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Electrophysiological indices of spatial attention during global/local processing in good and poor phonological decoders

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ABSTRACT

Previous research suggests a relationship between spatial attention and phonological decoding in developmental dyslexia. The aim of this study was to examine differences between good and poor phonological decoders in the allocation of spatial attention to global and local levels of hierarchical stimuli. A further aim was to investigate the relationship between global/local processing and electrophysiological indices (N1, N2) of spatial attention in these groups. Good ($n = 18$) and poor ($n = 16$) phonological decoders were selected on the basis of non-word reading ability. Participants responded to either the global or local level of hierarchical stimuli presented in the left or right visual field in a sustained attention task. Poor phonological decoders showed slower RT relative to good phonological decoders regardless of whether attention was directed to either global or local processing levels. This was accompanied by a lack of task-related modulation of the posterior N1 and N2 Event-Related Potential (ERP) components, suggesting differences in the early allocation of spatial attention and later perceptual processing respectively. Poor decoders also showed greater N2 amplitude overall, suggestive of compensatory processing at later perceptual stages. There was preliminary evidence for sex differences in hemispheric lateralisation, with a reversal of hemispheric lateralisation observed among male and female poor phonological decoders. These findings have important implications for the understanding of the relationship between spatial attention and phonological decoding in developmental dyslexia.

1. Introduction

Cognitive interpretations of developmental dyslexia emphasise the importance of a core phonological deficit in the aetiology of the disorder (Bradley & Bryant, 1983; Rack, Snowling, & Olson, 1992; Stanovich, 1988; Stanovich & Siegel, 1994; Wagner & Torgesen, 1987). This phonological deficit is often marked by poor ability to read non-words or pseudowords and therefore difficulty in reading through the process of grapheme–phoneme conversion or phonological decoding. Developmental dyslexia has also been associated with a right hemisphere posterior parietal deficit (see Stein & Walsh, 1997) and behavioural research suggests a disruption to areas of the brain involved in the allocation of spatial attention (e.g., Facoetti, Turatto, Lorusso, & Mascetti, 2001; Hari & Renvall, 2001; Vidyasagar & Pammer, 1999). Spatial attention is thought to be particularly important for the successive analysis of letters during phonological decoding (LaBerge & Brown, 1989; Mozer & Behrmann, 1990) and attentional difficulties in dyslexia are associated with non-word reading deficits (Facoetti et al., 2006). In the present research, allocation of spatial attention during visual processing was investigated among adult good and poor phonological decoders selected on the basis of non-word reading ability.

Reading requires the allocation of attention to both individual letters and whole words comprised of individual elements and therefore requires both global (holistic) and local (analytic) visual processing strategies. Some research indicates that poor readers are inclined towards more diffuse allocation of attention or an inclination for global processing (Facoetti & Molteni, 2001; Facoetti, Paganoni, & Lorusso, 2000; von Karolyi, 2001; von Karolyi, Winner, Gray, & Sherman, 2003; Williams & Bologna, 1985). However, few previous studies have investigated the relationship between global/local processing and reading ability using traditional hierarchical stimuli (Keen & Lovegrove, 2000). Hierarchical stimuli consist of a global letter that is composed of inconsistent or consistent local letters (Navon, 1977). Two consistent effects have been found in research investigating global/local processing. The global precedence effect refers to the Reaction Time (RT) advantage that is observed during global relative to local feature selection and the global-to-local interference effect refers to the RT decrement observed during local feature selection when global and local letters are inconsistent (Kimchi, 1992).

Keen and Lovegrove (2000) investigated the effects of size and retinal eccentricity on global/local processing in dyslexic children

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and chronological and reading age matched controls. Considering the evidence for a magnocellular deficit in dyslexia (see Stein, 2001) and the involvement of the magnocellular or transient system in global processing (Badcock, Whitworth, & Badcock, 1990; Shulman & Wilson, 1987), a global processing deficit was predicted (Keen & Lovegrove, 2000). Children with dyslexia showed longer RT relative to chronological age matched controls but there were no differences in the global precedence effect. It was argued that dyslexics are slow at processing visual information which affects rapid processing and integration across fixations during reading. However, another possibility is that the overall performance decrement was due to a deficiency in allocating spatial attention to either the global or local processing levels.

Attentional factors have been shown to moderate the global precedence effect (Hübner, 2000; Stöffer, 1994; Weber, Schwarz, Kneifel, Treyer, & Buck, 2000). According to attentional zooming theory (Ericksen & St James, 1986), the abrupt stimulus onset of hierarchical stimuli captures attention to the global level and the global precedence effect reflects the time required to refocus attention to the local level (Stöffer, 1994). The allocation or shifting of attention is affected by both bottom-up (stimulus driven) and top-down (goal directed) processes (Johnston & Dark, 1986) or exogenous and endogenous modes of attention respectively (Posner, 1980). When hierarchical stimuli are preceded by spatial cues that draw attention to the local level there is a reduction in the global precedence effect and global-to-local interference (Han & He, 2003) suggesting that top-down voluntary attentional control can overcome exogenous attentional capture (Hübner, 2000; Stöffer, 1994). Activation of oculomotor areas (often resulting in saccades) also occurs during local processing suggesting that attending to local details induces a shift or narrowing of attention, whereas attending to global features induces an expansion of attention (Weber et al., 2000).

Global/local processing is associated with attentional control by temporo-parietal areas over earlier processing in the visual cortex (Fink, Marshall, Halligan, & Dolan, 1999). Electrophysiological research has demonstrated task and attention related modulation of posterior ERP components (N1, N2) during global/local processing (Han & He, 2003; Han, Liu, Yund, & Woods, 2000; Heinze, Hinrichs, Scholz, Burchert, & Mangun, 1998). N1 amplitude is greater when attention is sustained to local relative to global levels of hierarchical stimuli (Han et al., 2000) and is also known to be modulated by spatial attention (Eimer, 1998; Mangun, 1995) providing further support for the relationship between global/local processing and spatial attention. In addition, N2 amplitude is greater during local relative to global feature processing under conditions of selective (Han & He, 2003; Han et al., 2000; Heinze et al., 1998) but not divided attention (Heinze et al., 1998) and task-related modulation of the N2 component in frontal and parietal areas has been associated with processing differences in anterior and posterior attentional networks respectively (Han & He, 2003).

The findings of both neuropsychological (lesion) (Lamb & Robertson, 1988; Lamb, Robertson & Knight, 1989, 1990; Robertson, Lamb & Knight, 1988, cited in Basso & Lowery, 2004) and neuroimaging studies (Fink et al., 1999; Martinez et al., 1997; Weber et al., 2000; Yamaguchi, Yamagata, & Kobayashi, 2000) indicate that local processing of letters is mediated by posterior areas of the left hemisphere, whereas global processing is mediated by posterior areas in the right hemisphere. These differences are thought to represent a processing bias and it is likely that both hemispheres are able to process global and local information but differ in their efficiency (see Hübner & Malinowski, 2002). It has also been argued that global/local processing and visual spatial perception share common underlying neural substrates that are both lateralised to the right hemisphere (Basso & Lowery, 2004).

The aim of the present study was to investigate the relationship between electrophysiological measures of spatial attention and global/local processing in good and poor adult phonological decoders. If poor phonological decoders show a selective deficit in global processing this would indicate difficulty processing low spatial frequency information which would be consistent with a magnocellular visual processing deficit. However, if poor decoders show an advantage for the global task this would indicate a propensity to process visual stimuli in a global or holistic fashion. Furthermore, an overall decrement in performance on both tasks relative to good decoders would suggest difficulty in focussing and expanding the spatial scale of attention to local and global levels respectively. Good decoders are expected to show greater N1 and N2 amplitude for the selection of local relative to global features. If poor decoders are less efficient in changing the focus of attention as a function of task demands they would not be expected to show the same task-related modulation of these components.

Although not central to the aims of the present study, previous research has indicated visual field differences between dyslexics and good readers, characterised by LVF inattention and RVF distractibility (or diffuse allocation of attention), which may be suggestive of a right hemisphere parietal abnormality (Eden, Wood, & Stein, 2003; Facoetti & Molteni, 2001; Facoetti & Turatto, 2000; Facoetti et al., 2001; Geiger & Lettvin, 1987; Hari, Renvall, & Tanskanen, 2001). While, the sustained/selective paradigm and unilateral presentation employed in the present study is not optimal for investigating hemispheric asymmetries in global/local processing (see Han & He, 2003; Heinze et al., 1998), exploratory analyses involving visual field and hemisphere were also conducted in the present study.

2. Method

2.1. Participants

This study was approved the University of Tasmania Human Research Ethics Committee. Thirty-six first year psychology students at the University of Tasmania participated in the experiment as part of their course requirements and all gave written informed consent prior to participation. Good ($n = 18$) and poor ($n = 17$) phonological decoders were selected on the basis of Martin and Pratt Non-word Reading Test scores (Martin & Pratt, 2001). One female poor phonological decoder was excluded from analyses due to outlying accuracy scores. The remaining sample consisted of 18 good (11 female, 7 male) and 16 poor (10 female, 6 male) decoders. Two good (1 male, 1 female) and two poor (both female) phonological decoders were left handed, the remaining participants were right handed as measured by the Edinburgh handedness inventory (Oldfield, 1971). All participants had normal or corrected to normal vision. Exclusion criteria included a history of drug, alcohol, or tobacco abuse, psychiatric or neurological disorder, head trauma, seizure, and those currently receiving medication.

A sample of over 300 Psychology 1 students were screened with the alternate form of the Martin and Pratt non-word reading test and those with scores in the upper and lower ends of the distribution were recruited. The Martin and Pratt non-word reading test was normed using standard scores based on a distribution with a mean of 100 and a SD of 15, with age appropriate norms provided up to the age of 16 years and 11 months, and percentile ranks calculated from standard scores. The non-word reading scores of good phonological decoders ranged from 49 to 54 (out of a possible score of 54) which equates to scores between the 66th and 98th percentiles for children between the ages of 16 and 17 years. The scores of poor phonological decoders ranged from 19 to 43 which equates to scores between the 2nd and 37th percentile for this age range.