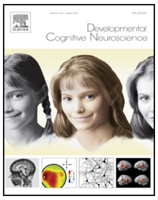
Developmental Cognitive Neuroscience 19 (2016) 152–163

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: http://www.elsevier.com/locate/dcn



Neural processing of amplitude and formant rise time in dyslexia

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ARTICLE INFO

Article history:
Received 7 December 2015
Received in revised form 10 March 2016
Accepted 20 March 2016
Available online 22 March 2016

Keywords:
Dyslexia
Amplitude rise time
Formant rise time
Mismatch response

ABSTRACT

This study aimed to investigate how children with dyslexia weight amplitude rise time (ART) and formant rise time (FRT) cues in phonetic discrimination. Passive mismatch responses (MMR) were recorded for a/ba/-/wa/contrast in a multiple deviant odd-ball paradigm to identify the neural response to cue weighting in 17 children with dyslexia and 17 age-matched control children. The deviant stimuli had either partial or full ART or FRT cues. The results showed that ART did not generate an MMR in either group, whereas both partial and full FRT cues generated MMR in control children while only full FRT cues generated MMR in children with dyslexia. These findings suggest that children, both controls and those with dyslexia, discriminate speech based on FRT cues and not ART cues. However, control children have greater sensitivity to FRT cues in speech compared to children with dyslexia.

1. Introduction

Developmental dyslexia is characterised by difficulties in learning to read despite normal intellectual functioning, normal hearing and vision and an adequate learning environment (Snowling, 2000; Vellutino et al., 2004). The characterising feature of children with dyslexia is a phonological deficit (i.e., deficits in the ability to attend to and mentally manipulate speech sounds) (Ramus et al., 2013, 2003; Snowling, 2000), and this is considered as the proximal cause in (most) children with dyslexia (Snowling, 2000; Vellutino, 1979). However, the precise nature of the phonological deficit in dyslexia is under debate. It is unclear whether the phonological representations (underlying sound structure of specific words stored in long-term memory) are themselves impaired (Ahissar, 2007) or whether the ability to access them is limited (Boets et al., 2014; Ramus and Szenkovits, 2008).

Many theories have tried to ascertain the cause of the phonological deficit in dyslexia. One group of theories holds that it stems from a more basic auditory processing deficit (Chandrasekaran et al., 2009; Tallal, 1980; Vandermosten et al., 2010). According to one prominent auditory processing deficit theory, children with dyslexia are impaired in tracking amplitude rise time cues (ART) in the auditory signal (Goswami et al., 2002). ART refers to the time from the onset of an acoustic stimulus to its maximum amplitude. Accurate perception of ART will lead to accurate perception of auditory rhythm. Speech rhythm assists the listener in segmenting the syllable into onset (the word initial phoneme) and rime (phonemes that follow the onset). Therefore if subtle differences in ART are not perceived, it will lead to deficits in the acquisition of phonological skills as the segmentation of speech into distinct phonological units is impaired (Goswami et al., 2002).

Many behavioural studies have shown a deficit in the processing of ART in children with dyslexia. Goswami et al. (2011) compared the discrimination of a phonetic minimal pair (/ba/versus/wa/) when the contrast was based on ART differences between/ba/and/wa/versus when it is based on differences between/ba/and/wa/in the rise time of the first and second formants (F1, F2, formant rise time; FRT). They showed that children with dyslexia were superior to control children in discrimination based on FRT cues, but impaired in discrimination based on ART cues. ART thresholds were also a significant predictor of phonological skills in these children. They concluded that the development of phonological skills in dyslexia is affected by insensitivity to ART cues. Richardson et al. (2004) also found that children with dyslexia are less sensitive to ART. Similar findings have been obtained in languages other than English (Finnish: Hämäläinen et al., 2005, Hungarian: Surányi et al., 2009; French: Muneaux et al., 2004). However, this cross-linguistic evidence is not conclusive as Hämäläinen et al. (2009) and Georgiou et al. (2010) did not find any difference between children with dyslexia and typically reading children on their sensitivity to ART.

Behavioural studies of auditory processing have the disadvantage that performance is affected by non-auditory factors such as attention and motivation, so some of the discrepancies in previ-

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http://dx.doi.org/10.1016/j.dcn.2016.03.006

ous studies could be explained by such factors. Neurophysiological measures such as mismatch negativity (MMN) provide an alternative. MMN is an event related potential (ERP) component that reflects the early stages of change detection in the auditory system. The MMN is elicited by any discriminable change in a repetitive sequence of sounds, or by a sound violating an abstract rule or regularity in the preceding auditory context (Näätänen et al., 1978, 2001). In a simple MMN paradigm an infrequent stimulus (deviant) is presented among a series of repeatedly presented stimuli (standard). The MMN is represented by a negative peak (between 100 and 250 ms in adults) in the difference waveform between the ERPs to deviants and ERPs to the standards. MMN is a result of a pre-attentive memory based comparison process in which each incoming sound is compared with the memory trace formed by the preceding sounds. If the features of the incoming sound (frequency, amplitude, etc.) do not match the memory trace, the MMN is generated. The MMN has been widely used in studies investigating auditory and speech perception in normal and clinical populations (for reviews see Näätänen et al., 2007, 2012). In infants and young children the difference waveform between standards and deviants shows a positive peak (rather than a negative peak) and this is referred to as mismatch response (MMR) (Cheng et al., 2013; Dehaene-Lambertz and Baillet, 1998; Ruhnau et al., 2013). Neural maturation is hypothesised to account for the polarity change of the mismatch response over age (He et al., 2007; Trainor et al., 2003). The polarity change also depends on the discriminability between the standard and deviant stimuli with easy to discriminate contrasts maturing earlier compared to more difficult contrasts (Cheng et al., 2015; Maurer et al., 2003; Morr et al., 2002).

A few studies have investigated the processing of ART cues in dyslexia using MMN. Hämäläinen et al. (2008) presented 8–10-year-old Finnish children with harmonic tone pairs with the tones having either 130 ms or 10 ms ART. The standard stimuli had both tones with long rise time whereas the deviant stimuli had the first tone with a long rise time and the second tone with a short rise time. The stimulus pairs were presented with two within-pair intervals of 10 ms or 255 ms. They found a larger MMN response in the dyslexia group when the ISI was 255 ms and was interpreted as the effect of larger N1 response (which overlapped with MMN) to short ART stimuli in dyslexia. In contrast, Hakvoort et al. (2015) did *not* find a reduction in MMN amplitude for ART manipulations in 11–12-year-old children with dyslexia. They used pure tone stimuli with 10 ms ART as standard and 90 ms, 180 ms and 270 ms ART as deviants with 250 ms ISI. No effect of deviance magnitude was also observed. They concluded that ART processing – when measured independent of attention – is not impaired in children with dyslexia. Plakas et al. (2013) investigated the discrimination on pure tone stimuli based on ART or on frequency in pre-school children at genetic risk of dyslexia (at least one parent with dyslexia) using MMN (15 ms ART as standard, 90 ms ART as deviant). They found that sensitivity to *both* ART and frequency were impaired in children at risk of dyslexia, although sensitivity to both ART and frequency did not predict reading skills at grade 2.

Most of the behavioural and MMN studies on ART processing in dyslexia (except Goswami et al., 2011) have used non-speech stimuli (either pure tones or harmonic tones). Speech differs from non-speech as it has multiple acoustic cues to signal phonetic contrasts. For example, the stop-glide contrast (/ba/vs/wa/) is cued by both ART and FRT (/ba/has short ART and FRT whereas/wa/has long ART and FRT). One question that could be asked is whether listeners perceptually attend to both cues, or if they prefer to attend to one cue because the other is redundant. This is the notion of perceptual weighting.

Behavioural studies have shown that adults use FRT and not ART in phonemic identification (Nittrouer and Studdert-Kennedy, 1986; Walsh and Diehl, 1991). Recently Nittrouer et al. (2013) investigated how adults and 4- to 6-year-old children weight ART and FRT cues in phonemic identification. Synthetic stimuli were presented with varying ART and FRT cues, and it was found that both adults and children based their phonemic decisions almost entirely on FRT cues. Similar findings were reported by Lowenstein and Nittrouer (2015) in 10- to 12- year-old children and adults with hearing impairment, although they also reported large variability across participants' use of FRT vs ART cues in making judgements. Using the MMN paradigm Moberly et al. (2014) studied the perceptual weighting of ART and FRT cues in adults and found a significant MMN for both ART and FRT deviants with larger MMN amplitude for FRT deviants indicating superior processing of FRT cues by adults. Therefore even though adults and children weight FRT cues above ART behaviourally, adults can preattentively discriminate speech sounds based on ART cues.

Perceptual weighting is important for the theories of dyslexia; if there is a deficit in the processing of a certain acoustic cue (e.g., ART deficit as predicted by Goswami et al., 2002), and if the cue is not heavily weighted then the perceptual consequence of the deficit would be minimal. To investigate this issue, this study investigated the weighting of ART and FRT cues in children with dyslexia using an MMN paradigm. If both cues are weighted equally, then similar MMNs will be generated for both ART and FRT. If one cue is weighted more than the other, then corresponding increases in MMN amplitude are expected.

2. Material and methods

2.1. Ethics statement

The ethics committee for Human Research at Western Sydney University approved all the experimental methods used in the study (Approval number: H9660). Informed consent was obtained from the parents of all the child participants. Children also gave verbal assent for the study.

2.2. Subjects

Seventeen children (3 female) with dyslexia and seventeen (5 female) age-matched control children participated in the study. Children's ages ranged from 6.0 to 11.8 years ($M = 8.9$ years, $SD = 17.1$ months). Children were recruited via advertisements in local media or via a database of families who previously expressed interest to participate in infancy and child research. All participants reported having no hearing difficulties. Families' socio-economic status was calculated based on the average household weekly income of their area of residence (Australian Bureau of Statistics). All families came from middle or higher middle socio-economic backgrounds, but the families in the control group came from areas with higher income than families in the dyslexia group, $t(32) = 4.64$, $p < .001$. An additional 5 children with dyslexia were tested, but their data were removed from analysis due to excessive artifacts in their electroencephalogram (EEG) epochs (more than 30% of their epochs were rejected).

2.3. Behavioural measurements

Group assignment (dyslexia and control) was determined based on children's performance on the tests from the screening battery set out below. Children were assigned to the dyslexia group if a) they obtained a score of 1.5*SD* below the age-appropriate mean in at least one reading task, *and* at least one phonological processing task, *and* b) had average scores (not lower than 1*SD* from the age appropriate mean) on the grammatical competence tests, *and* c) had average non-verbal IQ score and no indications of Autism