



# Effects of a Red Background on Magnocellular Functioning in Average and Specifically Disabled Readers

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Two experiments were conducted using metacontrast masking to examine responses in the magno system of adults, average reading adolescents and adolescents with specific reading disability. In Experiment 1 the effects of a red background field on the metacontrast functions of adult subjects were investigated. Results showed that a red, compared to a photometrically matched white background field, significantly attenuated metacontrast magnitude, supporting the interpretation of metacontrast as due to magno system suppression of parvo system responses. The finding of a red background effect was replicated in Experiment 2 with the two adolescent groups. The metacontrast functions of the adolescent groups also differed significantly, with those with specific reading disability exhibiting weaker metacontrast than the average readers. This result is consistent with a deficit in the magno system of individuals with specific reading disability and indicates the continuation of the deficit beyond childhood.

Dyslexia   Adolescents   Magnocellular system   Transient channel   Metacontrast masking

## INTRODUCTION

Specific reading disability (SRD) or dyslexia is defined as a severe and persistent difficulty in learning to read in the absence of intellectual, physical or emotional impairment (Critchley, 1970). Despite extensive research over many years, the causes of this condition are not yet established. Two popular etiological views have been visual and verbal deficit theories which have rivalled one another for the last 20 yr. Visual deficit explanations were popular until the 1970s when inconsistent research findings, a lack of understanding of how visual processing deficits were related to the difficulties experienced by individuals with SRD, and an increase in the number of studies identifying language, rather than visual, deficits as the cause of SRD, led to their decline (Benton, 1980; Prior, 1989; Vellutino, 1977; Vellutino, Steger & Kandel, 1972; see also Lovegrove, Garzia & Nicholson, 1990; and Lovegrove, Martin & Slaghuis, 1986). Since this time, language-based theories have prevailed.

More recently however, new insights into the visual processing characteristics of individuals with SRD have

been gained through studies conducted within the sustained and transient channel model of visual processing. These studies have addressed many of the objections to earlier visual deficit theories (see Lovegrove *et al.*, 1986) and have delineated both the types of visual difficulties experienced by those with SRD and the effects of these difficulties on their reading performance. Moreover, several recent studies have shown that many people with SRD are characterized by both visual and verbal processing problems (Eden, Stein & Wood, 1993; Eden, Stein, Wood & Wood, 1993; Lovegrove *et al.*, 1986; Lovegrove, Pepper, Martin, Mackenzie & McNicol, 1989; Slaghuis, Lovegrove & Davidson, 1993; Slaghuis & Pinkus, 1993). Visual processing problems in the transient subdivision of the visual system of subjects with SRD are the focus of this paper.

### *Transient/magno and sustained/parvo channels in vision*

Current conceptualizations of the human visual system are based on the notion of dual system processing. The visual system consists of at least two functionally independent yet interactive subsystems which travel in parallel from retina to cortex (Shapley, 1990). This dualism of function is supported by extensive psychophysical and physiological evidence, although the systems identified by these different approaches have been labelled in different ways.

Psychophysical research on human vision has led to a distinction between transient and sustained channels

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which respond selectively to the spatial and temporal properties of visual stimuli (Breitmeyer, 1980, 1983; Breitmeyer & Ganz, 1976; Kulikowski & Tolhurst, 1973). The transient channel responds to low to medium spatial frequency stimulation and has high temporal resolution. This system responds to the onset and offset of a stimulus and its responses are both rapid and brief. The sustained channel, on the other hand, has high spatial resolution and is specialized for analysing detailed pattern information in slow moving or motionless stimuli. Sustained channel responses are slower but more enduring than responses from the transient channel. Mutual inhibition between the channels has been reported with the most common process being transient inhibition of sustained activity (Breitmeyer, 1978; Breitmeyer & Ganz, 1976). Detailed reviews of the channels are provided by Breitmeyer and Ganz (1976) and Lovegrove *et al.* (1986).

A similar distinction has been drawn from physiological and anatomical investigations of the primate visual system. In primate vision separate channels specializing in the perception of form, colour, movement and depth have been identified (Livingstone & Hubel, 1987). These channels, referred to as magno- and parvo-cellular systems, correspond closely to the psychophysically derived transient and sustained channels, respectively. Like transient channel responses, magno responses are rapid and brief. The magno system is spectrally broad band, is sensitive to contrast, and has low spatial resolution. Parvo responses are more sustained-like; they are slow and enduring, have low contrast sensitivity and high spatial resolution, and are colour selective (Livingstone & Hubel, 1987).

With increasing recognition of the correspondence between the transient-sustained and magno-parvo distinctions there has been a shift towards reformulating the transient-sustained dichotomy within the magno-parvo framework (Breitmeyer, 1989, 1991, 1992; Breitmeyer & Williams, 1990; Grosser & Spafford, 1992; Livingstone, Rosen, Drislane & Galaburda, 1991; Williams & Lovegrove, 1992). Therefore, although most recent work concerning the relationship between visual processing and SRD has been based on the psychophysically derived transient-sustained distinction, for the remainder of this paper the terms magno and parvo will be used whenever these channels are referred to\*.

#### *Magno system function in SRD*

The process of the magno system inhibiting the parvo system (formerly discussed as transient inhibition of sustained activity) is thought to play a major role in the reading process. It is posited that this inhibitory mechanism underlies saccadic suppression, which in

reading facilitates the clear perception of information contained in successive visual fixations (Breitmeyer & Ganz, 1976). Based on this view, it has been proposed that SRD may result from a deficit in magno activity, leading to ineffective magno inhibition of parvo responding, and thus allowing the parvo system analysis of the information contained in one fixation to continue into the succeeding fixation. This would result in an overlaying of successive percepts, producing visual clutter and confusion (Slaghuis & Lovegrove, 1984).

A number of visual processing anomalies consistent with a magno system deficit have been identified in individuals with SRD. For example, Lovegrove and colleagues have found that under low spatial frequency conditions where the magno system is most responsive, subjects with SRD have longer visible persistence and are less sensitive to contrast than average readers (Badcock & Lovegrove, 1981; Lovegrove *et al.*, 1980, 1982; Slaghuis & Lovegrove, 1985). In addition, these between group differences have been found to diminish when uniform field flicker masking is used to reduce magno activity (Slaghuis & Lovegrove, 1984), and lower sensitivity to flickering gratings has also been reported in subjects with SRD (Martin & Lovegrove, 1987). Consistent with these findings Williams and others (see Williams & LeCluyse, 1990) have found that subjects classified as disabled readers perform poorly on perceptual tasks which involve accurate temporal processing of visual information. These researchers have shown that compared to normal readers, disabled readers show stronger perceptual grouping effects, take longer to make accurate temporal order judgements, have slower search times and show prolonged masking by light, which taken together suggest slow or sluggish magno responding in individuals with impaired reading skills.

Recent physiological and anatomical research has also revealed irregularities in the visual functioning of subjects with SRD which are consistent with a magno system deficit. For example, when measured under similar experimental conditions to those employed in psychophysical research, lower amplitude (Livingstone *et al.*, 1991) and longer latency (Lehmkühle, Garzia, Turner, Hash & Baro, 1993) visual evoked potentials have been recorded for subjects with SRD in comparison to controls, and smaller and more disorganized magno-cellular neurons have been found in the lateral geniculate nuclei of adult dyslexic brains (Livingstone *et al.*, 1991).

Estimates have indicated that as many as 75% of children with SRD have poor magno functioning (Lovegrove *et al.*, 1986). However, the precise nature of this impairment has not yet been resolved. For example, it is not known whether responding in the magno system is slow and/or weak in these children and nor has the severity or duration of the impairment been determined. How this visual processing deficit relates to the high incidence of verbal / linguistic processing deficits found in children with SRD also remains unexplained at present.

\* There have been some problems in attempts to define psychophysically the properties of the transient and sustained channels and in relating these channels to the magno and parvo streams. For a comprehensive review of these issues see Breitmeyer (1992).

### *Metacontrast masking as a measure of magno system function*

Metacontrast is a form of backward visual masking in which the visibility of a briefly presented target stimulus is suppressed when followed soon after by a flanking or surrounding mask (Alpern, 1953). The magnitude of masking varies as a function of the stimulus-onset-asynchrony (SOA) between the target and mask. Maximum masking occurs at intermediate SOAs with less masking at longer and shorter intervals, resulting in a U-shaped function.

One current model of metacontrast attributes the masking function to the effects of magno system suppression of parvo system responses (Breitmeyer & Ganz, 1976). According to this model, both the target and mask elicit a short latency magno system response followed by a longer lasting parvo system response. Suppression of the target's visibility occurs when the rapid magno system response to the mask is temporally superimposed on the slower parvo system response to the target, resulting in magno system inhibition of responding in the parvo system. At long and short SOAs mask-elicited magno system responses do not coincide temporally with target-elicited parvo system responses and hence less masking is observed. In monkey visual cortex the parvo system takes at least 50 msec longer than the magno system to respond to a stimulus (Dow, 1974). Similar timing of responses in human vision results in maximum metacontrast at target-mask delays of around 50–100 msec (Breitmeyer & Ganz, 1976).

Metacontrast provides an alternative paradigm for investigating the magno system characteristics of people with SRD. As the metacontrast function reflects the effects of magno system inhibition of parvo system responses, it provides a near optimal measure of magno activity. Also, the question of whether individuals with SRD have weak or slow magno responses can be addressed within this paradigm because both the strength and speed of magno responses are reflected in the major components of the masking function.

The strength of magno system inhibition of parvo system responding is reflected in the magnitude of metacontrast masking (Breitmeyer & Williams, 1990; Williams, Molinet & LeCluyse, 1989). Strong masking effects (a deep masking function) reflect powerful magno system responses and conversely weak masking effects (a shallow masking function) denote weaker magno system responses. Any differences between subjects with SRD and average readers in the strength of their magno system activity should therefore be manifest as differences in their extent of masking.

The speed of magno system responses is indicated by the SOA at which maximum masking occurs (Williams *et al.*, 1989). Maximum masking at long SOAs signifies rapid magno system processing. This is because at longer intervals only rapid mask-elicited magno system responses will coincide temporally with target-elicited parvo system responses and hence be able to inhibit the parvo system analysis of the target. A slower responding

magno system will be ineffective at long SOAs and will therefore yield maximum masking effects at shorter intervals.

An advantage of testing subjects with SRD on a metacontrast task is that individuals with impaired magno functioning are expected to have a high level of performance, i.e., weak masking. This is important considering the probable history of failure experienced by children with SRD in testing situations which have examined reading related skills (Hogben, Rodino, Clark & Pratt, 1995). It has also been suggested that when using psychophysical measures to test children with SRD and their average reading peers, the most effective way of reducing bias from differences in factors such as motivation, attention and cognitive load is to use a forced choice task on which the children with SRD obtain higher correct scores (Mueller, 1993).

Several studies have been conducted by Williams and colleagues (e.g. Williams & LeCluyse, 1990; Williams *et al.*, 1989) using metacontrast to examine the timing of magno system responses in disabled and normal readers. Results have shown that with both line and word stimuli, maximum masking occurs at shorter target-mask intervals for reading disabled children than for normal reading children and adults, suggesting slower magno system responding in this group. The size of the masking effects for the different groups was considered only briefly in these studies. It was reported that disabled readers showed an absence of masking in peripheral vision, and that when word stimuli were used, they experienced less masking than normal readers at the point of maximum masking.

Recently the effects of colour on magno and parvo system functioning have been investigated within a metacontrast paradigm. For example, Breitmeyer and Williams (1990) investigated the effects of white, green and red isoluminant background fields on metacontrast masking. In this experiment three adult subjects were tested using a subjective magnitude estimation technique. Results showed that ratings of metacontrast were decreased in the presence of red, as compared to white or green backgrounds, which led to the conclusion that a red background attenuates magno system activity. This finding is consistent with the physiological properties of the magnocellular pathway, which despite being predominantly broad band, has many neurons that are tonically suppressed by diffuse red light (Dreher, Fukada & Rodieck, 1976; Kruger, 1977; Livingstone & Hubel, 1987; Shapley, 1990; Wiesel & Hubel, 1966). In the present study it was hypothesized that if subjects with SRD already have weakened magno system responses, a red background should attenuate magno functioning less in this group than in a group of average readers.

### *Aims of the present research*

In the present study, metacontrast functions were obtained for adults, average reading adolescents and adolescents with SRD, using homogeneous white and red background fields. The purpose of Experiment 1 was to

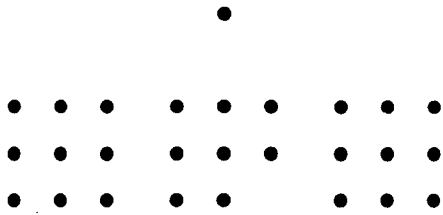


FIGURE 1. Schematic representation of a metacontrast display. On each experimental trial the centre (target) matrix and the flanking (mask) matrices were shown either above or below the fixation point, at random.

ensure that the original findings of Breitmeyer and Williams (1990) could be replicated in our laboratory using adult subjects. Experiment 2 was designed to compare magno responding in adolescents with SRD and average reading adolescents, and to compare the effects of a red background on magno responding in these two groups.

### EXPERIMENT 1: ADULT STUDY

Experiment 1 was a partial replication and extension of the study by Breitmeyer and Williams (1990). It employed a larger group of naive adult subjects and an objective performance measure, rather than the few observers making subjective magnitude judgements as in the previous study. Based on the earlier findings, weaker metacontrast was expected in the red compared to the white background condition.

#### Method

**Subjects.** Fourteen adults, 10 females and 4 males, participated in the study. All subjects had normal or corrected-to-normal visual acuity and normal colour vision. Subjects had no previous experience at performing psychophysical tasks.

**Stimuli and apparatus.** The target stimulus consisted of a  $3 \times 3$  matrix of dots with one randomly selected dot omitted from the display on each trial. Two complete  $3 \times 3$  dot matrices acted as the mask. The masking matrices spatially flanked the target array (see Fig. 1).

Stimuli were presented on a Tektronix 608 oscilloscope with fast decay P15 phosphor. The oscilloscope was driven by a 1 MHz point-plotting buffer (Finley, 1985). Each dot in both the target and the mask subtended 0.09 deg of visual angle, and the centre-to-centre horizontal and vertical separation between adjacent dots was 0.14 deg of visual angle. The target and mask displays were separated by 0.25 deg of visual angle.

On each experimental trial both the target and the mask were presented either above or below a central fixation point. The middle dot in the target matrix was always directly aligned with the fixation point, and was separated from it by 0.86 deg of visual angle. Viewing was binocular and was set at a distance of 36 cm, maintained by a head rest.

The target and masking stimuli were set at equal

luminance so that all matrices appeared of uniform brightness. Dot luminance was measured using a calibration technique similar to that described by Di Lollo (1979). A continuously displayed patch of  $30 \times 30$  dots had a luminance of  $294 \text{ cd/m}^2$ . Luminance was measured using a Spectra Spotmeter with a 1.0 deg luminance probe.

The stimuli were presented on homogeneous white and red background fields of 12.7 deg of visual angle, reflected by a half-silvered mirror. Neutral density filters were used to produce the white background and a red filter (Lee Filters: Primary Red) with cutoff  $< 580 \text{ nm}$  was used to produce the red background. The luminance of the background fields was set at  $3.0 \text{ cd/m}^2$  using a Spectra Spotmeter placed at the subject's viewing position. Breitmeyer and Williams (1990) obtained the same results whether they used photometrically matched background fields or fields matched for isoluminance by a flicker technique. Since it is important to minimize the duration of experimental procedures for younger subjects (and for subjects with SRD in particular), the photometric matching technique was employed in the present experiments.

Target and mask displays were each of 20 msec duration and six SOAs (0, 30, 60, 90, 120, 150 msec) were employed. Stimulus generation and presentation were controlled by an IBM PC/AT compatible computer and a joystick was used to initiate stimulus presentations and to make responses. Testing was conducted in a dark, sound-reduced cubicle.

**Procedure.** The task used in the study was based upon a technique developed by Hogben and Di Lollo (1984). Each experimental trial consisted of a brief sequential presentation of the target and mask stimuli. The SOA separating the target from the mask was varied across trials and the goal of the subject was to identify the location of the dot omitted from the target display.

In anticipation of using the task with younger subjects, it was made to appear as much like a game as possible. After viewing the stimulus display, the subject used the joystick to move a cursor on the screen onto one dot of a large, continuously displayed  $3 \times 3$  matrix, to indicate the dot that was missing from the target display. The subject then squeezed the joystick trigger to "shoot" the dot and if the response was correct, feedback was provided in the form of an on-screen animation of an explosion accompanied by computer-generated sound effects heard through a speaker. If the response was incorrect, there was no visual display and a short, low-frequency sound was presented.

The experiment began with a training/adaptation phase comprising 20-trial blocks of presentations of the target alone. This phase continued until 90% accuracy was attained, which took no more than two blocks (40 trials) for any subject. The training phase was followed by a practice phase consisting of 60 trials with the target accompanied by the mask (10 trials at each of the six SOAs). Subjects then completed the experimental trials which were presented in four blocks. Within each block

18 trials were run at each SOA, in random order. This resulted in each subject completing 432 trials in total.

The white background was used for all training and practice trials. In the experimental trials the order of background colour was partially counterbalanced between subjects to control for sequence effects (Winer, 1962). Two background order combinations (white, red, red, white; and red, white, white, red) were employed. Half of the subjects were administered the first order of colour presentations (WRRW) and the remaining half were exposed to the alternative combination (RWWR).

*Design.* The study used a 2 (background colour: white, red)  $\times$  6 (SOA: 0, 30, 60, 90, 120, 150)  $\times$  2 (order: WRRW, RWWR)  $\times$  2 (replications) mixed design with order of background colour presentation counterbalanced between subjects. The dependent measure was the number of correct identifications of the target stimulus made by the subject at each level of SOA.

### Results and discussion

The number of correct identifications of the target made at each combination of background colour and SOA was averaged across all subjects. The mean group data and standard error bars (SE) are shown in Fig. 2. Lower percentages of correct responses correspond to greater impairment of target detectability, i.e., greater masking.

For both background conditions the typical U-shaped function of metacontrast was obtained. Performance was best at the briefest and longest SOAs and decreased to a minimum at the 60 msec delay. Performance was also better in the red background condition at all SOAs. These trends were confirmed by a three-within (colour, SOA, replication)  $\times$  one-between (order) factor analysis of variance (ANOVA) which revealed significant main effects for SOA [ $F(5, 60) = 23.51, P < 0.01$ ] and colour [ $F(1, 12) = 18.02, P < 0.01$ ]. Mean performance in the red condition was 81.7% (SE = 1.5%) compared to 76.4% (SE = 1.2%) in the white condition. This result corroborates the findings of Breitmeyer and Williams (1990) showing that a red relative to a white background field significantly reduces the magnitude of metacontrast masking in adult subjects. If the effect of the red background is taken to result from suppression of the magno system, this finding also supports the interpretation of metacontrast as due to magno system suppression of parvo system activity.

The masking functions obtained in the two conditions were similar in shape and each yielded maximum masking at the 60 msec SOA. Any difference in shape (e.g. a shallower flatter function compared to a deeper V-shaped function) or a shift in the point of maximum masking, would be revealed as a significant colour  $\times$  SOA interaction effect. There was no suggestion of an interaction between these variables [ $F(5, 60) = 1.99, NS$ ], providing no evidence that a red background alters the speed of the magno system response.

The main effect of replication was significant [ $F(1, 12) = 7.36, P < 0.05$ ] reflecting a slight (approx-

mately 3.5%) improvement in performance from the first to the second half of the experimental session. This finding was not surprising as suppression in metacontrast is known to decline with practice (Hogben & Di Lollo, 1984; Ventura, 1980). The main effect of order was non-significant, as were all interaction effects.

### EXPERIMENT 2: ADOLESCENT STUDY

In Experiment 2 metacontrast was used to index magno system functioning in adolescents with SRD and average reading adolescents, and to investigate the effects of a red background on the magno system functioning of these groups. It was predicted that the subjects with SRD would have weaker metacontrast and/or maximum masking at shorter SOAs than the average readers. Weaker masking was expected if the magno responses of subjects with SRD are weak, and maximum masking at a short delay was expected if the response is slow. It was further predicted that the adolescent average readers would have weaker metacontrast in the red compared to the white background condition, but that the effect of the red background would be less pronounced in the group with SRD.

### Method

*Subjects.* Twenty-four adolescent boys, 12 with SRD and 12 with average reading skills, were recruited from three private High Schools in Perth, Western Australia. The following criteria adapted from Stanley and Hall (1973) were used to select the subjects with SRD:

Average or better performance in academic subjects other than reading, and at least average intelligence.

No known organic disorders.

No known behavioural disorders.

Normal or corrected-to-normal visual acuity.

A reading lag of at least 2 yr below grade level.

The control subjects satisfied the above criteria except their reading performance was within the average to above average range.

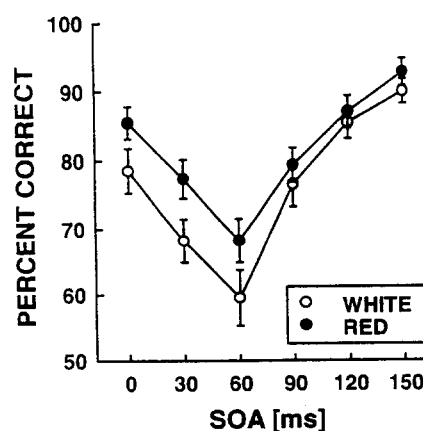


FIGURE 2. Metacontrast functions for adult subjects in red and white photometrically matched background conditions. Percent correct identifications of the target are plotted as a function of SOA.

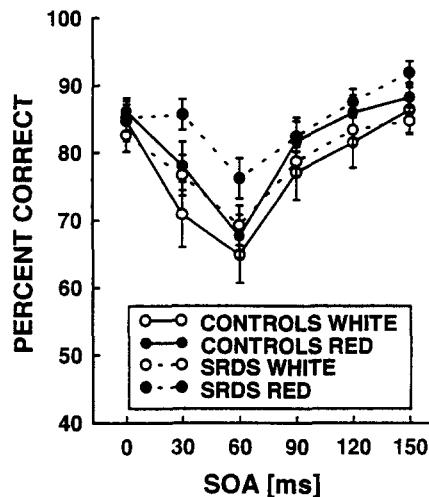


FIGURE 3. Metacontrast functions for adolescents with SRD and average reading adolescents in red and white photometrically matched background conditions. Percent correct identifications of the target are plotted as a function of SOA.

The experimental and control groups did not differ significantly in either age or intelligence. The mean age of the group with SRD was 14 yr 5 mo and of the control group was 14 yr 6 mo,  $t(22) = 0.25$  NS. Intelligence was assessed using Raven's Standard Progressive Matrices (Raven, 1958) and all subjects scored in the average range or above. The mean IQ for the subjects with SRD was 105.8 (SD = 9.0) and for the controls was 110.8 (SD = 8.1),  $t(22) = 1.4$  NS.

Reading ability was assessed using three subtests from the Woodcock Reading Mastery Tests/Form A (Woodcock, 1973). The three subtests administered were Word Identification (real words), Word Attack (nonsense words) and Passage Comprehension. Performance on the comprehension subtest was used as the primary reading measure. On this measure the mean reading age of the subjects with SRD (11 yr 4 mo) was significantly lower than that of the controls (15 yr 6 mo),  $t(22) = 5.340$ ,  $P < 0.001$ , and the SRD group had a mean reading lag of 3 yr 1 month. A Mann-Whitney Rank Sum Test was used to compare the groups on the other two reading measures as the assumptions of a parametric  $t$ -test were violated in both cases. On the word identification test the median reading age for the group with SRD was 12 yr 3 mo and for the controls was 16 yr 2 mo. These scores differed significantly,  $T = 99$ ,  $P < 0.01$ . A significant difference was also found on the word attack subtest which measured phonological decoding skills, with subjects with SRD obtaining a median reading age of 10 yr 8 mo and controls obtaining a median reading age of 18 yr 0 mo ( $T = 96$ ,  $P < 0.01$ ).

Subjects were also tested using the Ishihara Tests for Colour Blindness (Ishihara, 1978) and all were found to have normal colour vision.

*Stimuli, apparatus and procedure.* These were the same as in Expt 1.

*Design.* The design was a 2 (groups: SRD, control)  $\times$  (background colour: white, red)  $\times$  6 (SOA: 0, 30, 60, 90, 120, 150)  $\times$  2 (order: WRRW, RWWR)  $\times$  2 (replications) mixed design with the order of background colour presentation counterbalanced among subjects within groups and matched across groups.

#### Results and discussion

The number of correct identifications of the target made at each SOA over the two red and two white background blocks was averaged for each subject and individual masking functions were then plotted for each colour condition. Inspection of these figures revealed that when the target and mask were presented simultaneously (zero SOA) there was considerable variation in subject performance. With no time delay between the target and mask, little or no masking would be expected as mask-elicited magno responses would not coincide with target-elicited parvo responses. Variations at zero SOA therefore reflect differences in ability to perform the task rather than the effects of masking. A masking score based on the difference between performance at zero SOA and performance at the point of maximum masking was therefore used for data analyses. This score provides an index of the extent of masking experienced by the subject relative to his baseline level of performance. To calculate this score the raw scores for each subject at zero SOA and at the SOA of maximum masking were arcsin transformed (Steel & Torrie, 1980) and the difference between the transformed scores computed. This method of normalizing the data is similar to a technique used by Breitmeyer, May and Scott Heller (1991).

The mean masking functions for the two reader groups in the red and white background conditions are shown in Fig. 3. The functions obtained were similar to those of the adult subjects in the first study. Both adolescent groups produced a U-shaped function with maximum masking occurring at the 60 msec delay in the two colour conditions. The two groups also performed consistently higher at all SOAs in the red, compared to the white condition. The mean masking scores for the red and white conditions collapsed across groups were 11.36 (SE = 1.29) and 14.43 (SE = 1.29), respectively. A two-way ANOVA (group  $\times$  colour) with repeated measures on the colour factor, performed on the masking scores, revealed that the effect of colour was significant [ $F(1, 22) = 4.80$ ,  $P < 0.05$ ]. A significant main effect for group [ $F(1, 22) = 5.84$ ,  $P < 0.05$ ] was also obtained, with less masking observed in the group with SRD ( $M = 10.28$ , SE = 1.53) than in the controls ( $M = 15.51$ , SE = 1.53). The group  $\times$  colour interaction did not reach statistical significance [ $F(1, 22) = 0.11$  NS], indicating the effect of colour did not differ for the two groups.

The results suggest first, that a red background attenuates magno functioning in adolescents, and second, that adolescents with SRD have weaker magno responses than their average reading peers. These results confirm the prediction that adolescents with SRD differ from

controls in their magno system functioning, but contrary to prediction, the effect of the red background did not differ for the two reader groups.

### GENERAL DISCUSSION

These experiments establish that the attenuation of metacontrast masking by a red background extends to metacontrast measured with an objective performance indicator. They also show that subjects with SRD experience less metacontrast masking than average readers. The findings are consistent with the view that metacontrast depends on magno system activity, which is inhibited by a diffuse red field, and that subjects with SRD exhibit less magno system activity than average readers. However, the results provide no evidence to suggest that the magno system of subjects with SRD is affected less by a red background than that of average readers.

Attenuation of magno system activity by red background light was found in all three groups of subjects tested. Speed of magnocellular system responding however, was not significantly altered by the red background in any group. This result is consistent with predictions based on both physiological (Dreher *et al.*, 1976; Kruger, 1977; Livingstone & Hubel, 1987; Wiesel & Hubel, 1966) and psychophysical reports (Breitmeyer & Williams, 1990) of suppression of responding in magnocellular neurons in the presence of diffuse red light. Changes to the speed of responding in the magno pathway were not expected as there is no suggestion from previous studies that red background light slows activity in this system. An exception is some recent simple reaction time (RT) data reported by Breitmeyer and Breier (1994). Using luminance increment spot-stimuli presented against equiluminant red, green and blue backgrounds they reported slower RTs in the red condition compared to the blue and green conditions. These findings are claimed to indicate an effect of red background light on the speed of magno responding, however, they are equivocal as the effect of the background colour is confounded with that of the colour of the stimuli. In light of results from metacontrast research it seems plausible to suggest that the effect obtained by Breitmeyer and Breier (1994) may in fact, have been due to the colour of the stimuli. Whilst to date, metacontrast studies which have manipulated background colour have not reported evidence of an effect on the speed of magno processing, several recent studies have reported effects on the speed of the magno response when the colour of the masking stimuli has been manipulated. Specifically, these studies appear to indicate that red masking stimuli attenuate and slow the response of the magno system, as signified by weaker masking and a shift in maximum masking toward shorter SOAs (Williams, Breitmeyer, Lovegrove & Gutierrez, 1991; Williams, Rock-Faucheux & LeCluyse, 1992, reported in Rock-Faucheux, LeCluyse & Williams, 1993). It is important to note that studies which have shown this effect on speed of magno responding have

altered the colour of the masking stimuli rather than the colour of the background. The available evidence may therefore be taken to suggest that steady, red background light affects the magnitude of magno responding, whereas both the magnitude and speed of magno responding may be altered by transient flashes of red light to small regions of the visual field. The mechanisms underlying this latter effect have not yet been clearly delineated.

It has been argued that the effect of red background light on metacontrast magnitude is due to suppression of the magno system. An alternative explanation could be that diminished metacontrast in the red condition results from a change in the contrast of the target stimulus. The two backgrounds were set at equal luminance but the blue/green (P15) phosphor may have had a higher colour contrast against the red background than against the white. This does not seem a viable explanation, however, because metacontrast increases rather than decreases when the contrast of both the target and mask is increased (Breitmeyer, Clark, Hogben & Di Lollo, 1991).

The finding of reduced metacontrast in the adolescent subjects with SRD reveals weak responding in the magno system of this group. The failure to find a less pronounced effect of the red background on these subjects' magno system responding compared to the controls was therefore surprising, as a weaker responding system would be expected to be suppressed less by red light. It was thought that the background colour manipulation in the present experiment would have a similar effect to the flicker masking manipulation employed in some visible persistence studies. At low spatial frequencies, flicker masking has been shown to extend the duration of visible persistence in control subjects, but to have little effect on the persistence duration of subjects with SRD, indicating an already reduced level of magno activity in the latter group (Slaghuis & Lovegrove, 1984). In the present study, the masking function of the controls in the red background resembles the masking function of the subjects with SRD in the white background. It appears therefore that the red manipulation reduced the level of magno responding in the average readers to approximately the level normally experienced by the subjects with SRD, as did the flicker masking manipulation used by Slaghuis and Lovegrove (1984). Unexpectedly however, the red background also had a marked effect on responding in the magno system of the subjects with SRD. This seems to suggest that there was not a complete absence of magno system responding in this group as some level of responding must have been present for suppression to have occurred. The depth of the masking function obtained from the group with SRD in the white background condition also indicates some level of magno responding, although less than that exhibited by the controls. It is possible that the adolescents with SRD in the present study had stronger magno responses than the younger (12-yr-old) subjects with SRD tested by Slaghuis and Lovegrove (1984), which may reflect a general strengthening of the magno system with age. Brannan



and Williams (1988) reported an increase in flicker sensitivity in both good and poor readers with increasing age, while absolute differences in sensitivity between the groups remained the same. A stronger magno system which is more susceptible to manipulations designed to suppress magno responding might therefore be expected in older subjects with SRD compared to younger ones, whereas overall differences in magno responding between subjects with SRD and average readers may remain constant across age.

The different effect on magno responding observed in subjects with SRD with the red background manipulation compared to the flicker masking manipulation may also be due to differences in the methodologies employed in the two studies. In the visible persistence study two sinusoidal gratings separated at varying intervals by a blank field were presented on each trial, and subjects were required to indicate whether they saw a blank interval between the gratings. Some subjects tested in the present study reported not being able to see the dot missing from the target stimulus on many trials, although their performance scores revealed a substantial number of correct identifications. The objective performance measure employed in this study may therefore be more sensitive to low levels of visual system activity than the subjective measure used in the persistence task, as the former does not necessarily require conscious access to the visual experience for the identification of system activity, whereas the latter does.

Although the adolescent groups differed in their strength of magno responding, there was no difference in their speed of responding. This result is contrary to the trend reported by Williams *et al.* (1989) who found a 20 msec shift in the peak of maximum masking toward shorter SOAs, for younger children with SRD compared to controls. However, it must be noted that in the present study the sampling of SOAs may have been too coarse to detect subtle shifts in the location of maximum masking. The true peak of the function may have fallen within one SOA either side of the SOA at which maximum masking was found, i.e., within approximately a 60 msec interval. Alternatively, it is possible that the sluggish rate of magno responding found in younger children with SRD may disappear by middle adolescence. In future studies, the use of smaller intervals, particularly within the critical range of SOAs (30–90 msec), would enhance the possibility of detecting any change in the location of maximum masking.

In summary, the data indicate that red background light suppresses magno system functioning in adults, average reading adolescents and adolescents with SRD. The results also show that magno responses in adolescents with SRD are weaker than those of average readers, indicating the continuation of a magno system deficit in individuals with SRD beyond childhood. Further research is needed to investigate the speed of magno responses in adolescents with SRD and to assess magno responding in this group at different stages of development.

## REFERENCES

- Alpern, M. (1953). Metacontrast. *Journal of the Optical Society of America*, 43, 648–657.
- Badcock, D. & Lovegrove, W. (1981). The effects of contrast, stimulus duration, and spatial frequency on visible persistence in normal and specifically disabled readers. *Journal of Experimental Psychology: Human Perception and Performance*, 7, 495–505.
- Benton, A. L. (1980). Dyslexia: Evolution of a concept. *Bulletin of The Orton Society*, 30, 10–26.
- Brannan, J. R. & Williams, M. C. (1988). The effects of age and reading ability on flicker threshold. *Clinical Vision Sciences*, 3, 137–142.
- Breitmeyer, B. G. (1978). Disinhibition in metacontrast masking of vernier acuity targets: Sustained channels inhibit transient channels. *Vision Research*, 18, 1401–1405.
- Breitmeyer, B. G. (1980). Unmasking visual masking: A look at the “why” behind the veil of the “how”. *Psychological Review*, 87, 52–69.
- Breitmeyer, B. G. (1983). Sensory masking, persistence, and enhancement in visual exploration and reading. In Rayner, K. (Ed.), *Eye movements in reading: Perceptual and language processes* (pp. 3–30). New York: Academic Press.
- Breitmeyer, B. G. (1989). A visually based deficit in specific reading disability. *The Irish Journal of Psychology*, 10, 534–541.
- Breitmeyer, B. G. (1991). Reality and relevance of sustained and transient channels in reading and reading disability. In Schmid, R. & Zambardi, D. (Eds), *Oculomotor control and cognitive processes* (pp. 473–483). Amsterdam: Elsevier Science.
- Breitmeyer, B. G. (1992). Parallel processing in human vision: History, review and critique. In Brannan, J. (Ed.), *Applications of parallel processing in vision* (pp. 37–78). Amsterdam: Elsevier Science.
- Breitmeyer, B. G. & Breier, J. I. (1994). Effects of background color on reaction time to stimuli varying in size and contrast: Inferences about human M channels. *Vision Research*, 34, 1039–1045.
- Breitmeyer, B. G., Clark, C. D., Hogben, J. H. & Di Lollo, V. (1991). Metacontrast masking in relation to stimulus size and intensity. *Revue Suisse de Psychologie*, 50, 87–96.
- Breitmeyer, B. G. & Ganz, L. (1976). Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. *Psychological Review*, 83, 1–36.
- Breitmeyer, B. G., May, J. G. & Scott Heller, S. (1991). Metacontrast reveals asymmetries at red–green isoluminance. *Journal of the Optical Society of America*, 8, 1324–1329.
- Breitmeyer, B. G. & Williams, M. C. (1990). Effects of isoluminant-background color on metacontrast and stroboscopic motion: Interactions between sustained (P) and transient (M) channels. *Vision Research*, 30, 1069–1075.
- Critchley, M. (1970). *The dyslexic child*. London: Heinemann.
- Di Lollo, V. (1979). Luminous calibration of oscilloscopic displays. *Behavior Research Methods and Instrumentation*, 11, 419–421.
- Dow, B. M. (1974). Functional classes of cells and their laminar distribution in monkey visual cortex. *Journal of Neurophysiology*, 37, 927–946.
- Dreher, B., Fukada, Y. & Rodieck, R. W. (1976). Identification, classification and anatomical segregation of cells with X-like and Y-like properties in the lateral geniculate nucleus of old-world primates. *Journal of Physiology*, 258, 433–452.
- Eden, G. F., Stein, J. F. & Wood, F. B. (1993). Visuospatial ability and language processing in reading disabled and normal children. In Wright, S. F. & Groner, R. (Eds), *Facets of dyslexia and its remediation* (pp. 321–335). Amsterdam: Elsevier Science.
- Eden, G. F., Stein, J. F., Wood, M. H. & Wood, F. B. (1993). Dyslexia: A study of preserved and impaired visuospatial and phonological functions. In Tallal, P., Galaburda, A. M., Llinas, R. R. & von Euler, G. (Eds), *Temporal information processing in the nervous system: Special reference to dyslexia and dysphasia* (pp. 335–338). New York: New York Academy of Sciences.
- Finley, G. (1985). A high-speed point plotter for vision research. *Vision Research*, 25, 1993–1997.



- Grosser, G. S. & Spafford, C. S. (1992). Reply to Stuart and Lovegrove's question, "Visual processing deficits in dyslexia: Receptors or neural mechanisms?" *Perceptual and Motor Skills*, 75, 115–120.
- Hogben, J. H. & Di Lollo, V. (1984). Practice reduces suppression in metacontrast and in apparent motion. *Perception and Psychophysics*, 35, 441–445.
- Hogben, J. H., Rodino, I. S., Clark, C. D. & Pratt, C. (1995). A comparison of temporal integration in children with a specific reading disability and normal readers. *Vision Research*, 35, 2067–2074.
- Ishihara, S. (1978). *Tests for colour-blindness*. Tokyo: Kanehara Shuppan Co.
- Kruger, G. (1977). Stimulus dependent colour specificity of monkey lateral geniculate neurones. *Experimental Brain Research*, 30, 297–311.
- Kulikowski, J. J. & Tolhurst, D. J. (1973). Psychophysical evidence for sustained and transient detectors in human vision. *Journal of Physiology*, 232, 149–162.
- Lehmkuhle, S., Garzia, R. P., Turner, L., Hash, T. & Baro, J. A. (1993). A defective visual pathway in children with reading disability. *The New England Journal of Medicine*, 328, 989–996.
- Livingstone, M. S. & Hubel, D. H. (1987). Psychophysical evidence for separate channels for the perception of form, color, movement, and depth. *The Journal of Neuroscience*, 7, 3416–3468.
- Livingstone, M. S., Rosen, G. D., Drislane, F. W. & Galaburda, A. M. (1991). Physiological and anatomical evidence for a magnocellular defect in developmental dyslexia. *Proceedings of the National Academy of Science U.S.A.*, 88, 7943–7947.
- Lovegrove, W. J., Bowling, A., Badcock, D. & Blackwood, M. (1980). Specific reading disability: Differences in contrast sensitivity as a function of spatial frequency. *Science*, 210, 439–440.
- Lovegrove, W. J., Garzia, R. P. & Nicholson, S. B. (1990). Experimental evidence for a transient system deficit in specific reading disability. *Journal of the American Optometric Association*, 61, 137–146.
- Lovegrove, W. J., Martin, F., Bowling, A., Blackwood, M., Badcock, D. & Paxton, S. (1982). Contrast sensitivity functions and specific reading disability. *Neuropsychologia*, 20, 309–315.
- Lovegrove, W., Pepper, K., Martin, F., Mackenzie, B. & McNicol, D. (1989). Phonological recoding, memory processing and visual deficits in specific reading disability. In Vickers, D. & Smith, P. L. (Eds), *Human information processing: Measures, mechanisms and models* (pp. 65–79). Amsterdam: Elsevier.
- 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. & Lovegrove, W. (1987). Flicker contrast sensitivity in normal and specifically disabled readers. *Perception*, 16, 215–221.
- Mueller, P. U. (1993). Some reflections on psychophysical measurement with dyslexic children. In Wright, S. F. & Groner, R. (Eds), *Facets of dyslexia and its remediation* (pp. 207–214). Amsterdam: Elsevier.
- Prior, M. R. (1989). Reading disability: Normative or pathological. *Australian Journal of Psychology*, 41, 135–158.
- Raven, J. C. (1958). *Standard Progressive Matrices*. Victoria: Australian Council for Educational Research.
- Rock-Faucheux, A., LeCluyse, K. & Williams, M. (1993). The effects of wavelength on visual processing and reading performance in normal and disabled readers. In Wright, S. F. & Groner, R. (Eds), *Facets of dyslexia and its remediation* (pp. 77–94). Amsterdam: Elsevier.
- Shapley, R. (1990). Visual sensitivity and parallel retinocortical channels. *Annual Review of Psychology*, 41, 635–658.
- Slaghuis, W. L. & Lovegrove, W. J. (1984). Flicker masking of spatial frequency dependent visible persistence and specific reading disability. *Perception*, 13, 527–534.
- Slaghuis, W. L. & Lovegrove, W. J. (1985). Spatial frequency dependent visible persistence and specific reading disability. *Brain and Cognition*, 4, 219–240.
- Slaghuis, W. L., Lovegrove, W. J. & Davidson, J. A. (1993). Visual and language processing deficits are concurrent in dyslexia. *Cortex*, 29, 601–615.
- Slaghuis, W. L. & Pinkus, S. Z. (1993). Visual backward masking in central and peripheral vision in late-adolescent dyslexics. *Clinical Vision Sciences*, 8, 187–199.
- Stanley, G. & Hall, R. (1973). Short-term visual information processing in dyslexics. *Child Development*, 44, 841–844.
- Steel, R. G. D. & Torrie, J. H. (1980). *Principles and procedures of statistics: A biometrical approach* (2nd edn). New York: McGraw-Hill.
- Vellutino, F. R. (1977). Alternative conceptualizations of dyslexia: Evidence in support of a verbal-deficit hypothesis. *Harvard Educational Review*, 47, 334–354.
- Vellutino, F. R., Steger, J. A. & Kandel, G. (1972). Reading disability: An investigation of the perceptual deficit hypothesis. *Cortex*, 8, 106–118.
- Ventura, J. (1980). Foveal metacontrast: I. Criterion content and practice effects. *Journal of Experimental Psychology: Human Perception and Performance*, 6, 473–485.
- Wiesel, T. N. & Hubel, D. H. (1966). Spatial and chromatic interactions in the lateral geniculate body of the rhesus monkey. *Journal of Neurophysiology*, 29, 1115–1156.
- Williams, M. C., Breitmeyer, B. G., Lovegrove, W. J. & Gutierrez, C. (1991). Metacontrast with masks varying in spatial frequency and wavelength. *Vision Research*, 31, 2017–2023.
- Williams, M. C. & LeCluyse, K. (1990). Perceptual consequences of a temporal processing deficit in reading disabled children. *Journal of the American Optometric Association*, 61, 111–121.
- Williams, M. C. & Lovegrove, W. (1992). Sensory and perceptual processing in reading disability. In Brannan, J. (Ed.), *Applications of parallel processing in vision* (pp. 263–302). Amsterdam: Elsevier.
- Williams, M. C., Molinet, K. & LeCluyse, K. (1989). Visual masking as a measure of temporal processing in normal and disabled readers. *Clinical Vision Sciences*, 4, 137–144.
- Winer, B. J. (1962). *Statistical principles in experimental design*. New York: McGraw-Hill.
- Woodcock, R. W. (1973). *Woodcock Reading Mastery Tests / Form A*. Minnesota: American Guidance Service.

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