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Brain and Cognition 57 (2005) 30–34

Brain and Cognition

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Adults with dyslexia demonstrate space-based and object-based covert attention deficits: Shifting attention to the periphery and shifting attention between objects in the left visual field

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Accepted 12 August 2004

Abstract

Performance on a covert visual attention task is compared between a group of adults with developmental dyslexia (specifically phonological difficulties) and a group of age and IQ matched controls. The group with dyslexia were generally slower to detect validly-cued targets. Costs of shifting attention toward the periphery when the target was invalidly cued were significantly higher for the group with dyslexia, while costs associated with shifts toward the fovea tended to be lower. Higher costs were also shown by the group with dyslexia for up-down shifts of attention in the periphery. A visual field processing difference was found, in that the group with dyslexia showed higher costs associated with shifting attention between objects in they LVF. These findings indicate that these adults with dyslexia have difficulty in both the space-based and the object-based components of covert visual attention, and more specifically to stimuli located in the periphery.

Keywords: Dyslexia; Covert attention; Periphery; Space-based; Object-based; Shifting attention; Visual attention

1. Introduction

Reading is a learned skill which requires selective attentional processes, both to correctly locate words within a visual array and to shift attention to the different locations of words in a sentence. Adults and children with dyslexia have demonstrated impairments on a number of selective visual attention tasks. Furthermore, their level of impairment has been shown to be related to the degree of reading impairment shown (e.g., Brannan & Williams, 1987; Buchholz & McKone, 2004; Vidysagar & Pammer, 1999).

Several authors have proposed that these findings are consistent with a neural deficit in the magnocellular system which provides information to the posterior parietal cortex. Evidence has indicated an asymmetry of attentional distribution between the two visual fields, reflecting impairments specifically in right parietal function. For example, in a study by Hari, Renvall, and Tanskanen (2001), adults with dyslexia demonstrated a left visual field (LVF) "mini-neglect" for stimuli. And children with dyslexia have been shown to omit a greater number of targets presented in the LVF in a visual search task (Fowler, Riddell, & Stein, 1990; also see Eden, Stein, & Wood, 1993). More recently, children with dyslexia have been shown to have problems with target eccentricity when stimuli are projected to the LVF (Facoetti & Molteni, 2001).

There are two major views of how covert visual attention selects information for further processing. The space-based view holds that attention is directed to a specific area in space, and is unaffected by the presence of objects at that location. In contrast, the object-based

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0278-2626/$ - see front matter
doi:10.1016/j.bandc.2004.08.017

view posits that information about particular objects is selected independently of the objects' spatial location. Egly, Driver, and Rafal (1994) developed a variation of the Posner (1980) precuing methodology, which allowed both space-based (the cost of shifting attention within an object) and object-based (the cost of shifting attention between objects) components of attention to be measured in a single task. Patients with right-parietal-lobe damage demonstrated a space-based attentional deficit, while patients with left-parietal-lobe damage showed an object-based attentional deficit. The authors concluded that the two hemispheres might be differently specialized for space-based and object-based components of attention.

If we regard words as objects, and letters as features at locations within objects, then reading requires both components of selective attention. It is proposed that if either, or both, components are not functioning correctly, one might expect reading difficulties. In the present study, the attentional abilities of adults with dyslexia were examined using the precuing methodology of Egly, Rafal, Driver, and Starrveveld (1994). The aim was to investigate visual field differences in the group of individuals with dyslexia, and to determine if these differences were related specifically to particular space-based or object-based components of visual attention.

2. Method

2.1. Subjects

All subjects were recruited from the Australian National University. The experimental group consisted of 8 adults who met the criteria of dyslexia as determined by the Dyslexic Adult Screening Test (DAST: Fawcett & Nicolson, 1998). Untimed single word reading and spelling abilities were evaluated using the Wide Range Achievement Test (WRAT: Jastak & Wilkinson, 1984). Intellectual functioning was assessed using the Wechsler Abbreviated Scale of Intelligence (WASI). The control group consisted of 8 adults with no history of reading difficulties. The two groups did not differ with regard to IQ. Significant group differences were documented on the DAST measure, as well as both subtests of the WRAT. For the subjects with dyslexia, the scores fell outside the 95% confidence intervals of the control sample on each relevant measure. Group characteristics are presented in Table 1.

Table 1
Subject group characteristics

	Control $n = 8$	Dyslexia $n = 8$
Mean age (Years)	31.1 (8.8)	31.3 (12.1)
WASI		
Full-scale IQ	123.0 (11.0)	127.4 (13.3)
Verbal IQ	120.1 (10.7)	113.9 (6.5)
Performance IQ	121.5 (10.1)	123.3 (6.5)
DAST		
At risk quotient (ARQ)*	0.01 (0.03)	1.24 (0.45)
Phonological ability (PA)*	0	−1.94 (0.76)
Literacy measure (LM)*	0	−1.53 (0.75)
WRAT (Standard, $M = 100$, $SD = 15$)		
Reading*	109.5 (5.1)	89.3 (10.8)
Spelling*	114.0 (5.6)	87.6 (11.1)
Highest level of education	Tertiary	Tertiary

Note. For phonological ability and literacy measure breakdown from the DAST refer Buchholz and McKone (2004). Values are Mean (SD) unless otherwise noted.

* $p < 0.001$.

2.2. Materials and procedure

The stimuli were presented using PsyScript software on an Apple Macintosh computer with a 17-in. monitor and a refresh rate of 85 Hz. Objects in the fixation display were light grey and were drawn on a white background.

Stimuli were very similar to those used by Egly et al. (1994). Each trial began with four rectangular objects (two in each visual field) presented on the screen in either a horizontal or vertical orientation. Each object subtended $4.5° \times 1°$ of visual angle. The distance between the two objects in a visual field was 4.5°, and the closest edge of any object was 2.5° from the central fixation stimulus (a black plus sign, +). The fixation stimuli remained on screen throughout the experiment. After 1000 ms, a cuing display (a black "U" shape) was superimposed on the end of one of the objects in the fixation display for 100 ms. The target event appeared after a 200 ms delay. In any given block of trials, the target (a black rectangle about $1° \times 1°$) appeared at the cued location on 60% of trials (valid cue) and at an uncued location on 20% of trials (invalid cue). On 10% of trials a target was presented without a preceding cue (no cue) and in a further 10% of trials a cue was presented without a target (catch trials). On the invalid-cue trials, the target appeared equally often either at the opposite end of the cued object (within-object shift of attention) or in the adjacent object within the same hemifield (between-object shift of attention). Both types of shifts of attention were of equal distance, and the target never appeared at a position diagonal to the cued location. The target remained on the screen for a maximum of 1200 ms. During this period, a key press ended the trial. Stimuli were presented in 6 blocks of 160 trials. All conditions were randomly intermixed in each block, with 50% of trials for each condition occurring in each visual field. Subjects were seated comfortably with their head supported on a chin rest which held their eyes level with the fixation cross at a distance of 57 cm from the monitor. They were instructed to maintain fixation throughout each trial. The task was to press the "0" key as soon as the target appeared. Subjects were encouraged to pause between blocks for not more than 2–3 min. Individual testing lasted approximately 45 min, and began with twenty randomised practice trials.

3. Results

Response times (RT) shorter than 100 ms were discarded as anticipations. The frequency of these errors was low in both groups (0.62% vs 0.73%, *ns*). For each participant, mean RT was calculated for each of the within-subject conditions. To increase power of the analyses, data for upper and lower locations were combined for each location in each visual field. Several repeated measures Analysis of Variance (ANOVA) were calculated in which the between-subject factor was always group (controls, individuals with dyslexia).

3.1. Cue type

Response times were entered into a three-way ANOVA, in which the within-subject factors were cue type (no cue, valid cue, and invalid cue) and visual field of presentation (LVF, RVF). There was a significant main effect of group, $F(1,14) = 5.72$, $p < 0.04$, demonstrating longer RTs for the group with dyslexia (425 ms) compared with the control group (359 ms). There was also a significant main effect of cue type, $F(2,28) = 199.84$, $p < 0.001$, demonstrating shorter mean RTs for valid-cue trials (323 ms) compared with invalid-cue trials (354 ms) and no-cue trials (499 ms). There were no other significant findings for this analysis.

3.2. Valid-cue condition

Response times were entered into a four-way ANOVA, in which the within-subject factors were orientation of rectangles (vertical, horizontal), visual field (left, right) and position of cue presentation within the visual field (left, right). There was a significant main effect of group, $F(1,14) = 7.21$, $p < 0.02$, demonstrating longer mean RTs for the group with dyslexia (353 ms) compared with the control group (289 ms). The only other significant finding was that of a two-way interaction between visual field and position of presentation, $F(1,14) = 14.95$, $p < 0.01$, demonstrating shorter RTs associated with stimuli presented close to fixation (right side of the LVF = 319 ms; left side of the RVF = 317 ms) compared with those presented more peripher-

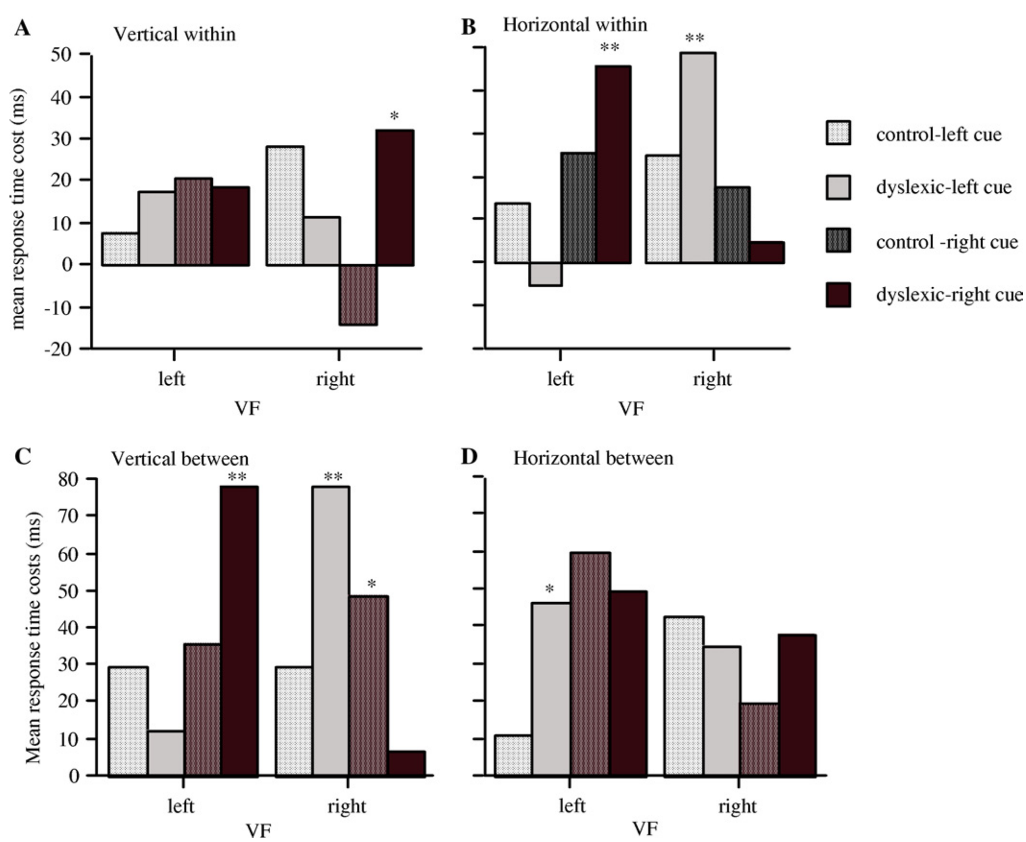

Fig. 1. Mean response time costs (RT) for horizontal and vertical rectangle orientation, in the invalid-cue conditions (within and between) presented either to the left or right of the left and right visual fields. *Represents significant differences between the control group and the group with dyslexia. **Represents significant differences between the two groups for shifts away from fixation.

ally (left side of the LVF = 326 ms; right side of the RVF = 321 ms).

3.3. Invalid-cue condition

The cost of shifting attention was calculated by subtracting valid-cue means from invalid-cue means (target position being the same) for each condition. These were entered into a five-way ANOVA, where the within-subject factors were orientation of rectangle (horizontal, vertical), type of attentional shift (within, between), visual field (left, right) and position of cue presentation (left, right). There was a significant main effect of shift type, $F(1,14) = 35.75$, $p < 0.001$, demonstrating lower costs for within-object shifts (19 ms) compared with between-object shifts (39 ms). The visual field by position of cue presentation interaction was also significant, $F(1,14) = 30.79$, $p < 0.001$, demonstrating lower costs for attentional shifts toward fixation (shift left to right in the LVF = 19 ms; shift right to left in the RVF = 17 ms) compared with those away from fixation (shift right to left in the LVF = 42 ms; shift left to right in the RVF = 38 ms).

A significant five-way interaction was also found, $F(1,14) = 59.51$, $p < 0.001$ (see Fig. 1). Planned comparisons revealed, first, that the group with dyslexia (compared to the control group) showed greater attentional costs for between-object shifts in the LVF, $t(14) = 1.99$, $p < 0.05$. Second, this group showed comparatively greater costs for shifts away from fixation (p's < 0.01, see Fig. 1). Also, there was a trend for this group with dyslexia to have comparatively lower costs than the control group for shifts toward fixation, however, only the between-object shifts (in the vertically oriented rectangles) toward fixation in the RVF reached significance ($t(14) = 3.06$, $p < 0.01$, see Fig. 1). Finally, the group with dyslexia showed higher costs compared to the control group for up and down shifts of attention in the periphery, that is, shifts on the right of the RVF and left of the LVF (p's < 0.01, see Fig. 1).

4. Discussion

The results of this study have shown that the ability of adults with dyslexia to covertly orient attention following a precue is generally intact in both hemispheres, in that these individuals show the same overall pattern of responses as controls. That is, they are faster to detect validly-cued targets compared with invalidly-cued targets or targets without a cue. Adults with dyslexia also demonstrated a normal overall pattern of responses for object-based and space-based components of orienting, in that they were faster at responding to within-object shifts of attention compared to between-object shifts of attention. However, there were some consistent differences in the responses made by individuals with dyslexia.

First, the findings clearly indicate that there were visual field differences for the between-object component of covert orienting of attention since the adults with dyslexia demonstrated slower responses to between-object shifts of attention in the left visual field. Second, and consistent with previous findings with children (Brannan & Williams, 1987; Facoetti & Molteni, 2001), the adults with dyslexia in the present study demonstrated difficulties in engaging stimuli at the periphery. This was clearly demonstrated in the finding that the adults with dyslexia were slower to detect validly-cued targets, regardless of position in the visual field. In addition, these individuals also demonstrated significant difficulties with movement away from the fovea in both visual fields, while a trend for faster orienting toward the fovea was apparent. Shifting attention in an up and down direction at the periphery was also slowed. These findings may indicate that individuals with dyslexia have difficulties with maintaining and shifting attention which occurs in addition to their difficulties demonstrated with engaging attention in the periphery. This is an area requiring further investigation.

Fluent reading requires learned left-to-right and right-to-left shifts of covert attention away from a central fixation point. These shifts need to be maintained long enough for some processing of the written word to occur before overt recognition takes place. Also, since written information is presented to both visual fields, transfer between hemispheres is necessary. Clearly the results of this study have shown differences in the pattern of covert orienting of attention between adults with dyslexia and those without, which could have negative effects on the requirements of reading listed above. Future research is needed to investigate the relative importance of each apparent attentional difficulty to reading ability.

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