal order of two tones with a different pitch when the time interval between the two tones was short (below 305 ms) was found to be more difficult for children with dyslexia compared to control children (Tallal, 1980). On the other hand, when the interval between the tones was long (428 ms), both groups of children performed equally well on the task. Performance on this task was found to be associated with the reading and spelling skills of these children. The RAP theory was later extended to other temporal aspects of auditory processing in addition to temporal order judgment tasks such as perception of short and rapidly-changing elements in speech, for example stop consonant formant transitions, the time scale for these usually being below 50 ms (Tallal et al., 1993; Tallal and Gaab, 2006). Several studies have replicated the finding of rapid auditory processing deficits in individuals with dyslexia (e.g. Booth et al., 2000; Reed, 1989; for a review see Farmer and Klein, 1995). However, some studies have not found reading group differences in the rapidness of sensory processing but in the phonetic similarity of the stimuli, thus arguing that dyslexics are impaired only in speech perception (Breier et al., 2002; Mody et al., 1997). Furthermore, some studies have found group differences in RAP tasks but only weak or no connections to phonology or reading ability (Bretherton and Holmes, 2003; Heiervang et al., 2002).

Although the majority of studies investigating the RAP and rise time processing deficits in children and adults with dyslexia have used behavioral methods, some studies have also deployed brain event-related potential (ERP) techniques. The main components of interest in the present study are described below, followed by a brief review of studies that have used brain activation measures to study the auditory processing deficits in dyslexia.

In a passive oddball experiment several ERP components of interest are elicited by stimuli deviating (the so-called 'deviant' stimuli) from the repeatedly-presented reference sound (the standard stimuli). One of the components of interest is mismatch negativity (MMN), a change detection response peaking at approximately 150–200 ms after the onset of a change in a sound feature. Attention is not required for MMN elicitation and participants are usually engaged in some other activity such as reading a book or watching a silent film during ERP recording. This component is based on a memory trace which is formed by the repeated standard stimulus and MMN is generated when the deviant stimulus does not match this memory trace (Näätänen, 1992; Näätänen and Alho, 1997; Picton et al., 2000). Several studies have shown that the MMN response in school-age children is largely comparable to that of adults in showing similar fronto-central negative distribution with a reversal of polarity into positivity below the Sylvian fissure (Cheour et al., 2001; Ceponiene et al., 1998). This distribution is compatible with sources in the supratemporal auditory areas. A separate frontal component of MMN has been observed in response to a deviant stimulus in addition to the sources in the auditory cortex (Picton et al., 2000; Rinne et al., 2000). In children, small differences in the location or orientation of MMN sources can cause the MMN amplitude to be somewhat larger and of longer latency than in adults (Gomot et al., 2000; Martin et al., 2003).

Research has shown that, after the MMN response, from 400 ms post-stimulus, another negativity called the late discriminative negativity (LDN) is elicited by the deviant stimulus (Ceponiene et al., 1998, 2002, 2004; Korpilahti et al., 2001). This response also has a fronto-central distribution but the amplitude of the component diminishes with age (Cheour et al., 2001). LDN is thought to reflect further processing of the deviant stimulus after the detection of change (reflected in the MMN component) although its function is still unclear (Ceponiene et al., 2004).

Novel sounds and deviants with strong perceptual salience produce a P3a component that is associated with