# Are dyslexics' visual deficits limited to measures of dorsal stream function?

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We tested the hypothesis that the differences in performance between developmental dyslexics and controls on visual tasks are specific for the detection of dynamic stimuli. We found that dyslexics were less sensitive than controls to coherent motion in dynamic random dot displays. However, their sensitivity to control measures of static visual form coherence was not significantly different from that of controls. This dissociation of dyslexics' performance on measures that are suggested to tap the sensitivity of different extrastriate visual areas provides evidence for an impairment specific to the detection of dynamic properties of global stimuli, perhaps resulting from selective deficits in dorsal stream functions. *NeuroReport* 12:1527–1530 © 2001 Lippincott Williams & Wilkins.

**Key words**: Coherent form; Coherent motion; Developmental dyslexia; Dorsal; Ventral stream

## INTRODUCTION

Developmental reading disabilities have long been prominently associated with failures in processing the phonological and orthographic information in text (see [1] for review). More recently, however, there has been evidence linking these disabilities with more basic impairments in the detection of dynamic auditory and visual stimuli (see [2] for review). These deficits often contrast with dyslexics' relatively unimpaired detection thresholds for more static stimuli (see [3,4] for review; cf. [5]). Such selective deficits have been argued to result from impaired sensitivity of the extrastriate visual dorsal stream, including the magnocellular retinocortical pathway (see [6] for review).

It is well known that visual information is processed in parallel by neural pathways segregated from retina to primary visual cortex, and that these streams project mainly to separate areas in extrastriate visual cortex (see [7,8] for review). Although there is significant anatomical linking between them, especially in higher visual areas beyond primary visual cortex [7], the ventral stream projecting to areas in temporal cortex and the dorsal stream projecting to structures in parietal areas mediate different types of visual function [8]. Dorsal stream structures generally impart information about the spatial properties of objects and about their motion, processes that aid the localization of objects. Ventral stream structures are involved more in providing information about the surface properties of objects such as their shape and colour, serving object recognition processes [8].

Within the primate dorsal stream, cells in the middle temporal visual area (V5/MT) are extremely sensitive to global coherent motion [9], whereas many cells within area V4 in the ventral stream are sensitive to the global coherence of complex visual patterns [10]. In humans, psychophysical detection thresholds for dynamic motion and for static form stimuli are known to be statistically independent, both in normal development and in some clinical populations [11,12]. Such experimental evidence supports the idea that these stimuli are tapping into the different individual sensitivities of the two main extrastriate visual pathways.

In this study we used both global coherent motion and global coherent form stimuli to investigate the visual task differences reported in developmental dyslexia, where there already exists evidence of impaired detection of motion stimuli [13,14]. However, the conclusion that the extrastriate dorsal stream is impaired selectively in many dyslexics has been based primarily on studies that did not explicitly control for ventral stream sensitivity. Here, therefore, we compared dyslexics and controls on a measure of coherent motion detection and on two variants of a coherent form detection task [11,15]. The results, on these psychophysical measures that had identical task demands, confirmed that thresholds for measures of putative dorsal and ventral stream sensitivity are statistically independent [11,12]. Dyslexics were significantly less sensitive than controls on the measure of coherent motion detection but not significantly different than controls on the coherent form detection measures.

## MATERIALS AND METHODS

Fifteen adults with a history of developmental dyslexia and 34 similarly aged controls were tested. Subject selection was based on availability; no other selection criteria were applied. All of the dyslexic subjects had prior diagnoses of specific reading disability, most within the

previous 3 years. The literacy skills of both groups were measured near the time of testing with standardized assessments of single word reading and spelling achievement [16], and additional tests of phonological and orthographic skill [1]. We also obtained standardized measures of verbal (similarities and vocabulary) and non-verbal (block design and picture arrangement) cognitive skills [17] for all the poor readers and for a subset ($n = 16$) of the control group. Age-adjusted t-scores on these measures were summed to form composite verbal and performance scores. Data for all the psychometric tests are shown in Table 1. Many of those in the experimental group showed the pattern typical of partially remediated adult dyslexia: compensated single word reading accuracy with persistent difficulties in phonological and orthographic processing, including spelling [18]. Systematic differences were evident between groups on these measures of literacy skill but not on the composite measure of non-verbal intelligence.

The visual processing tasks comprised: (a) a measure of global motion processing using a dynamic random dot kinematogram (MOT), (b) a measure of static global pattern processing where the position of the target was randomized (FORM-R) and (c) a measure of static global pattern processing in which the target position was fixed (FORM-F). Each of these measures required the detection of a global visual signal embedded in noise. This global signal was defined in terms of its coherence, the ratio of stimulus elements in the target signal to the remaining noise elements (see Fig. 1).

Psychophysical thresholds for detecting global coherent motion and global coherent form were measured using the same spatial two-alternative, forced-choice procedure. Subjects were instructed to inspect the stimulus panels (see below) and determine which one contained the coherent signal, guessing when necessary. Signal coherence was adjusted by computer software on a trial by trial basis using a weighted one-up, one-down, adaptive staircase technique [19]. For each correct response this procedure reduces the coherence of the target stimulus by 1 dB (a factor of 1.122). For each incorrect response the proportion of signal elements was increased by 3 dB (a factor of 1.412). The staircase procedure was terminated after 10 reversals

**Table 1.** Descriptive statistics on the psychometric tests (Values are mean ± s.d.).

| Measure (unit) | Controls ($n = 16$) | Dyslexics ($n = 15$) | t-test |
|---|---|---|---|
| Age (years) | 24.0 ± 4.5 | 28.9 ± 7.9 | N.S. |
| Verbal (Sum SS) | 25.8 ± 2.9 | 21.6 ± 5.2 | * |
| Performance (Sum SS) | 28.4 ± 2.6 | 24.6 ± 6.3 | N.S. |
| Reading (SS) | 118.4 ± 5.5 | 91.9 ± 17.9 | *** |
| Spelling (SS) | 115.3 ± 7.0 | 82.6 ± 14.1 | *** |
| Non-word naming (% correct) | 92.7 ± 0.03 | 68.7 ± 0.17 | *** |
| Non-word naming time (s) | 43.9 ± 8.5 | 139.2 ± 108.7 | * |
| Orthographic choice (% correct) | 97.8 ± 0.01 | 88.9 ± 0.06 | *** |
| Othographic choice mean reaction time (s) | 0.84 ± 0.16 | 1.49 ± 0.30 | *** |

N.S. group difference not significant by t-test (with degrees of freedom corrected for inhomogeneous variance when necessary).
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. SS = standard score. For verbal and performance measures SS mean = 10 and s.d. = 3; for reading and spelling measures SS mean = 100 and s.d. = 15.
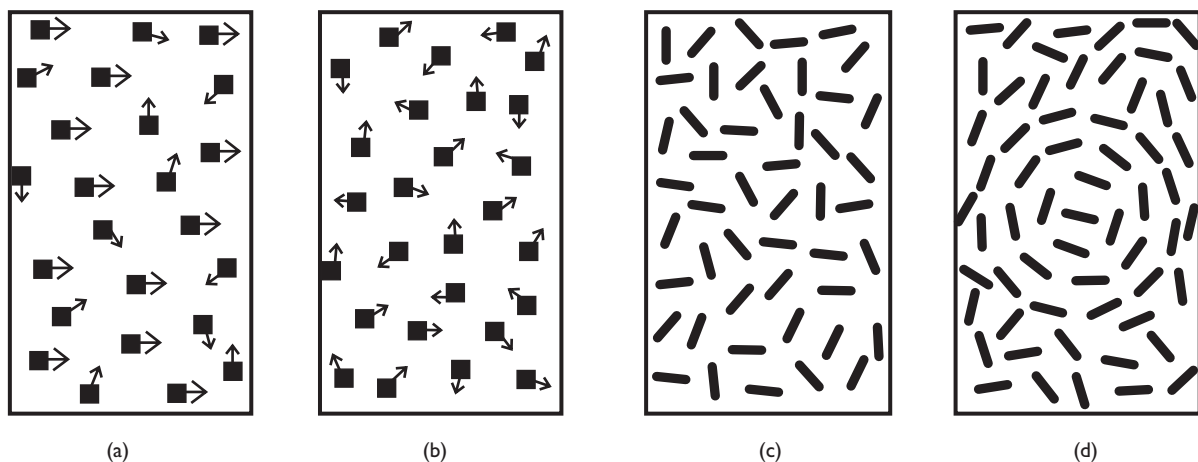


| (a) | (b) | (c) | (d) |

**Fig. 1.** Schematic diagrams of the coherent motion (**a,b**) and coherent form (**c,d**) stimuli (not drawn to scale). For the motion task, arrows represent the vector motion of each dot during a given frame. (a) depicts 50% coherent motion where half the dots (large arrows) are moving together in horizontal motion. Noise dots move in random directions. The non-target RDK patch (b) has an average coherence value close to 0%. (c) and (d) depict the coherent form task. The target panel (d) contains a coherent circle delineated by line segments oriented in 100% coherence. Noise stimuli are line segments with random orientations. The position of the target circle was either fixed in the center of the patch or varied in the two versions of the test. See text for further details.

and the detection threshold was defined as the geometric mean of the final eight reversals. Two estimates of threshold were obtained for each stimulus type, the mean of which comprised the threshold estimate.

The RDK motion stimuli were similar to those used previously [20]. Two patches of 300 high luminance ($130 \, cd/m^2$) white dots (1 pixel) were presented on the black background of a computer monitor. One patch contained a variable percentage of target dots that moved coherently in the same direction (either leftwards or rightwards) over successive screen refreshes and reversed direction every 572 ms. The remaining noise dots moved with the same speed but with a randomly changing direction between screen refreshes in a Brownian manner. The second patch contained only noise dots. The patch containing the coherently moving dots was selected at random by the stimulus program. In order to eliminate the possibility of tracking the trajectory of a single dot, each element in the RDK had a fixed lifetime of three animation frames (85 ms) after which it would disappear before being regenerated at a random place within the same stimulus patch. Percentage of coherent motion was corrected for this finite dot lifetime. When all the dots in the target patch were moving coherently, and dots had a lifetime of three frames, this is equivalent to 66.7% coherence. The percentage of target dots (angular velocity 7.0°/s) within a given software animation frame (28.6 ms) was varied to the detection threshold starting from an initial value of 66.7% coherence.

Binocular viewing of the patches was conducted in a darkened room. At a viewing distance of 57 cm, each patch subtended $10 \times 14°$ of visual angle separated horizontally by 5°. The subjects were asked to inspect each stimulus patch during the 2.3 s stimulus interval and detect which patch contained the coherent motion. Threshold was defined as the smallest proportion of coherently moving target dots required for detecting coherent motion.

The two control measures of global form coherence were similar in application and design to the coherent motion task. Both required the detection of a coherent form signal, defined by line segments that were oriented in tangent to imaginary concentric circles within an area 8° in diameter. Noise stimuli were line segments that were oriented randomly. The second patch contained only noise elements. The form stimuli comprised two patches of 600 high luminance line segments, each 0.4° in length. The size of the patches and luminance of the line segments were matched to the values used in the motion task. The percentage of coherently oriented line segments was determined algorithmically and varied to the subject's detection threshold. For these tasks, detection threshold was defined as the proportion of coherently oriented line segments necessary to detect the circle target. The order of all the visual tests was counterbalanced across subjects.

In the form-fixed task (FORM-F) the target could only appear in the center of either the left or right patch. In the form-randomized task (FORM-R), the position of target pattern within either patch was assigned randomly, with the additional constraint that the entire target circle remained within the confines of the patch. Detection of the target in the FORM-R task thus required visual search over both panels, rather than monitoring a limited area within either patch. These increased task demands required that

the stimulus duration was unlimited compared to the 2.3 s allocated to each trial of the motion task. This was unlikely to have significantly effected the results reported here however, since the performance of both dyslexics and controls on tasks of motion detection asymptotes at stimulus durations of around 1 s [14]. It should be noted that coherent motion detection is limited more by the dot lifetime than by the overall duration of the display [21], suggesting reliance on a time-independent parallel process, rather than a time-dependent serial process [22].

## RESULTS

As demonstrated previously [11], subjects' thresholds for the coherent motion and FORM-F tasks were not correlated (Spearman r ($r_s$) = −0.04, n.s.). However, sensitivity on the FORM-R and motion tasks was moderately, yet significantly, related ($r_s = 0.33$, $p < 0.05$). This relatively stronger correlation may have resulted from the requirement for additional visual search in the FORM-R task. FORM-R and FORM-F thresholds were also correlated ($r_s = 0.29$, $p < 0.05$), although thresholds for FORM-R were systematically higher than for the FORM-F task (Wilcoxon signed-ranks: z = 3.30, $p < 0.001$).

Group performance on each of the tasks is shown in Fig. 2. Non-parametric tests (Mann-Whitney U) showed that the dyslexic group was less sensitive to coherent motion (U = 119, $p = 0.002$), whereas their thresholds to coherent form did not differ significantly from controls for either task (FORM-R, $p = 0.09$; FORM-F, $p = 0.55$). This pattern of result did not vary when the control group was restricted to those individuals for whom we had complete psychometric data (MOT, $p < 0.01$; FORM-R, $p = 0.21$; FORM-F, $p = 0.81$) nor were there any significant differences between the two groups of controls on any of the visual measures (MOT, $p = 0.21$; FORM-R, $p = 0.53$; FORM-F, $p = 0.74$).

## DISCUSSION

Consistent with previous results, we found that a group of dyslexic adults were significantly less sensitive than controls to coherent motion in random dot displays [13,14]. However, the same subject group was not significantly impaired, relative to the controls, on either of two control measures of coherent form detection. The trend toward dyslexics having decreased sensitivity on the FORM-R task, in which the position of the static target was randomised, may have resulted from the additional visual search component demanded in this task. Namely, a series of eye movements between candidate target areas was necessary for locating the variable target position. Such eye movements may have elicited additional dorsal stream processing that was not evoked in the FORM-F task where the target position was more predictable. Dorsal stream areas are important for the generation and control of eye movements toward targets during visual search and such mechanisms have been suggested to be deficient in many developmental dyslexics [6,23,24].

We also confirmed previous reports that detection thresholds for coherent form and coherent motion determined psychophysically can be independent statistically [11,12]. However, we found that the FORM-R task and the motion task were moderately, yet significantly, correlated, whereas no such relationship was found between the
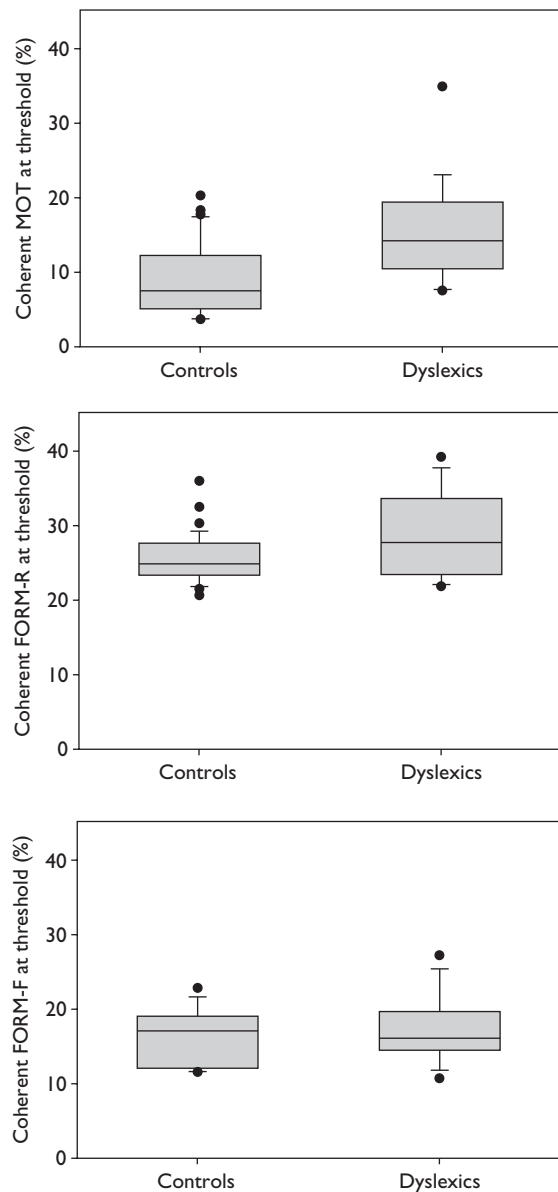
**Fig. 2.** Box plots showing the groups' performance on the visual measures. Top Panel, MOT; Middle Panel, FORM-R; Bottom Panel, FORM-F. Horizontal lines within boxes represent the group medians. Box edges define the first and third quartiles, whisker edges define the 10th and 90th centiles. Solid circles define outlying threshold values.

motion task and the FORM-F task. This supports the hypothesis that the randomised position variant of the form task (FORM-R) introduced additional processing by the visual dorsal stream.

The activations of visual areas when detecting global form have recently been compared with those when detect-

ing motion coherence using fMRI [15]. Although the patterns of activation elicited by form and motion did not overlap in spatial extent, the foci of activations indicated a more tightly integrated network of the visual areas that support object localization and recognition than had been suggested previously [8,15]. The finding that it is object localization rather than recognition processes that are impaired selectively in developmental disorders such as Williams syndrome [11], autism [12], and now dyslexia, suggests that the dorsal stream is particularly susceptible to genetic and/or adverse developmental influences.

## CONCLUSION

A dissociation was found between dyslexics' and controls' sensitivity on two types of global visual processing. Dyslexics were less sensitive than controls to coherent visual motion, whereas their thresholds for two variants of a coherent form detection task were not different by comparison. Dyslexics' visual task deficits therefore may be restricted to the domain of dynamic stimulus detection, of which coherent motion detection measures provide a good index.

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