ARTICLE IN PRESS

Neuropsychologia ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at SciVerse ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Neural evidence of allophonic perception in children at risk for dyslexia

M.W. Noordenbos [a,*], E. Segers [a], W. Serniclaes [b,c], H. Mitterer [d], L. Verhoeven [a]

[a] Behavioural Science Institute, Radboud University Nijmegen, The Netherlands
[b] CNRS, Laboratoire de Psychologie de la Perception, Université Paris Descartes, France
[c] UNESCOG, Brussels' Free University, Belgium
[d] Max Planck Institute for Psycholinguistics, The Netherlands

ARTICLE INFO

Article history:
Received 12 October 2011
Received in revised form
21 March 2012
Accepted 26 April 2012

Keywords:
At risk for dyslexia
Allophonic perception
Mismatch Negativity
Event-related potentials

ABSTRACT

Learning to read is a complex process that develops normally in the majority of children and requires the mapping of graphemes to their corresponding phonemes. Problems with the mapping process nevertheless occur in about 5% of the population and are typically attributed to poor phonological representations, which are – in turn – attributed to underlying speech processing difficulties. We examined auditory discrimination of speech sounds in 6-year-old beginning readers with a familial risk of dyslexia ($n=31$) and no such risk ($n=30$) using the mismatch negativity (MMN). MMNs were recorded for stimuli belonging to either the same phoneme category (acoustic variants of /bə/) or different phoneme categories (/bə/ vs. /də/). Stimuli from different phoneme categories elicited MMNs in both the control and at-risk children, but the MMN amplitude was clearly lower in the at-risk children. In contrast, the stimuli from the same phoneme category elicited an MMN in only the children at risk for dyslexia. These results show children at risk for dyslexia to be sensitive to acoustic properties that are irrelevant in their language. Our findings thus suggest a possible cause of dyslexia in that they show 6-year-old beginning readers with at least one parent diagnosed with dyslexia to have a neural sensitivity to speech contrasts that are irrelevant in the ambient language. This sensitivity clearly hampers the development of stable phonological representations and thus leads to significant reading impairment later in life.

1. Introduction

Developmental dyslexia is a specific and persistent failure to acquire efficient reading and spelling skills despite average or above average intelligence, adequate and effective classroom instruction, and good socio-cultural opportunities (Démonet, Taylor, & Chaix, 2004). The disorder typically persists into adulthood and is characterized by slow and error-prone reading, poor non-word reading, and weak spelling. Although there is still no consensus on the causes of developmental dyslexia, it is agreed that problems with phonological awareness (i.e., the ability to identify and manipulate speech elements such as phonemes and syllables) constitute the core deficit (Ramus, 2003; Snowling & Hulme, 2010; for a review see Vellutino, Fletcher, Snowling, & Scanlon, 2004). Impaired phonological processing prohibits the establishment of stable phonological representations, and thus affects the mapping of graphemes onto their corresponding phonemes (Anthony & Francis, 2005; Elbro, Borstrom, & Petersen, 1998; Goswami, 2002). And, indeed, deficits in the perception of contrastive speech sounds have been found to positively relate to phonological awareness, reading ability, and speech-in-noise perception (Hornickel, Skoe, Nicol, Zecker, & Kraus, 2009; McBride-Chang, 1995).

Speech perception involves the mapping of a spectrally complex and rapidly changing acoustic signal onto discrete phonological units. A basic property of speech perception is that listeners perceive speech sounds categorically. That is, most listeners attend to acoustical cues that signal phonologically relevant speech contrasts and have learned to ignore cues that signal irrelevant distinctions (Liberman, Harris, Hoffman, & Griffith, 1957). Deficits in the detection of acoustic speech cues may thus play a role in difficulties with the development of stable phonological representations (McBride-Chang, 1996; Studdert-Kennedy, 2002). Numerous behavioral studies have shown that individuals at-risk or with dyslexia present poorer categorization for consonants in both identification tasks (e.g., Boets et al., 2011; Breier et al., 2001; Chiappe, Chiappe, & Siegel, 2001; Gerrits & De Bree, 2009; Joanisse, Manis, Keating, & Seidenberg, 2000; Maassen, Groenen, Crul, Assman-Hulsmans, & Gabreëls, 2001; Manis et al., 1997) and discrimination tasks (e.g., Bogliotti, Serniclaes, Messaoud-Galusi, & Sprenger-Charolles, 2008; Breier, Fletcher, Denton, & Gray, 2004; Maassen et al., 2001;

* Correspondence to: Behavioural Science Institute, Radboud University Nijmegen, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands.
Tel.: +31 24 3612070; fax: +31 24 3616211.
E-mail address: m.noordenbos@bsi.ru.nl (M.W. Noordenbos).

0028-3932/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.neuropsychologia.2012.04.026

Mody, Studdert-Kennedy, & Brady, 1997; Serniclaes, Van Heghe, Mousty, Carre, & Sprenger-Charolles, 2004). For example, Maassen et al. (2001) has shown children with dyslexia to have less sharply defined phoneme boundaries along both voicing and place-of-articulation continua than control children.

The reduced between-category discrimination in individuals with dyslexia suggests that their phonological representations are not properly developed. It has been further suggested that their phonological representations are over-specified, as reflected by better behavioral discrimination of well-specified allophonic contrasts within the same phoneme category than controls (Bogliotti et al., 2008; Serniclaes et al., 2004). Recent neuroimaging data suggest that when individuals with dyslexia do not show heightened sensitivity to allophonic contrasts behaviorally, it might still be present in the form of neural activation (Dufor, Serniclaes, Sprenger-Charolles, & Démonet, 2009). Note, however, that not all studies have found better within-category discrimination in individuals with dyslexia (e.g., Breier et al., 2004; Van Beinum, Schwippert, Been, Van Leeuwen, & Kuijpers, 2005). This could be due to the different features of the speech continua being used, as the speech perception deficits in dyslexia are quite subtle. For example, Breier et al. (2004) investigated within-category discrimination in general and not specifically allophonic perception in English speaking children; they used a continuum with only positive voice-onset-times (VOT) with the phonemic boundary placed around +30 ms VOT, but allophonic boundaries for VOT continua are located around −30 and +30 ms VOT as evidenced by studies in infants (Aslin, Pisoni, Hennessy, & Perey, 1981; Hoonhorst et al., 2009). These ±30 ms VOT boundaries are phonemic in a three voicing category language, such as Thai (Lisker & Abramson, 1970). Furthermore, the continuum used by Breier et al. contained no well-specified allophonic boundaries, contrary to the full VOT continuum used in the study of Bogliotti et al. (2008). This means that discrimination of within-category differences in studies without well-specified allophonic contrasts (e.g., Breier et al., 2004; Van Beinum et al., 2005) might arise from the discrimination of simply any kind of acoustic contrast rather than those that straddle an allophonic boundary per se.

Studies showing better discrimination of stimuli crossing allophonic boundaries suggest that individuals with dyslexia perceive speech using allophonic rather than phonemic units and are thus sensitive to phonetic variation that is actually irrelevant for the ambient language. The perception of speech using an allophonic mode is the same ability that all newborns have—an ability that allows them to acquire the language that they hear (Kuhl et al., 2006; Werker & Tees, 2002). This ability is reorganized during the first year of life in accordance with the relevance of the allophonic contrasts within the language being acquired (Hoonhorst et al., 2009; Kuhl, 2004). Stable grapheme–phoneme correspondences are then easily established by most children when they start to read but not by children with dyslexia.

A heightened allophonic sensitivity in individuals diagnosed with dyslexia does not – in and of itself – demonstrate a possible causal relationship between speech perception difficulties and dyslexia (Bogliotti et al., 2008; Dufor et al., 2009; Serniclaes et al., 2004). In the present study, we therefore examined auditory discrimination of speech sounds belonging to either the same phoneme category (acoustic variants of /bə/) or different phoneme categories (/bə/ vs. /də/) in 6-year-old beginning readers with a familial risk of dyslexia by means of event-related potentials (ERP).

Event-related potentials have the advantage of being considerably less affected by attentional, motivational, and task-related artifacts than behavioral tasks. The Mismatch Negativity (MMN) is a negative deflection of the event-related potential and is elicited by any noticeable change in the preceding auditory stimulus sequence—irrespective of attention or the behavioral task (for reviews see Näätänen, Paavilainen, Rinne, & Alho, 2007; Näätänen & Winkler, 1999). The MMN usually reaches its maximum amplitude on the fronto-central scalp about 100–250 ms after deviance onset, but its amplitude is enlarged and its peak latency is shortened as the degree of stimulus change increases (Pakarinen, Takegata, Rinne, Huotilainen, & Näätänen, 2007; Sams, Paavilainen, Alho, & Näätänen, 1985; Tiitinen, May, Reinikainen, & Näätänen, 1994). Several studies have also shown better pre-attentive discrimination of phonetic contrasts to be reflected by larger MMN amplitudes (Cheour et al., 1998; Dehaene-Lambertz & Baillet, 1998; Näätänen et al., 1997; Winkler et al., 1999). For example, Näätänen et al. (1997) showed the MMN amplitude to be larger in healthy adults when the *infrequent* deviant stimulus reflects a relevant contrast in the participant's native language (Finnish) as opposed to an irrelevant foreign contrast (Estonian). In still other cross-linguistic research using the MMN, Cheour et al. (1998) showed memory traces for language-specific speech sounds to develop between 6 and 12 months of age. The finding of larger MMN amplitudes to familiar speech sounds compared to unfamiliar sounds suggests the activation of language-specific memory traces and is therefore increasingly being used in research on developmental language disorders.

In dyslexia research, several studies have shown both children and adults with dyslexia to have diminished MMN amplitudes for changes of consonants (Lachmann, Berti, Kujala, & Schröger, 2005; Schulte-Körne, Deimel, Bartling, & Remschmidt, 1998, 2001; Sharma et al., 2006) and tone frequencies (Baldeweg, Richardson, Watkins, Foale, & Gruzelier, 1999; Kujala, Lovio, Lepistö, Laasonen, & Näätänen, 2006). Normal MMNs have been found for duration changes in only adults with dyslexia (Baldeweg et al., 1999; Kujala et al., 2006) but not in children with dyslexia (Corbera, Escera, & Artigas, 2006). Studies of children and infants with a familial risk for dyslexia have also shown diminished MMN responses for changes in phonemes (Maurer, Bucher, Brem, & Brandeis, 2003; Van Leeuwen et al., 2008), vowels (Lovio, Näätänen, & Kujala, 2010), and duration (Leppänen et al., 2002). However, the pre-attentive auditory processing of allophonic variants was not investigated in these studies while such allophonic processing may be an important marker for dyslexia.

In the present study, we therefore investigated the auditory discrimination of phonemic and allophonic contrasts in 6-year-old beginning readers at risk for dyslexia using the MMN. These children were tested after about six months of formal reading instruction, the first moment that reading problems can be detected despite formal reading instruction, because differences in reading performance at this time can be a possible indication of later dyslexia. We recorded MMNs to speech sounds belonging to either the same or different phoneme categories. If children at risk for dyslexia are sensitive to acoustic properties that are irrelevant for their language, this can be hypothesized to cause more phonological variants (i.e., allophones) to be used to process the ambient language than necessary, lead to grapheme–phoneme mismatches, and thereby impair later reading. Furthermore, the only neural evidence for an allophonic mode of speech perception so far comes from a PET study with adults diagnosed with dyslexia (Dufor et al., 2009). These authors demonstrated that the discrimination of within-category pairs was related to reduced activation in the left inferior premotor cortex in non-dyslexic adults while discrimination of the same pairs was related to enhanced activation in the same region in dyslexic adults. It has yet to be demonstrated, however, that children at risk for dyslexia are similarly sensitive to such allophonic variants