BRAIN RESEARCH 1448 (2012) 42–55

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BRAIN RESEARCH

Research Report

Reading skill and neural processing accuracy improvement after a 3-hour intervention in preschoolers with difficulties in reading-related skills

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ARTICLE INFO

Article history:
Accepted 28 January 2012
Available online 7 February 2012

Keywords:
Reading
Intervention
Dyslexia
Event-related-potential (ERP)
Mismatch negativity (MMN)

ABSTRACT

This study aimed at determining whether an intervention game developed for strengthening phonological awareness has a remediating effect on reading skills and central auditory processing in 6-year-old preschool children with difficulties in reading-related skills. After a 3-hour training only, these children made a greater progress in reading-related skills than did their matched controls who did mathematical exercises following comparable training format. Furthermore, the results suggest that this brief intervention might be beneficial in modulating the neural basis of phonetic discrimination as an enhanced speech-elicited mismatch negativity (MMN) was seen in the intervention group, indicating improved cortical discrimination accuracy. Moreover, the amplitude increase of the vowel-elicited MMN significantly correlated with the improvement in some of the reading-skill related test scores. The results, albeit obtained with a relatively small sample, are encouraging, suggesting that reading-related skills can be improved even by a very short intervention and that the training effects are reflected in brain activity. However, studies with larger samples and different subgroups of children are needed to confirm the present results and to determine how children with different dyslexia subtypes benefit from the intervention.

1. Introduction

Reading is an essential skill in modern societies, yet 5–17% of children become dyslexic and face persisting problems in reading and writing (Shaywitz, 2003), which has negative effects on the child's cognitive development, school motivation, self-esteem and well-being. In order to avoid this vicious circle, it is important to try to help the child as early as possible.

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doi:10.1016/j.brainres.2012.01.071

Dyslexia is a neurodevelopmental disorder that is defined as a persistent difficulty in learning to read that is not explained by sensory or cognitive deficits, lack of motivation, or lack of adequate reading instruction and schooling (Shaywitz, 2003). Typically, there is a discrepancy between an average or above-average intelligence test score and a low score on a standardized reading test. Dyslexia is highly heritable, occurring in up to 50% of individuals with a parent or a sibling with dyslexia (Pennington and Gilger, 1996).

Problems with phonological awareness are common in dyslexia (Bradley and Bryant, 1978; Snowling et al., 2000; for a review, see Gabrieli, 2009). Younger children with dyslexia often face problems when asked to operate with sounds within words or to segment words into parts. They have difficulties in learning the alphabet or letter order, in associating letters to the corresponding sounds, and may have problems with rapid word retrieval and working memory (Lyytinen et al., 2007). Older children who can read have, in turn, problems with unfamiliar words or are very slow readers (Wimmer et al., 2010).

There is an ongoing debate about the underlying causes of these defects (for a review, see Ramus, 2004; Vellutino et al., 2004). Different theories of the underlying causes have also resulted in varying attempts to help dyslexic individuals to overcome their difficulties with reading and writing. Recent remediation studies of dyslexia especially highlight the importance of combining auditory and visual training (Brem et al., 2010; Kujala et al., 2001; Törmänen and Takala, 2009; Veuillet et al., 2007; for a review, see Loo et al., 2010). Children who develop the ability to hear individual sounds within words are also able to associate these phonemes to their written letter representations (Lyytinen et al., 2005). The pairing of letters with the sounds supports the differentiation of the learner's phonemic space and phonological awareness and concomitantly the acquisition of reading and spelling skills (Lyytinen et al., 2009). Improving children's audio–visual matching of sounds and letters might therefore provide a key for improved reading and spelling skills.

The effects of interventions are reflected both in improved reading-related skills and underlying neural changes. A recent functional magnetic resonance imaging (fMRI) study showed that training including auditory and oral language exercises had an effect on dyslexic children's oral language and reading performance (Temple et al., 2003). At the same time, the children's brain activity increased in left temporo-parietal cortex and left inferior frontal gyrus, bringing activation in these regions closer to that seen in normal-reading children. Increased activation was also seen in the right-hemispheric frontal and temporal regions and in the anterior cingulate gyrus, interpreted as reflecting additional, compensatory, activation. In an electrophysiological study by Kujala et al. (2001), audiovisual training without linguistic material, in turn, improved dyslexic children's word reading and caused changes in auditory responses.

Event-related potentials (ERPs) enable one to study central auditory processing in children with no demands on the child's performance, as it might be difficult for a child to go through long measurements that require staying still, active concentration, or decision making. The early obligatory components P1, N2, and N4 of the auditory ERP can be used to measure neural correlates of the reception and encoding of a stimulus in children (Čeponienė et al., 2001, 2002; Sharma et al., 1997). Further, the mismatch negativity (MMN) ERP can be used to measure cortical auditory discrimination (Näätänen, 1979, 1985, 1992; Näätänen et al., 1978). The MMN reflects change detection in a pre-attentive memory-based comparison process (Näätänen and Winkler, 1999; Näätänen et al., 2005) and is elicited by any discriminable change in a sequence of auditory stimuli (Kujala et al., 2007). The easier the change is to discriminate, the larger the MMN amplitude, and the shorter its peak (Kujala and Näätänen, 2010; Pakarinen et al., 2007; Rinne et al., 2006; Sams et al., 1985; Tiitinen et al., 1994). The MMN is a useful tool for language studies as it can be used to study memory representations for speech sounds (Dehaene-Lambertz 1997; Näätänen et al., 1997). Furthermore, recent developments in MMN paradigms enable one to record MMNs for several features in a more efficient way than with the traditional oddball paradigm (Lovio et al., 2009; Näätänen et al., 2004; Pakarinen et al., 2009). The P3a response, usually following the MMN, reflects involuntary attention shifting elicited by perceivable sound changes (for reviews, see Escera et al., 2000; Escera and Corral, 2007; Kujala and Näätänen, 2010). The P3a is especially large in response to surprising sounds, and its amplitude diminishes as the novelty value of the stimulus decreases (Cycowicz and Friedman, 1997).

Auditory processing was shown to parallel reading abilities (Ahissar et al., 2000; Espy et al., 2004; Sharma et al., 2006). Deficiencies at the early sound feature processing stage have been found in adults and children with dyslexia as well as in children at familial risk for dyslexia. Diminished (Byring and Järvilehto, 1985; Van Herten et al., 2008) or increased (Bernal et al., 2000; Hämäläinen et al., 2007; Helenius et al., 2002a, 2002b; Van Herten et al., 2008) obligatory ERP amplitudes as well as atypical ERP sources for speech stimuli (Fried et al., 1981; Guttorm et al., 2001; Heim et al., 2003; Leppänen et al., 1999; Molfese, 2000; Pihko et al., 1999; Renvall and Hari, 2002) have been reported.

Moreover, several studies with individuals with reading-related difficulties suggest problems at the early auditory sensory–memory stage reflected by the MMN (for reviews, see Bishop, 2007; Csépe, 2003; Kujala, 2007; Kujala and Näätänen, 2001). The impaired cortical discrimination of sound frequency (Baldeweg et al., 1999; Kujala et al., 2003, 2006; Renvall and Hari, 2003), consonant changes in syllables (Lachmann et al. 2005; Schulte-Körne et al., 1998; Sharma et al., 2006), and duration changes (Kujala et al., 2006) have been reported in dyslexic individuals. In children at risk for dyslexia, deficient cortical discrimination of sound frequency (Leppänen et al., 2010; Maurer et al., 2003), duration (Corbera et al., 2006; Leppänen et al., 2002; Lovio et al., 2010), and intensity (Lovio et al., 2010) were reported. Furthermore, while normally developing children have enhanced MMNs to native-vowel prototypes in comparison to atypical vowels, children with dyslexia do not show this effect (Bruder et al., 2011).

Some studies also report a tendency for a diminished P3a in dyslexia. In adults, the P3a tends to be smaller for changes in pitch (Kujala et al., 2003) and for novel sounds (Russeler et al., 2002) in unattended stimulus sequences. In children, the P3a amplitude is reduced and its latency delayed for a duration change in non-phonological sounds (Corbera et al.,