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Yellow Filters Can Improve Magnocellular Function: Motion Sensitivity, Convergence, Accommodation, and Reading

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ABSTRACT

The magnocellular system plays an important role in visual motion processing, controlling vergence eye movements, and in reading. Yellow filters may boost magnocellular activity by eliminating inhibitory blue input to this pathway. It was found that wearing yellow filters increased motion sensitivity, convergence, and accommodation in many children with reading difficulties, both immediately and after three months using the filters. Motion sensitivity was not increased using control neutral density filters. Moreover, reading-impaired children showed significant gains in reading ability after three months wearing the filters compared with those who had used a placebo. It was concluded that yellow filters can improve magnocellular function permanently. Hence, they should be considered as an alternative to corrective lenses, prisms, or exercises for treating poor convergence and accommodation, and also as an aid for children with reading problems.

Key Words: magnocellular system • vergence eye movement • visual motion processing • reading impairment • motion sensitivity • cones • density filters

INTRODUCTION

The Visual Magnocellular Pathway

Three functionally distinct visual pathways project from the retina to the geniculocortical system. The magnocellular and parvocellular systems are thought to be separately responsible to some extent for determining the location of objects, the "where" stream, and the form of objects, the "what" stream, respectively.[1] Less is known about the third system, the koniocellular pathway, but it is believed to mediate color processing along the blue-yellow axis.[2] Magnocells are characterized by their sensitivity to high temporal and low spatial frequencies, whereas parvocells respond preferentially to low temporal and high spatial frequencies.

Although the magnocellular pathway is not directly involved in color vision, it receives from all three cone types. Monasterio[3] recorded retinal ganglion cell responses: Type III cells receive input from both M cones and L cones both to their centers and inhibitory surrounds, making them sensitive to luminance, but not chromatic, borders. Type IV cells (constituting 9% of those sampled) receive L-, M-, and sometimes S-cone inputs to their centers, and either only L-cone, or L-cone and S-cone inputs to their inhibitory surrounds. Both types III and IV probably contribute to the magnocellular pathway, because they exhibit both on and off responses, doubling their response frequency when tested with bipartite field stimuli.

Stockman *et al.*[4] examined the temporal properties of S cones using flicker photometry, and found that blue flickering light could null flickering yellow light, confirming an inhibitory S-cone input to the transient/magnocellular pathway. To produce a convincing null, however, significant adjustments in temporal phase had to be made. These adjustments suggested that the S-cone contribution to the magnocellular pathway is both delayed and negative. Stockman *et al.* attribute the negative S-cone signal to the type IV cell surrounds described by Monasterio. Thus, even though they do not support color vision, M cells may be most sensitive to yellow and inhibited by blue.

Yellow filters not only cut out short wavelengths ("negative blue"), but also could normalize the relative phase of L-cone and M-cone input.[5] Swanson *et al.*[6] demonstrated that orange and green adapting fields cause different magnocellular phase lags. If the adapting field was orange, the L-cone contrast signal lagged behind the M-cone contrast signal, and vice versa for green adapting backgrounds. The adapting backgrounds also influenced the relative L- and M-cone contrast weights measured at 15 Hz. The L-cone contrast weighting was significantly reduced when the background was orange. Stromeyer *et al.*,[5] therefore, used a yellow adapting field to eliminate the phase lag and normalize the cone contrast weighting.

These findings suggest that yellow light can increase the efficiency of M cells. A normally functioning system might not benefit from reduction in S-cone input, but one that was sluggish could benefit both by being released from the negative influence of the S cones, and by rebalancing M- and L-cone input by the remaining M-cone and L-cone wavelengths. Note, however, that for this realignment to be of benefit there must be an abnormal cone weighting in the pathway.

Motion Sensitivity and the Magnocellular Pathway

Although most of the world is stationary most of the time, the visual system is particularly sensitive to movement, as its detection is vital to survival. This is mediated by the high temporal resolution of the magnocellular pathway. Cells that respond to the direction of moving stimuli first appear in V1, and their outputs are integrated in extrastriate areas V2, V3a, and V5/MT.

Britten[7] found that increases in the signal-to-noise ratio in a random-dot kinematogram (RDK; panels of moving dots that contain a coherent motion signal) causes increases in neuronal activity in the macaque homologue to human area V5/MT. Hence, motion sensitivity can be measured using RDKs, and RDK thresholds index magnocellular efficiency. Many poor readers have been shown to exhibit elevated thresholds in motion tasks.[8] Therefore, we compared motion sensitivity in subjects wearing yellow filters with that in subjects wearing control neutral density filters.

Vergence Eye Movements and the Magnocellular Pathway

The evolution of frontally directed eyes meant that we no longer had to depend upon monocular cues such as motion parallax and contour overlay in order to obtain a three-dimensional percept of the world. Stereoscopic vision is achieved by the precise alignment of the visual axes toward an object in near space, which relies upon the ability of our vergence to make disjunctive eye movements. By moving the eyes in opposition, so that an object of interest falls upon corresponding retinal coordinates, the dissimilarities between the remainder of the images seen by each eye allows our brain to make inferences about how far away an object is and whether it is moving toward or away from us.

Studies of the cerebral control of vergence have implicated dorsal area MT,[9] suggesting magnocellular involvement. Erkelens[10] used random-dot stereograms to compare vergence control and depth perception. He found that the behavior of the two systems was so markedly different that they are likely to be independent. Leigh and Zee[11] showed that MT and MST neurons discharge with vergence, whereas Schiller *et al.*[12] showed that only parvocellular LGN lesions impair stereopsis. Erkelens argues, therefore, that vergence is mediated by the magnocellular pathway and stereopsis by the parvocellular pathway.

If vergence is a magnocellular process and yellow can increase magnocellular function, ability to make vergence eye movements should improve with a yellow filter. Here, therefore, we have compared convergence and accommodation in children with severely reduced convergence (>18 cm) wearing a yellow filter with that in children wearing no filter. We then asked the children to wear the filter for three months for all reading and writing work, after which we reassessed convergence and accommodation.

Dyslexia and the Magnocellular Pathway

Developmental dyslexia can be defined as an inability to learn to read and write properly despite normal intelligence and educational opportunity.[13] Although the association between poor phonological processing and reading difficulties is well accepted,[14] whether visual deficits play any important part is much more controversial. However, a substantial body of research suggests that a high proportion of dyslexics have visual impairments that are not found in the normal population.[15-17]

Dyslexics are often found to exhibit magnocellular deficits, whereas processing in the parvocellular pathway is preserved.[12] Lovegrove[17] was the first to suggest that dyslexics have a specific deficit of the transient system, after finding that they had a reduced sensitivity to low spatial frequencies relative to controls, whereas their sensitivity to high spatial frequencies was slightly elevated. Livingstone *et al.*[16] showed that this could be explained by impaired development of magnocells, which were found to be 30% smaller than usual in postmortem brains of known dyslexics.

Stein[18] suggested that because the magnocellular pathway plays such an important role in eye-movement control, disordered magnocellular processing may impair binocular stability and thus cause visualperceptual confusion when reading. Stein and his colleagues have consistently found that dyslexics perform badly on tasks that load heavily upon the magnocellular system, for example. Hansen *et al.*[19] reported that although dyslexics exhibited reduced motion sensitivity compared with controls, their ability to detect coherent static form patterns was unimpaired.

Chase[20] found that reading in general is impaired under red light conditions, compared with green or blue light. Because red attenuates magnocellular activity due to type IV magnocellular L-cone-dominated inhibitory surrounds,[21] Chase argued that the magnocellular system must play an important part in reading, and that the problems of dyslexics result in part from an abnormally large L-cone to M-cone ratio in their magnocellular surrounds.

Yellow filters that eliminate blue and mimic the adapting backgrounds that reduce the L-cone contrast weighting in magnocells[6] should, therefore, be of particular benefit to dyslexics. Accordingly, we tested reading ability in children before and after wearing a yellow filter or placebo for three months.

METHODS

Subjects

Children with reading difficulties were recruited from clients of the Dyslexia Research Trust clinics for visual reading problems in Reading and Oxford. All were native English speakers between the ages of 7 and 14.

Materials and Procedure

Convergence and Accommodation

An orthoptist measured the vergence and accommodation of 15 children with reading problems chosen because they had severely reduced convergence (>18 cm) and accommodation (N5 > 18 cm) using the RAF rule; this allows the orthoptist to observe the eyes as the subject converges and accommodates to stimuli at varying distances. These measurements were then repeated with the children wearing yellow filters.

Motion Sensitivity

Psychophysical estimates of motion sensitivity were obtained in another 24 poor readers (BAS II similarities and matrices >0.5 SD higher than their BAS II reading scores). All had normal visual acuity and vergence within normal limits. Their motion sensitivity while viewing through a yellow filter was compared with that while viewing through a control neutral density filter. The motion task stimuli were identical to those used by Hansen *et al.*[19] The subject viewed two adjacent panels of moving dots. Each panel subtended 10 x 14 degrees of visual angle. In one panel, all of the dots moved in random directions in a Brownian manner between screen refreshes. In the other panel, a proportion of the dots moved coherently from side to side (reversing every 1000 ms). It was impossible to ascertain which panel contained the signal dots simply by following the trajectory of a single signal dot, because each dot disappeared after 250 ms and subsequently reappeared within the same panel. Subjects viewed the stimuli binocularly in a darkened room for 2500 ms and were asked to indicate which side showed the motion. Signal coherence was adjusted by computer software on a trial-by-trial basis using a one up/one down adaptive staircase technique.[22] After 10 reversals the threshold was calculated as the geometric mean of the last 8 reversals.

Reading Ability

Thirty-eight severely disabled readers (BAS II reading or spelling scores 1.5 SD below BAS II similarities or matrices scores) were studied. All had normal visual acuity and vergence within normal limits. However, all found that viewing though yellow filters improved the clarity of N5-sized text compared with blue, pink, green, red, or gray filters or no filter. Subjects were randomly selected to receive either a yellow filter or a placebo to use for three months. The placebo was a card with a rectangular window cut through, designed so that only one line of text could be viewed at a time; this has been claimed to benefit poor readers by limiting distraction from surrounding print.[23] After the three-month period, BAS II reading was repeated. The experimenter was blind as to which treatment each child had been given, as were the children as to which treatment was supposed to be effective.

Figure 1 shows the transmittance of the yellow filter for each of the cone types. Absorbance while wearing the yellow filter was approximately 80% for L cones and about 70% for M cones. This is similar to normal daylight, but S-cone absorbance was reduced to under 10%.

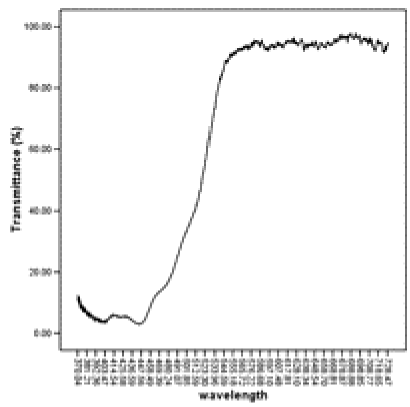

FIGURE 1. Transmittance of yellow filters.

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RESULTS

Convergence and Accommodation

Fifteen children with very severely reduced convergence and accommodation (>18 cm) were tested with an RAF rule withand without a yellow filter. They were then asked to wear the filter for three months for all reading and writing work, after which convergence and accommodation measurements were repeated.

Figures 2 and 3 show that the children's convergence and accommodation improved significantly immediately with the use of a yellow filter compared with no filter (convergence: $F = 39.9$, $P < .001$; accommodation: $F = 30$, $P < .001$). After the children had worn the yellow filters for three months for all reading and writing work, their convergence and accommodation was improved compared with results from three months earlier, even when not wearing the filters (convergence: $F = 35.1$, $P < .001$; accommodation: $F = 32.4$, $P < .001$).

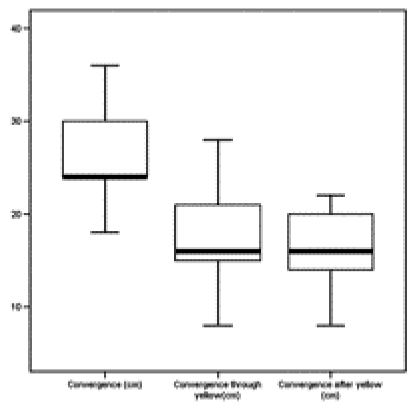

FIGURE 2. Convergence with no filter, a yellow filter, and after wearing a yellow filter for three months.

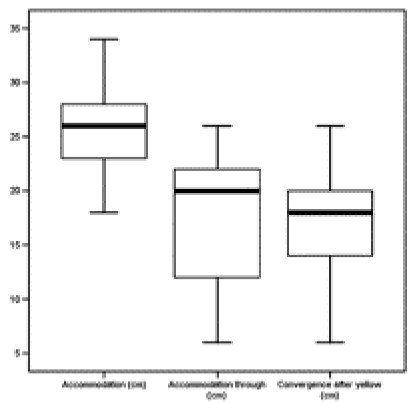

FIGURE 3. Accommodation with no filter, a yellow filter, and after wearing a yellow filter for three months.

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Motion Sensitivity

Twenty-four poor readers completed a motion sensitivity task while wearing a yellow filter and while wearing a neutral density filter. Figure 4 indicates that these children's motion sensitivity thresholds were lowered significantly when they viewed the RDKs through yellow filters as compared with motion sensitivity when they viewed through control neutral density filters ($F = 7.08$, $P < .05$), supporting the hypothesis that their magnocellular function was improved by the yellow filter.

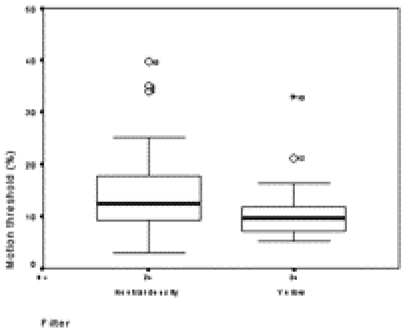

FIGURE 4. Motion sensitivity with and without a yellow filter.

Reading Ability

Thirty-eight poor readers wore yellow filters or used the placebo for three months, after which reading ability was reassessed.

Figure 5 shows that reading ability increased significantly more in those who had worn a yellow filter for three months than in those who had used the placebo ($F = 4.1$, $P < .05$).

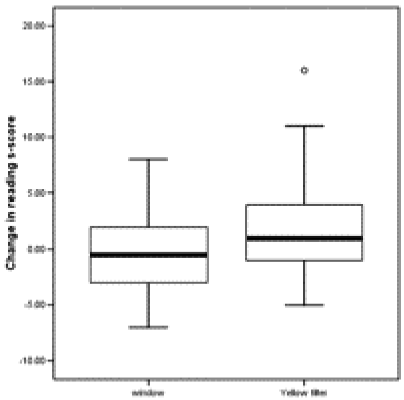

FIGURE 5. Reading ability changes after yellow filter or placebo treatment.

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DISCUSSION

In children with various reading disabilities, viewing through yellow filters increased motion sensitivity, convergence, accommodation, and reading ability. In the motion sensitivity task, we controlled for possible benefits afforded by the reduced luminance when wearing yellow, by comparing this with using a neutral density filter. Hence, changes in performance are likely to have been caused by the altered wavelength input alone. Wearing yellow filters for three months was also shown to have beneficial effects on vergence, accommodation, and reading. These improvements were seen without the filter on the second visit, suggesting that three months wearing the filter had a beneficial long-term treatment effect.

It must be admitted that whether blue input really does inhibit the magnocellular pathway is controversial. Stockman's[4] psychophysical data could reflect cortical interference from other pathways. However, Stockman used flicker to measure S-cone inputs, which are processed lower down the pathway than the higher-level processing of motion and reading. Thus, one can argue that whether this happens in the retina or later in the pathway, nevertheless M cells are probably inhibited by S-cone input.

Poor readers may be benefiting not only from the reduced S-cone input but also from redressing the imbalance in the M-cone and L-cone input. It has been suggested that poor readers have an overly strong L-cone input to the surrounds of their M cells,[20] perhaps causing the same temporal phenomena described by Swanson.[6] Stromeyer[5] found that red backgrounds reduced the L-cone contrast weighting relative to M-cone contrast weighting in magnocells and suggested that yellow filters normalize the imbalance.

It may seem counterproductive that our yellow filters allowed more red than green to pass through when one considers that M-cell activity is attenuated by red light.[21] However, Kremers *et al.*[24] used flickering cone-isolating stimuli to assess the affects of adaptation on M and L cones feeding into the magnocellular pathway. They found that when L cones were more adapted than M cones using red light, M-cone sensitivity increased, whereas L-cone sensitivity decreased. However, using green light that adapts L cones less than M cones, there was no change in response amplitude of either of the cone types. Thus, M-cone input to the magnocellular pathway may be favored by yellow light because L cones are more adapted than M cones. This may reduce the inhibitory influence of L cones in the magnocellular pathway, while affording the M cones a compensatory increase in sensitivity. Hence, yellow filters may be of particular benefit for those with an oversensitivity to L-cone input. However, these effects of L cones may apply only to these poor readers; how L-/M-cone ratios affect vergence in normal readers is not known.

Although motion, accommodation, convergence, and reading were tested in different groups of children, all had lowered magnocellular sensitivity and poor reading. Many of the children we see at these clinics have difficulty with all three of the abilities tested in this study, and all can be improved by wearing yellow filters. Therefore, we suggest that yellow filters should be tried in all children with reduced convergence and accommodation and poor reading before prisms, corrective lenses, or exercises are prescribed.

REFERENCES

1. Ungerleider, L.G. & M. Mishkin. 1982. Two cortical visual systems. *In* Analysis of visual behavior. D.J. Ingle, M.A. Goodale & R.J.W. Mansfield, Eds.: 549-586. MIT Press. Cambridge, MA.

2. Rodieck, R.W. & M. Watanabe. 1993. Survey of the morphology of macaque retinal ganglion cells that project to the pretectum, superior colliculus, and parvicellular laminae of the lateral geniculate nucleus. J. Comp. Neurol. **338:** 289-303.[CrossRef][Medline] [Order article via Infotrieve]

3. de Monasterio. 1978. Properties of concentrically organized X and Y ganglion cells of macaque retina. J. Neurophysiol. **41:** 1394-1417.[Abstract/Free Full Text]

4. Stockman, A., D.I. MacLeod & D.D. DePriest. 1991. The temporal properties of the human short-wave photoreceptors and their associated pathways. Vision Res. **31:** 189-208.[CrossRef][Medline] [Order article via Infotrieve]

5. Stromeyer, C.F., 3rd, A. Chaparro, A.S. Tolias & R.E. Kronauer. 1997. Colour adaptation modifies the long-wave versus middle-wave cone weights and temporal phases in human luminance (but not red-green) mechanism. J Physiol. **499:** 227-254.[Abstract]

6. Swanson, W.H., J. Pokorny & V.C. Smith. 1988. Effects of chromatic adaptation on phase-dependent sensitivity to heterochromatic flicker. J. Opt. Soc. Am. A **5:** 1976-1982.[Medline] [Order article via Infotrieve]

7. Britten, K.H., M.N. Shadlen, W.T. Newsome & J.A. Movshon. 1993. Responses of neurons in macaque MT to stochastic motion signals. Vis. Neurosci. **10:** 1157-1169.[Medline] [Order article via Infotrieve]

8. Talcott, J.B., P.C. Hansen, E.L. Assoku & J.F. Stein. 2000. Visual motion sensitivity in dyslexia: evidence for temporal and energy integration deficits. Neuropsychologia **38:** 935-943.[CrossRef][Medline] [Order article via Infotrieve]

9. Toda, H., M. Takagi, T. Yoshizawa & T. Brando. 1991. Disjunctive eye movement evoked by microstimulation in an extrastriate cortical area of the cat. Neurosci. Res. **12:** 300-306[CrossRef][Medline] [Order article via Infotrieve]

10. Erkelens, C.J. 2001. Organisation of signals involved in binocular perception and vergence control. Vision Res. **41:** 3497-3503.[CrossRef][Medline] [Order article via Infotrieve]

11. Leigh. RJ. & D.S. Zee. 1999. The neurology of eye movements, 3rd edn.. Oxford University Press. New York.

12. Schiller, P.H., N.K. Logothetis & E.R. Charles. 1990. Role of the color-opponent and broad-band channels in vision. Vis Neurosci. **5:** 321-346.[Medline] [Order article via Infotrieve]

13. American Psychiatric Association. 1994. Diagnostic and statistical manual of mental disorders, 4th rev. edn. Washington, D.C.

14. Snowling, M., D.V. Bishop & S.E. Stothard. 2000. Is preschool language impairment a risk factor for dyslexia in adolescence? J. Child Psychol. Psychiatry **41:** 587-600.

15. Brannan, J.R., H.A. Solan, A.P. Ficarra & E. Ong. 1988. Effect of luminance on visual evoked potential amplitudes in normal and disabled readers. Optom. Vis. Sci. **75:** 279-283.

16. Livingstone, M.S., G.D. Rosen, F.W. Drislane & A.M. Galaburda. 1991. Physiological and anatomical evidence for a magnocellular defect in developmental dyslexia. Proc. Natl. Acad. Sci. USA **88:** 7943-7947.[Abstract/Free Full Text]

17. Lovegrove, W.J., A. Bowling, D. Badcock & M. Blackwood. 1993. Specific reading disability: differences in contrast sensitivity as a function of spatial frequency. (Erratum) Proc. Natl. Acad. Sci. USA **90:** 2556.

18. Stein, J. 2003. Visual motion sensitivity and reading. Neuropsychologia **41:** 1785-1793.[CrossRef][Medline] [Order article via Infotrieve]

19. Hansen, P.C., J.F. Stein, S.R. Orde, *et al.* 2001. Are dyslexics' visual deficits limited to measures of dorsal stream function? Neuroreport **12:** 1527-1530.[CrossRef][Medline] [Order article via Infotrieve]

20. Chase, C., A. Ashourzadeh, C. Kelly, *et al.* 2003. Can the magnocellular pathway read? Evidence from studies of color. Vision Res. **43:** 1211-1222.

21. Hubel, D.H. & T.N. Wiesel. 1966. Effects of varying stimulus size and color on single lateral geniculate cells in Rhesus monkeys. Proc. Natl. Acad. Sci. USA **55:** 1345-1346.[Medline] [Order article via Infotrieve]

22. Kaernbach, C. 1991. Simple adaptive testing with the weighted up-down method. Percept-Psychophys. **49:** 227-229.[Medline] [Order article via Infotrieve]

23. Geiger, G.L. & J.Y. Lettvin. 1987. Peripheral vision in persons with dyslexia. N. Engl..J. Med. **316:** 1238-1240.[Abstract]

24. Kremers, J., M.W. Stepien, H.P. Scholl & C. Saito. 2003. Cone selective adaptation influences L- and M-cone driven signals in electroretinography and psychophysics. J. Vis. **3:** 146-160.[Medline] [Order article via Infotrieve]