*Research Report*

# Attentional Modulation of Visual Processing in Adult Dyslexia

## A Spatial-Cuing Deficit

**Neil W. Roach and John H. Hogben**

*School of Psychology, The University of Western Australia, Crawley, Australia*

ABSTRACT—*A number of researchers have suggested that deficient visual attention may play a causal role in dyslexia. However, traditional methods for investigating this assertion have been limited by the conflation of sensory and attentional factors and the inability to isolate large attentional effects. In this study, we sought to overcome these problems by combining spatial cuing with a visual search task measuring psychophysical thresholds. In normal readers, uncued search performance was characterized by a strong dependence on the number of elements in the stimulus array. Cuing the location of the target removed much of this effect, suggesting attentional facilitation of performance. Although dyslexic participants' performance in uncued search was nearly identical to that of normal readers, all dyslexic participants failed to gain the same effect of cuing that normal readers did. However, dyslexic participants did not differ from normal readers on tests of magnocellular function, suggesting that this spatial-cuing deficit is not merely a secondary consequence of magnocellular dysfunction.*

Dyslexia is an intriguing disability in reading that occurs in the absence of intellectual, physical, or emotional impairment and despite adequate motivation and educational opportunity (Critchley, 1970; Rutter & Yule, 1975). As reading is a complex process, the underlying cause of dyslexia could be a dysfunction of any number of requisite cognitive and perceptual processes. As a result, the range of etiological theory about dyslexia is diverse (for a review, see Snowling, 2000). Although there is widespread agreement that difficulties with phonological processing are central to dyslexia, it has also been suggested that many people with dyslexia have low-level visual deficits, consistent with dysfunction of the magnocellular pathway (e.g., Lovegrove, Martin, & Slaghuis, 1986; Stein & Walsh, 1997). Many psychophysical studies have demonstrated differences between dyslexics and normal readers on putative measures of magnocellular functioning, although very few studies have shown converging evidence from multiple tasks (Evans, Drasdo, & Richards, 1994; Walther-Müller, 1995). Lack of a coherent account of how such a visual deficit would lead to a reading difficulty has caused some researchers to suggest a mediating role of visual attention (Hogben, 1997; Iles, Walsh, & Richardson, 2000; Steinman, Steinman, & Garzia, 1996).

The notion that deficient visual attention might contribute to reading problems in dyslexia is an appealing one. Reading is a visually demanding process, requiring the detailed analysis of a small subset of retinal information. Visual attention is essential for selecting the relevant area of text for further processing. Additionally, a number of researchers have suggested that covert orienting of attention may play an important role in the planning of saccades, the rapid ocular movements made between successive fixations during reading (Henderson, 1992; Inhoff, Pollatsek, Posner, & Rayner, 1989; Kustov & Robinson, 1996). Research into visual attention in dyslexia has primarily focused on two experimental paradigms: visual search and spatial cuing.

In a traditional search task, an observer is asked to locate a target stimulus embedded within a multi-element array of distractor stimuli. Search performance is inferred from the function relating latency of response to set size, the number of items in the array. Traditionally, a shallow function is taken as a sign of parallel processing, whereas a steep function is thought to reflect a limited-capacity, serial process in which attention is directed to each object in turn until the target is located (e.g., Treisman & Gelade, 1980). However, this serial-parallel dichotomy has been challenged by the discovery that set-size effects decrease systematically with practice, are critically dependent on the difficulty of the task, and are confounded with sensory aspects of the task such as retinal eccentricity (Palmer, Ames, & Lindsey, 1993; Verghese & Nakayama, 1994; Wolfe, 1998). In recent years, set-size effects have been successfully modeled using variants of signal detection theory, without any need for assumptions regarding capacity limitations (e.g., Palmer et al., 1993; Verghese, 2001).

Studies comparing visual search in normal and dyslexic readers have produced inconsistent results. Although some researchers have found steeper search functions in dyslexics (e.g., Vidyasagar & Pammer, 1999), others have found shallower functions in dyslexics (e.g., Facoetti, Paganoni, & Lorusso, 2000) or no differences between the groups at all (Casco & Prunetti, 1996; Hayduk, Bruck, & Cavanagh, 1996). A problem with this method is that because the search display is presented for a long period of time until the subject

Address correspondence to Neil Roach, School of Psychology, The University of Western Australia, 35 Stirling Highway, Crawley 6009, Australia; e-mail: nroach@psy.uwa.edu.au.

 Copyright © 2004 American Psychological Society 

responds, shifts in attention are linked to eye movements made by the subject. Interpretation of slow visual search in dyslexics in terms of impaired visual attention is complicated by findings that dyslexics have abnormal eye movements and fixations (e.g., Biscaldi, Gezeck, & Stuhr, 1998). Also problematic are findings of longer response latencies in dyslexic than in normal readers, irrespective of condition (e.g., Iles et al., 2000).

Another popular approach to quantifying visual attention is to use spatial cues to direct the locus of attention. In a traditional cuing paradigm, a target can appear either to the left or to the right of fixation (e.g., Posner, 1980). The cue can either be valid (correctly indicating the target location) or invalid (indicating the location in which the target does not appear). Numerous studies have demonstrated that invalid and valid cuing are associated with costs and benefits, respectively, on reaction time to detect the target (for a review, see Posner, 1988).

There is some evidence to suggest that orienting of attention to peripheral cues is impaired in dyslexia. A number of studies have found that although normal readers exhibit the benefits of valid cuing and costs of invalid cuing, dyslexics show no effect of cue validity for peripheral cues (Brannan & Williams, 1987; Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000). However, systematic differences between the groups tend to be small and are obscured by generally inflated reaction times in the dyslexic group.

In this study, we investigated visual attention in adult dyslexics using spatial cuing in conjunction with a single-fixation search task measuring psychophysical thresholds for orientation discrimination (Baldassi & Burr, 2000). In addition to avoiding the problems often found with using reaction time measures with dyslexic groups, this approach has the advantage of making it possible to control a number of the potential sensory confounds inherent in more traditional methods. As threshold estimation involves manipulating the difference between target and distractors to achieve a set accuracy level, the approach inherently equates stimulus discriminability for all participants. Additionally, using brief displays to limit search to a single fixation removes the problem of eye movements and allows precise control of stimulus eccentricity (Palmer et al., 1993).

## EXPERIMENT 1

Spatial cuing of target stimuli in visual search has been shown to produce large effects on performance in normal observers (Baldassi & Burr, 2000; Palmer et al., 1993). However, data for this task have been reported for a very limited number of observers. To assess the performance of dyslexics, we first needed to know the range of natural variation in the slopes of the search functions in the normal population.

### Method

Thirty-six adults were recruited for the study. All had normal or corrected-to-normal visual acuity and reported no history of reading difficulties. Gabor patches (2-cycle/deg sinusoidal gratings with 50% contrast in a 0.5° Gaussian envelope) were presented for 110 ms in locations 5° from fixation; the target was tilted left or right of vertical, and the distractors were vertical (see Fig. 1). Stimuli were presented on a Sony 20SE monitor (mean luminance = 20 cd/m$^2$) controlled by a Cambridge Research Systems VSG2/3. The task was to discriminate the direction of tilt of the target irrespective of its location, which was random. Threshold tilt for 75% correct identification was estimated by the PEST (parameter estimation by sequential testing) adaptive procedure (Taylor & Creelman, 1967) for set sizes (target plus distractors) of 1, 2, 4, 8, and 16. In half the trials, the stimulus array was immediately preceded by a 30-ms cue that reliably indicated the position of the target stimulus. The cue was a high-contrast black dot presented at 4° eccentricity in the direction of the target patch. For each subject, one threshold measurement was made at each set size under each cuing condition.

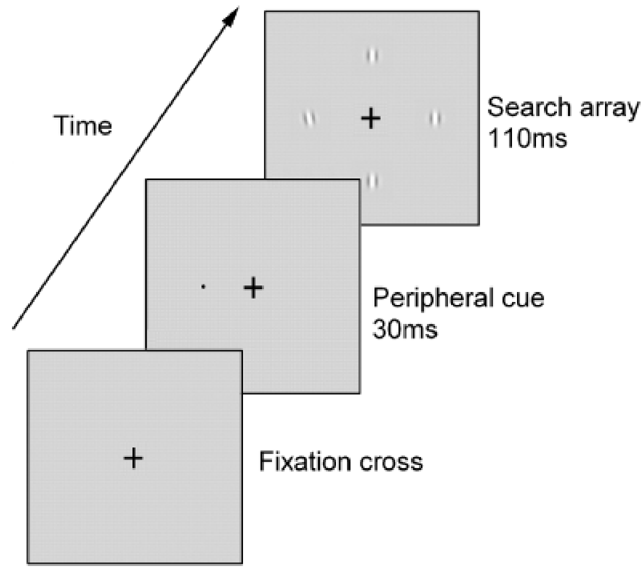


**Fig. 1.** Schematic of the display sequence for a cued trial with a set size of 4. The target is shown at 9 o'clock and is tilted counterclockwise from vertical.

### Results and Discussion

Figure 2 (upper panel) shows that there was little variability across subjects in either the cued or the uncued condition. In each case, the linear fit of log threshold to log set size was good, for individual observers as well as for the group. In the uncued condition, mean orientation threshold increased from 1.5° when there was only 1 Gabor patch to 12.3° when there were 16. Cuing dramatically reduced the cost of searching, as shown by the modest slope of the search function in the cued condition.

Given that the maximum total stimulus duration of 140 ms ensured that participants' eyes did not move from fixation, we can be confident that the retinal image of the stimulus array did not vary between the cued and uncued conditions. Accordingly, there is good reason to believe that the performance benefits of cuing were mediated by selective visual attention.

## EXPERIMENT 2

Spatial cuing of target location in Experiment 1 produced large improvements in performance for normal adult readers, with little variability between individuals. Combined with the control for basic sensory factors inherent in the task, these features of the cuing effect make the task a sensitive tool with which to investigate visual attention in dyslexia.

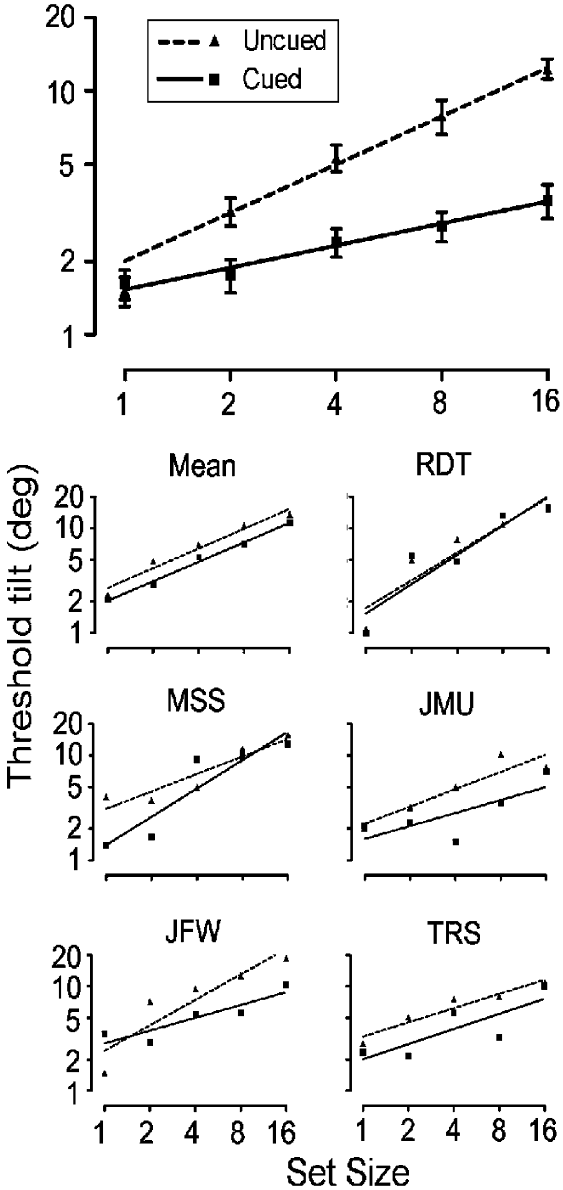


**Fig. 2.** Orientation-discrimination thresholds for the cued and uncued conditions, as a function of set size. The upper panel shows the mean thresholds obtained with normal readers in Experiment 1. Error bars are 95% confidence intervals. Individual and mean thresholds for the 5 adult dyslexics in Experiment 2 are shown below in the six smaller panels. In each graph, best-fitting linear functions relating log threshold to log set size are shown.

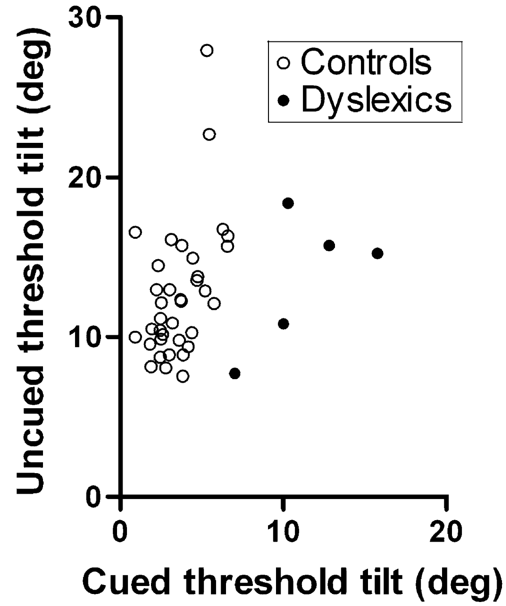


**Fig. 3.** Scatter plot of tilt thresholds in the cued and uncued conditions at set size 16. Results for both control and dyslexic subjects are shown.

### Method

Five adult dyslexics completed the task described in Experiment 1. They were members of a panel maintained for experimental purposes; their diagnosis of dyslexia was confirmed by their poor performance on a speeded nonword reading test (Martin, 1982). All reported lifelong histories of specific reading difficulties.

### Results and Discussion

Results for the psychophysical task are presented in the small panels of Figure 2. Whereas the dyslexics' performance in the uncued condition was in no way different from that of normal readers, all the dyslexic participants failed to gain the advantage of cuing shown by the normal readers. On average, the dyslexics' functions for cued search had the same slope as their functions for uncued search, showing that for them the cost of searching additional items was the same in the cued and uncued conditions.

In normal readers, the difference between orientation thresholds was greatest at a set size of 16. A scatter plot of cued and uncued thresholds at this set size (Fig. 3) shows that the dyslexics performed well within the normal range in the uncued condition, but could be perfectly discriminated from normal readers in the cued condition. This point is underscored by considering the thresholds of the dyslexic subjects as standard ($z$) scores in relation to the distribution of scores of the normal readers (Table 1): Whereas the dyslexics' performance was unremarkable in the uncued condition, the best performance of a dyslexic in the cued condition ($z = 2.38$) would be expected in less than 1% of a population of normal readers; the worst ($z = 8.68$) would be very rare indeed.

## EXPERIMENT 3

It has been suggested that many dyslexic individuals may have an impairment of the magnocellular division of the visual system, possibly as part of a more general deficit in processing by large cells in sensory and motor systems. We therefore considered the possibility that the spatial-cuing deficit evident in our dyslexic subjects was a secondary consequence of a magnocellular deficit. All subjects completed two tasks (flicker contrast sensitivity and global dot motion) to assess their magnocellular systems. We chose these tasks because in the current literature they are the tasks most commonly accepted as reflecting magnocellular functioning.

**TABLE 1**
*Thresholds of the Dyslexic Subjects in Search of an Array of 16 Stimuli, Expressed as Standard (z) Scores in Relation to the Distributions of the Normal Readers*

| | Condition | |
|---|---|---|
| Subject | Uncued | Cued |
| R.D.T. | 0.63 | 8.68 |
| J.F.W. | 1.39 | 4.72 |
| M.S.S. | 0.74 | 6.54 |
| J.M.U. | −1.18 | 2.38 |
| T.R.S. | −0.43 | 4.53 |

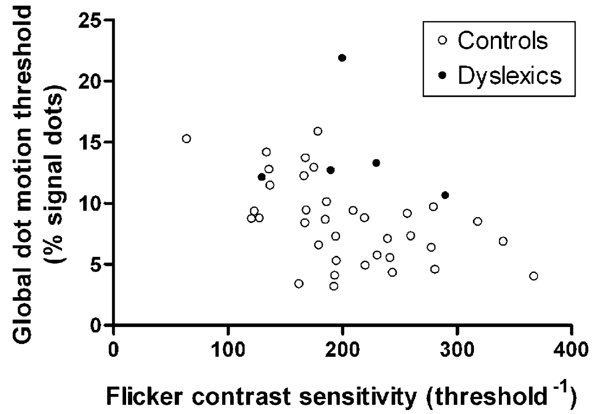


**Fig. 4.** Scatter plot of performance on two tests of magnocellular function (global-dot-motion threshold and flicker contrast sensitivity) among control and dyslexic subjects in Experiment 3.

### Method

Flicker contrast sensitivity was measured using a 1-s Gaussian blob that had a standard deviation of 3.15° and was counterphase flickered at 10 Hz around a mean luminance of 20 cd/m$^2$. This stimulus was centered in the middle of the screen and paired with a nonflickering stimulus of the same mean luminance, in a two-alternative, temporal forced-choice procedure. A PEST procedure was used to estimate the threshold contrast for 75% correct discrimination.

Global-dot-motion thresholds were also estimated with a PEST procedure converging on 75% correct discrimination. Stimuli were 20-frame sequences made up of 100 dots, each subtending 0.11°. Dots were distributed randomly over the screen according to a proximity rule that prevented them from overlapping. Each frame was presented for 30 ms, yielding a total duration of 600 ms for a sequence. A limited-lifetime technique was employed so that the motion signal was carried by an independently chosen set of dots on each transition from one frame to the next. Velocity of the dots was 6.33°/s, and the task of the observer was to indicate the direction (upward or downward) of the global signal.

### Results and Discussion

Although the dyslexic subjects were sharply differentiated from normal readers in the results for cued search, this was not the case for either of the putative magnocellular measures. Figure 4 shows a scatter plot of performance in the two magnocellular tasks for both the normal readers and the dyslexic subjects. Flicker-contrast-sensitivity scores for the dyslexic adults are very similar to those of normal readers, whereas global-dot-motion thresholds for the dyslexic subjects fall toward the higher end of the normal range. Although the correlation between the tasks was a respectable −.52, neither task differentiated between normal readers and dyslexic subjects on an individual level. The apparent failure of attentional facilitation of cued visual search among adult dyslexics cannot be thought of as a secondary consequence of a magnocellular deficit, contrary to previous suggestions.

## GENERAL DISCUSSION

The results of the present study reveal a marked difference in the effect of spatial precuing between dyslexic and normal adult readers. Normal readers' search performance improved considerably when the target location was cued, with very little variability between subjects. However, 5 out of 5 dyslexic adults showed little or no such benefit. A particular strength of this finding is that the dyslexic participants performed as well as the control subjects in the uncued condition. Thus, it is unlikely that the observed difference between the groups reflects difficulties with making orientation judgments, or with any other general task demands. Our results contrast with many previous findings based on reaction time measures, which have shown large discrepancies between dyslexic and control groups irrespective of condition. A further strength of the finding is the degree of separation between normal and dyslexic readers. Although many studies have demonstrated statistically significant differences between groups' mean performance on perceptual tasks, very few studies have been able to discriminate between groups on an individual level.

Given that restricting search to a single fixation effectively equates the basic sensory representation of the stimulus array for cued and uncued conditions, the cuing advantage seen in normal readers most likely reflects the effect of selective visual attention. Accordingly, the absence of a cuing effect in adult dyslexics is consistent with previous suggestions that visual attention is impaired in these individuals (e.g., Facoetti, Paganoni, & Lorusso, 2000; Facoetti, Paganoni, Turatto, et al., 2000; Steinman et al., 1996; Vidyasagar & Pammer, 1999). However, the contention that such impairments result from deficient magnocellular functioning is not supported by the current findings. The magnitude of the observed difference between normal and dyslexic readers, coupled with the advantages of the current method over more traditional paradigms, makes it ideal for future investigation of visual attention in dyslexia.

The finding that 5 out of 5 dyslexics showed a spatial-cuing deficit may appear odd in view of current thinking that dyslexia is a heterogeneous condition, probably encompassing multiple different underlying etiologies. However, all 5 dyslexics in this study were poor at speeded nonword reading, and it remains to be seen whether dyslexics selected on a different basis will show the same deficit. This question may be more readily studied in children, for whom the tests for subtypes of dyslexia are much better established.

*Acknowledgments*—This research was supported by a grant from the Australian Research Council.

## REFERENCES


Baldassi, S., & Burr, D.C. (2000). Feature-based integration of orientation signals in visual search. *Vision Research*, *40*, 1293–1300.

Biscaldi, M., Gezeck, S., & Stuhr, V. (1998). Poor saccadic control correlates with dyslexia. *Neuropsychologia*, *36*, 1189–1202.

Brannan, J.R., & Williams, M.C. (1987). Allocation of visual attention in good and poor readers. *Perception & Psychophysics*, *41*, 23–28.

Casco, C., & Prunetti, E. (1996). Visual search of good and poor readers: Effect with targets having single and combined features. *Perceptual and Motor Skills*, *82*, 1155–1167.

Critchley, M. (1970). *The dyslexic child*. London: Heinemann.

Evans, B.J.W., Drasdo, N., & Richards, I.L. (1994). An investigation of some sensory and refractive visual factors in dyslexia. *Vision Research*, *34*, 1913–1926.

Facoetti, A., Paganoni, P., & Lorusso, M.L. (2000). The spatial distribution of visual attention in developmental dyslexia. *Experimental Brain Research*, *132*, 531–538.

Facoetti, A., Paganoni, P., Turatto, M., Marzola, V., & Mascetti, G.G. (2000). Visual-spatial attention in developmental dyslexia. *Cortex*, *36*, 109–123.

Hayduk, S., Bruck, M., & Cavanagh, P. (1996). Low-level visual processing skills of adults and children with dyslexia. *Cognitive Neuropsychology*, *13*, 975–1015.

Henderson, J.M. (1992). Visual attention and eye movement control during reading and scene perception. In K. Rayner (Ed.), *Eye movements and visual cognition* (pp. 260–283). New York: Springer-Verlag.

Hogben, J.H. (1997). How does a visual transient deficit affect reading? In C. Hulme & M.J. Snowling (Eds.), *Dyslexia: Biology, cognition and intervention* (pp. 59–71). London: Whurr.

Iles, J., Walsh, V., & Richardson, A. (2000). Visual search performance in dyslexia. *Dyslexia*, *6*, 163–177.

Inhoff, A.W., Pollatsek, A., Posner, M.I., & Rayner, K. (1989). Covert attention and eye movements during reading. *Quarterly Journal of Experimental Psychology*, *41*, 63–89.

Kustov, A.A., & Robinson, D.L. (1996). Shared neural control of attentional shifts and eye movements. *Nature*, *384*, 74–77.

Lovegrove, W., Martin, F., & Slaghuis, W. (1986). A theoretical and experimental case for a visual deficit in specific reading disability. *Cognitive Neuropsychology*, *3*, 225–267.

Martin, F. (1982). *A test of orthographically legal non-words*. Unpublished manuscript, University of Tasmania, Hobart.

Palmer, J., Ames, C.T., & Lindsey, D.T. (1993). Measuring the effect of attention on simple visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *19*, 108–130.

Posner, M.I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25.

Posner, M.I. (1988). Structures and functions of selective attention. In T. Ball & B.K. Bryant (Eds.), *Clinical neuropsychology and brain function: Research, measurement, and practice* (Master Lecture Series Vol. 7, pp. 173–202). Washington, DC: American Psychological Association.

Rutter, M., & Yule, W. (1975). The concept of specific reading retardation. *Journal of Child Psychology and Psychiatry*, *16*, 181–197.

Snowling, M.J. (2000). *Dyslexia* (2nd ed.). Oxford, England: Blackwell.

Stein, J., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia. *Trends in Neurosciences*, *20*, 147–152.

Steinman, B.A., Steinman, S.B., & Garzia, R.P. (1996). Reading with an M neuron: How a defective magnocellular pathway interferes with normal reading. In R.P. Garzia (Ed.), *Vision and reading* (pp. 209–228). London: Mosby.

Taylor, M.M., & Creelman, C.D. (1967). PEST: Efficient estimates on probability functions. *Journal of the Acoustical Society of America*, *41*, 782–787.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*, 97–136.

Verghese, P. (2001). Visual search and attention: A signal detection theory approach. *Neuron*, *31*, 523–535.

Verghese, P., & Nakayama, K. (1994). Stimulus discriminability in visual search. *Vision Research*, *34*, 2453–2467.

Vidyasagar, T.R., & Pammer, K. (1999). Impaired visual search in dyslexia relates to the role of the magnocellular pathway in attention. *NeuroReport*, *10*, 1–5.

Walther-Müller, P.V. (1995). Is there a deficit of early vision in dyslexia? *Perception*, *24*, 919–936.

Wolfe, J.M. (1998). Visual search. In H. Pashler (Ed.), *Attention* (pp. 13–73). London: Psychology Press.


(Received 8/8/03; Revision accepted 9/23/03)