International Journal of Psychophysiology 74 (2009) 199–208

Contents lists available at ScienceDirect

International Journal of Psychophysiology

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

# Reading words and pseudowords in dyslexia: ERP and behavioural tests in English-speaking adolescents

Naira A. Taroyan [a],*, Roderick I. Nicolson [b]

[a] Department of Psychology, Sheffield Hallam University, Sheffield S10 2BP, UK
[b] Department of Psychology, Western Bank, University of Sheffield, Sheffield S10 2TP, UK

ARTICLE INFO

*Article history:*
Received 6 December 2008
Received in revised form 14 August 2009
Accepted 2 September 2009
Available online 10 September 2009

*Keywords:*
Dyslexia
Word
Pseudoword
Event related potentials
Reaction time

ABSTRACT

The study reports neurophysiological and behavioural correlates of lexical decision processes in English speaking dyslexic and non-dyslexic readers. Nine dyslexic adolescents (ages 15.6–17.8) and 9 control (ages 15.4–19.3) adolescents were tested, and the event related potentials (ERPs) to words and pseudowords were recorded simultaneously with behavioural measures. As expected, both groups showed significantly lower accuracy and longer response times for the pseudowords. Furthermore, overall performance (in terms of lower accuracy and longer response times) was significantly worse for the dyslexic group. The ERP analysis indicated that the later positive peaks, P4 (around 400 ms from stimulus onset) and P5 (around 500 ms), were significantly delayed and attenuated for the dyslexic group. Analysis of the early ERP peaks recorded in the occipitotemporal region led to an interesting dissociation. The controls showed a left lateralised Condition effect, with the amplitude of P1 significantly smaller to words than pseudowords. By contrast, there was no such lexical effect for the dyslexic group, with equal P1 amplitudes for words and pseudowords, at the control level for pseudowords. The deviations in the early ERP components of dyslexics support the evidence of deficits in pre-lexical visual word form recognition within the first 110 ms of activation together with altered hemispheric asymmetry. In addition, the slowed and attenuated late ERP components and weaker behavioural performance of the dyslexic group highlight deficits in the later, cognitive, processing stages.

## 1. Introduction

Developmental dyslexia, a learning disorder that affects 5–10% of school-age children (Shaywitz, 1998), is characterised by difficulties in reading, spelling and writing. It is often reported to be accompanied with other, non-linguistic problems, such as visual and auditory sensory deficits, visuo-motor coordination, attention and working memory (Tallal and Percy, 1973; Lovegrove et al., 1980; Nicolson et al., 1999; Smith-Spark et al., 2003; Vidyasagar, 2004). Different theories have been proposed regarding the causes and neurobiological origins of dyslexia. According to one of the currently influential theories, the phonological deficit hypothesis (Bradley and Bryant, 1978; Vellutino, 1979), a failure to adequately develop phonological skills is at the core of reading problems in dyslexia. According to the magnocellular deficit hypothesis impairment in visual sensory processing contributes to reading problems in individuals with dyslexia (Livingstone et al., 1991; Stein and Walsh, 1997). According to the automatisation deficit hypothesis, the lack of ability to automatise any skills, including motor skills, as well as reading and phonological skills, is characteristic to dyslexia (Nicolson and Fawcett, 1990).

Reading acquisition is a complex and multi-stage process that requires many years of training. It involves identification of letters and letter combinations (graphemes), their subsequent conversion to sounds (phonemes), which are then combined to give the whole word pronunciation (phonology) and, eventually, its meaning (semantics). In transparent languages, such as German or Italian, the mapping between graphemes and phonemes is straightforward, and it allows the young readers to reach proficiency in reading considerably quickly (Frith et al., 1998). This is not the case in languages with deep and irregular orthography, such as English. Current cognitive models of reading suggest there are different types of strategies in languages with complex orthography. According to the dual-mechanisms model (Coltheart et al., 1993, 2001) orthography-to-phonology translation can be accomplished through lexical or sublexical procedures. The processing of frequently used words, especially those with irregular grapheme-to-phoneme relationship, is thought to be accomplished through a direct route from the word's visual form to its phonology and meaning. When processing novel words and pseudowords, however, individual letters are mapped onto phonological units before these are assembled into a phonological word form (Price and Mechelli, 2005), as in beginning readers. The pseudowords are word-like letter strings that

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* Corresponding author. Tel.: +44 114 222 6553; fax: +44 114 276 6515.
*E-mail address:* N.A.Taroyan@shu.ac.uk (N.A. Taroyan).

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doi:10.1016/j.ijpsycho.2009.09.001

do not have a stored representation in the mental lexicon, but are phonologically and orthographically regular.

Numerous functional imaging studies have concentrated recently on the research of different stages in reading. In a recent review of neuroimaging research Price and Mechelli (2005) argued that reading activates widely distributed brain regions from occipitotemporal to posterior temporal, precentral and frontal cortical areas. Pugh and colleagues suggested that posterior reading circuits including both dorsal (temporo-parietal) and ventral (occipitotemporal) components are disrupted in people with reading disability, which is compensated by heightened reliance on both inferior frontal and right hemisphere parietal regions (Pugh et al., 2001). In an earlier MEG study by Salmelin et al. (1996) distinct time courses in activation during passive reading of words were found for dyslexic and control participants. Controls showed activation at about 180 ms after stimulus onset in the left temporo-occipital area, whereas dyslexics either did not show any activation in this area or showed a slowly increasing late response. In a more recent study Helenius et al. (1999) showed an earlier activation at about 150 ms in the left inferior occipito-parietal area among fluent readers to the letter-string stimuli, whereas no such activation was found among dyslexic readers. In a MEG study by Wilson et al. (2007) with English speaking normally achieving readers the words and pseudowords activated the same anatomical areas but in a different sequence after the first 100 ms of word onset. Thus, the activation to both words and pseudowords was recorded initially in the left posterior fusiform gyrus with no differences between conditions. Then, activation to words proceeded to inferior temporal (110–150 ms) and to superior temporal area eventually, whereas for pseudowords it was recorded in the superior temporal (95–215 ms) first, and then in the inferior temporal area. The authors suggested that the neural processes in the left posterior region, where the activation for words and pseudowords was similar, had already discerned the word types, and engaged one pathway for lexical items, i.e., words, that proceeded to semantic inferior temporal area first, and another parallel pathway for the pseudowords that proceeded to the phonological superior temporal area first. The non-familiar pseudowords would need an initial phonological decoding first before the semantic association could be attempted. They have proposed that the dual mechanisms hypothesis of reading by Coltheart et al. (1993) and Price et al. (2003) applies to processing of both words and pseudowords in deep orthographic languages like English. Wilson et al. (2007) have also argued that their results are consistent with a proposal of Devlin et al. (2006) for a functional role of the left posterior fusiform gyrus as a perceptual interface between visual form and lexical representations of words. This region in the occipitotemporal cortex has been labelled The Visual Word Form Area (VWFA) (McCandliss et al., 2003; but see Price and Devlin, 2004), and it was reported to be highly sensitive to orthographic regularity, i.e., words and pseudowords, but not to irregular letter strings (e.g., Polk and Farah, 2002).

Differences in processing of words and pseudowords are important for understanding of reading disturbances in dyslexia. There is a large body of evidence on problems that dyslexic children encounter in phonological awareness tasks, with grapheme-to-phoneme conversion (Vellutino, 1979; Nicolson and Fawcett, 1994, 1995; Bruck, 1993). Coltheart et al. (1993) suggested there are two types of dyslexia: phonological (difficulty with pseudowords) and surface (difficulty with irregular words). According to recent evidence (e.g., Bowey and Rutherford, 2007), however, this division may not be clear cut as relatively few cases of either type of dyslexia appeared to be ‘pure’. It is well established that dyslexic children and adults have particular difficulties in reading pseudowords (Yap and Van der Leij, 1993; Snowling, 1995). Consequently the lexical decision task (in which a stimulus is presented and the participant has to classify it as word or pseudoword) is a valuable diagnostic test. Nicolson and Fawcett (1994, 1995) established clear behavioural difficulties in this task, including slower and less accurate responses.

At a neurological level, the behavioural deficits in reading among dyslexics are usually linked to abnormalities in language areas of the cortex. The early anatomical work (Galaburda et al., 1985) and more recent neuroimaging studies (e.g., Paulesu et al., 1996; Shaywitz, 1998) support the notion of dysfunction in the perisylvian areas of the left hemisphere. Price and Mechelli (2005) reviewed the evidence of abnormalities in dyslexia, both structural and functional in some of these areas, including occipitotemporal, that correlated with reading disturbance. They suggested that the damage in the left occipitotemporal region (acquired dyslexia) impairs the reading more than the object naming as the right occipitotemporal activation is able to sustain object naming more than reading.

Recent years have seen a growing use of electrophysiological techniques, such as event-related potentials (ERPs), in research of neurobiological origins underlying different learning disorders. The ERPs provide a continuous record of brain activity, and they can elucidate the levels and stages of cognitive processing involved in reading that can be difficult to differentiate with behavioural measures and neuroimaging techniques with low temporal resolution. ERPs have been used previously in investigations of dyslexia with paradigms ranging from simple pattern-reversal stimulation to complex cognitive tests like visual selective attention and continuous performance tasks (CPT) (Livingstone et al., 1991; Fawcett et al., 1993; Facoetti et al., 2005; Taroyan et al., 2007).

In a recent ERP study with British English-speaking healthy adults the lexical frequency effect that reflects familiarity of an individual word has been found at 110 ms from stimulus onset (Hauk et al., 2006). The activation to high frequency words was smaller than to the low frequency words, and this effect was lateralised to the left hemisphere. Shortly after these initial effects, at about 160 ms, ERPs distinguished between familiar words and unfamiliar pseudowords. The authors suggested there is only minimal delay between processing of the visual word form (110 ms) and the word's lexical representations (160 ms). The lexicality effects were still present in later latency windows of ERPs, with responses to pseudowords being more negative than to words at around 400–500 ms.

The problems encountered by dyslexics in lexical decision tasks were recently studied by means of recording ERPs in German-speaking children (Wimmer et al., 2002) and in young adults with Hungarian as their first language (Csepe et al., 2003). Wimmer et al. (2002) used number-words and corresponding pseudowords. The study was designed to test the hypothesis of right parietal lobe dysfunction in dyslexia. There were between-group ERP differences, with N1 amplitude smaller in the right hemisphere in response to pseudowords for the dyslexics compared to controls. It was concluded, that the pseudowords were particularly difficult and required higher attention levels, and consequently higher demands on the right parietal lobe. However, Csepe et al. (2003) have argued that the number-words were particularly difficult, even for the controls, as non-frequent words. In the latter study the ERPs to frequently used words, number-words and pseudowords were recorded, and the most pronounced differences between dyslexics and controls were found for the ERPs to frequently used words. Wimmer et al. (2002) and Csepe et al. (2003) did not report any word/pseudoword specific effect or lateralisation of such effect (as in the studies described above), i.e., no ERP differences (including hemispheric) were found in the controls' or dyslexics' group depending on whether words or pseudowords were processed. However, in both these studies the activation at occipitotemporal sites was not included into analysis. Additionally, as already mentioned, German and Hungarian are languages with transparent orthography and straightforward grapheme-to-phoneme mapping, and the word/pseudoword effects may be different from those in English.

We aimed to use a lexical decision task similar to those used by Wimmer et al. and Csepe et al., only with high frequency nouns and corresponding pseudowords. We were interested to study the dynamics of brain activation at different recording sites, including occipitotemporal