Spatiotemporal Visual Function in Tinted Lens Wearers

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Purpose. Tinted lenses have been widely publicized as a successful new treatment for reading disorders and visual stress in children. The present study was designed to investigate a variety of visual deficits reported by children who experience high levels of visual stress and perceptual distortions when reading (Meares–Irlen syndrome; MIS) and to assess the improvements in visual comfort they report when tinted lenses are worn.

Methods. Twenty children (13.1 ± 0.9 years of age) were recruited who had successfully worn tinted lenses for at least 6 months and were compared with an age-matched control group (12.6 ± 2.2 years of age) of 21 children who were not lens wearers. A range of psychophysical tasks was adapted to identify specific anomalous visual perceptions. Spatiotemporal contrast sensitivity and contrast increment thresholds were used to investigate subjective reports of dazzle and hypercontrast, and a minimum motion perception (D_{min}) and a motion-coherence task were used to assess subjective reports of visual instability and motion.

Results. In all viewing conditions (with versus without lens), no selective functional visual loss was demonstrated with any of the tasks used. Psychometric functions also revealed no significant difference between subject groups (control versus MIS).

Conclusions. Under thorough psychophysical investigation, these results revealed no significant difference in visual function between subject group, and this finding is consistent with the absence of any effect of the tinted lenses in the group with MIS. (*Invest Ophthalmol Vis Sci.* 2001;42:879–884)

Certain geometric and repetitive patterns can be uncomfortable to look at and may sometimes provoke anomalous visual effects: illusions of color, shape, and motion.[1–3] Susceptibility to discomfort and anomalous visual effects from these patterns varies considerably from one observer to another and is found to be particularly pronounced in persons with migraine[3,4] and visual discomfort.[5]

The spatial characteristics of stimuli that induce such visual distortions are surprisingly specific. In a series of experiments,[3,4] groups of normal observers were found to report more numerous perceptual distortions and visual discomfort when the parameters of a high-contrast square-wave grating had a spatial frequency of between 2 and 8 cyc/deg, subtended 3° or more, and had a duty cycle of 50%. Text has been shown to have spatial characteristics within this critical range.[4]

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The visual processing of text occurs spontaneously for most readers.[6] Reading can, however, provoke pattern glare that causes both eyestrain (sore, strained eyes and headaches) and perceptual distortions (blurring, movement of letters, diplopia, and illusions of shapes or colors on the page).[7,8] The successive lines of printed text form a pattern resembling stripes (Fig. 1). It is possible that these stripes may provoke some of the eye strain and headaches that are attributed to reading.[8] This visual system hypersensitivity has been referred to as visual stress or discomfort. Visual discomfort is closely linked to Meares–Irlen syndrome (MIS).[9] The term Meares–Irlen syndrome is used to refer to the signs and symptoms of visual stress and discomfort and performance difficulties when reading (those affected usually have a slower reading speed than other persons of equivalent intelligence). It has been stated that MIS affects up to 20% of children in mainstream education[10] and 65% of children with dyslexia.[11]

The types of perceptual distortions reported by patients with MIS and the types that induce visual discomfort are similar,[4,5] appearing to be both contrast and spatial-frequency dependent. Reported distortions of text include blurring, apparent motion and flickering, diplopia, and the illusion of shapes or colors on the page. Other commonly reported symptoms are glare from the page and headaches and sore eyes with sustained reading.

Patients who have MIS often report that the perceptual distortions they experience when they read are reduced when the text is illuminated by light of a particular optimal color that is unique for each person.[5,9,10,12] When spectacles tinted this color are worn, eye strain and headaches are reduced. The reduction appears greater than that obtained with spectacles with a similar but suboptimal color, even in double-blind placebo-controlled trials.[12] Colored filters have also been shown to increase reading speed in some persons.[10,13]

A physiological basis of the therapeutic effects and rationale for tinted-lens therapy is difficult to specify. It has been speculated that the use of chromatic filters manipulates the transient visual system or that the therapeutic color may reduce excitation in areas of hyperexcitability in the visual cortex.[14] However, it is still unclear how tinted lenses affect the visual system and why in many cases the lenses show an immediate efficacy.

The results of tinted-lens therapy may depend on the primary visual deficit present, making it difficult to predict the effects of therapy. Patients demonstrate no significant improvement in traditional visual acuity measures but report a subjective improvement in visual function that may be due to changes in some aspect of their visual function that are not being measured by conventional examination.

The present study was designed to investigate a variety of visual deficits specified by observers who report high levels of visual stress and the improvements they report when tinted lenses are worn.

A range of psychophysical tasks was adapted to identify the specific perceptual distortions experienced in MIS. The tasks themselves did not measure anomalous perceptions; rather, they measured visual thresholds to determine whether these were also anomalous. These tasks were completed by subjects who had high visual stress, both with and without tinted lenses, and by observers who reported no visual stress. Sub-

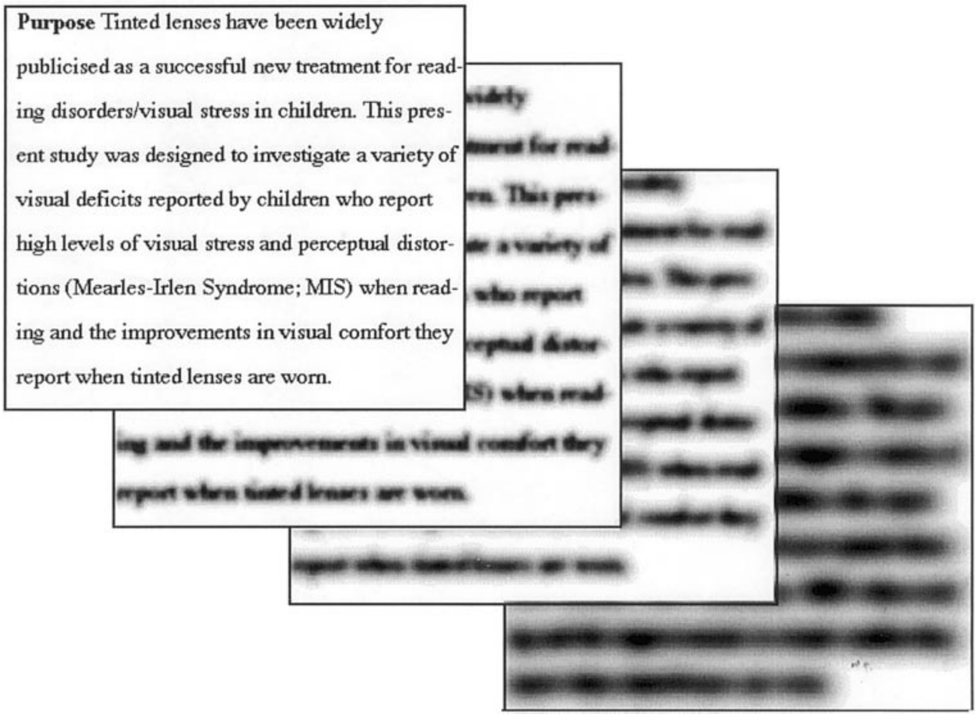

FIGURE 1. Text as a striped pattern. The text has been filtered, with the effect of removing the high spatial frequencies, and the contrast of the filtered images has then been exaggerated to make the stripes more apparent.

jective reports of dazzle and hypercontrast were examined with measurements of spatiotemporal contrast sensitivity and contrast increment thresholds. Subjective reports of visual instability and motion were examined with minimum motion perception and a motion-coherence task. It was hypothesized that perceptual reports of hypercontrast would be correlated with a saturated contrast response function. Thus, contrast increment sensitivity would be low at high contrasts, according to Weber's law. Similarly, it was hypothesized that illusory motion would be accompanied by lower sensitivity to small (but real) spatial shifts or by lower sensitivity to global motion coherence.

METHODS

Subjects

Twenty subjects (13.1 ± 0.9 years of age) who successfully worn tinted lenses for a period of at least 6 months were recruited for the study from the practice of a local optometrist.

These subjects initially attended the optometrist because of the signs and symptoms of visual stress and discomfort described herein, which were not alleviated by conventional optometric and/or orthoptic treatment.

Before prescription of tinted lenses, patients had reported a sustained benefit (a reduction in symptoms of asthenopia and perceptual distortions) from the voluntary use of a colored overlay (one school term or semester). Only then were patients examined for the prescription of tinted lenses using the Intuitive Colorimeter (Cerium, Kent, UK), an apparatus that allows the independent control of hue and saturation without any change in luminance.[15]

Twenty-one control subjects (12.6 ± 2.2 years of age) were also tested on the same series of tasks. These subjects comprised an opportunity sample from siblings of the staff and students at the University of Essex. All experimental procedures followed the tenets of the Declaration of Helsinki, and informed consent was obtained after the nature and possible consequences of the experiment had been explained.

Apparatus and Stimuli

Stimuli were generated by computer (Macintosh G3; Apple, Cupertino, CA) using software adapted from the VideoToolbox routines (available without charge at http://www.vision.nyu.edu/VideoToolbox, host institution, New York University).[16] Images were displayed on a multiscan gray-scale monitor (model 400PS, Trinitron; Sony, Tokyo, Japan) at a frame rate of 75 Hz and a mean luminance of 50 candelas (cd)/m^2. The luminance of the display was linearized to a pseudo 12-bit resolution with an ISR video attenuator[17] and calibrated with a photometer (Minolta, Osaka, Japan). Pseudo 12-bit resolution in this case allowed the presentation of 2^8 monochrome levels from a possible 2^{12} levels. Images were presented in gray-scale by amplifying the monochrome signal and driving the red-green-blue guns equally. The display was 9° horizontally (1152 pixels) by 6.8° vertically (870 pixels) and was viewed binocularly in a dark room from a distance of 230 cm. Conventional psychophysical procedures were used throughout. Observers were required to perform two-alternative forced-choice (2-AFC) discriminations, with auditory feedback provided for incorrect responses. In those subjects wearing tinted lenses this measurement was repeated both with and without the lenses, in random order. Stimulus levels were varied from trial to trial according to an adaptive staircase Quality, Utilization, Effectiveness, Statistically Tabulated (QUEST) procedure designed to concentrate observations near threshold level.[18] The raw data across a minimum of four runs for each condition for each observer were combined and were fitted with cumulative normal psychometric functions by a least χ^2 fit. From this fit, the thresholds and 95% confidence limits were estimated at the 75% correct point with standard methods.[19]

Spatiotemporal Contrast Sensitivity

Spatiotemporal contrast sensitivity for static and counterphase flickering sinusoidal grating stimuli were measured using a 2-AFC staircase technique. Each trial consisted of an interval in which the stimulus was presented 2.5° to the right or to the left of a central fixation cross at random. The observer's task was to fixate the cross and to identify by pressing the mouse button on the side on which the stimulus was presented. Stimuli were horizontally oriented, static sinusoidal gratings, with a spatial frequency of 0.8, 2.4, or 9.6 cyc/deg. In two additional conditions, the 0.8- and 2.4-cyc/deg gratings were counterphase flickered at a temporal frequency of 15 Hz. Spatial and temporal phase was randomized every trial. Stimuli were presented in a gaussian spatial ($\sigma_{x,y}$ = 1°) and temporal (σ_t = 213 msec) envelope, the peak contrast of which was varied by the QUEST staircase to concentrate observations at a 75% correct level. The five conditions were randomly interleaved, with 16 presentations of each condition per run. There were four runs per condition, resulting in a total of 64 observations per point.

Contrast Increment Thresholds

Contrast discrimination thresholds were again measured in a 2-AFC paradigm. Two static sinusoidal gratings were presented simultaneously 2.5°either side of a central-fixation cross. The stimuli were circular patches (4° in diameter, with a 15-arc min raised-cosine spatial envelope) presented in a raised-cosine temporal envelope (1 second with 100-msec onset and offset). The subject was instructed to fixate the cross and to identify which grating (right or left) had the higher contrast. Apart from a phase randomization every trial, the two gratings were identical in all respects, except that they varied in contrast. The contrast of one grating, referred to as the standard, was constant across trials, whereas that of the comparison was varied by the QUEST staircase to concentrate observations at a 75% correct level. The standard contrast was fixed at either 16%, 32%, or 64%. The contrast of the comparison grating was always higher than that of the standard, by ΔC. The order of testing the three standard contrasts was counterbalanced across subjects. Within each standard contrast condition, six spatial frequencies (1, 2, 4, 6, and 8 cyc/deg) were tested in random order. Each run contained 32 trials per condition, with four runs per psychometric function, with the result that each point was based on 128 observations.

Motion Perception

The minimum motion threshold (D_{min}) refers to the smallest displacement that can be reliably detected.[20–22] In this experiment, the stimuli were horizontally oriented, sinusoidal gratings with a Michelson contrast of 64%, with spatial frequency of 1, 2, 4, 6, or 8 cyc/deg, with phase randomized for each trial. Two sinusoidal gratings of the same spatial frequency were presented simultaneously on either side of a central-fixation cross. The stimuli were circular patches (4° in diameter, with a 15-arc min raised-cosine spatial envelope) and were presented in a raised-cosine temporal envelope (1 second with 100-msec onset and offset). At a random point during the central 500 msec of the interval, one of the two gratings was abruptly displaced by an amount determined by the QUEST staircase. The observer's task was to identify which grating (right or left) had moved. There were 32 presentations per run and four runs per psychometric function, resulting in 128 observations per point.

Random-Dot Motion Coherence

Motion sensitivity was also measured with a motion-coherence task.[21] In this task, the elements in a field of random dots can either move coherently (signal dots) or in random directions (noise dots). Sensitivity was determined by measuring the proportion of signal dots required to detect the direction of coherent movement on 75% of trials. There were 100 dots—50 white (99 cd/m^2) and 50 black (1 cd/m^2)—drifting at 2.5° per second. Each dot subtended 2 arc min and had a limited lifetime of two frames (a single displacement), after which it was randomly relocated. Dots were constrained to fall within a circular aperture subtending 4°, except for a central-fixation circle subtending 0.5°, to facilitate steady fixation. Dots falling outside the viewing area were randomly repositioned. The observer's task was to fixate a central cross and to indicate whether the signal dots had moved to the left or right. There were 32 presentations per run and four runs per psychometric function, resulting in 128 observations per point.

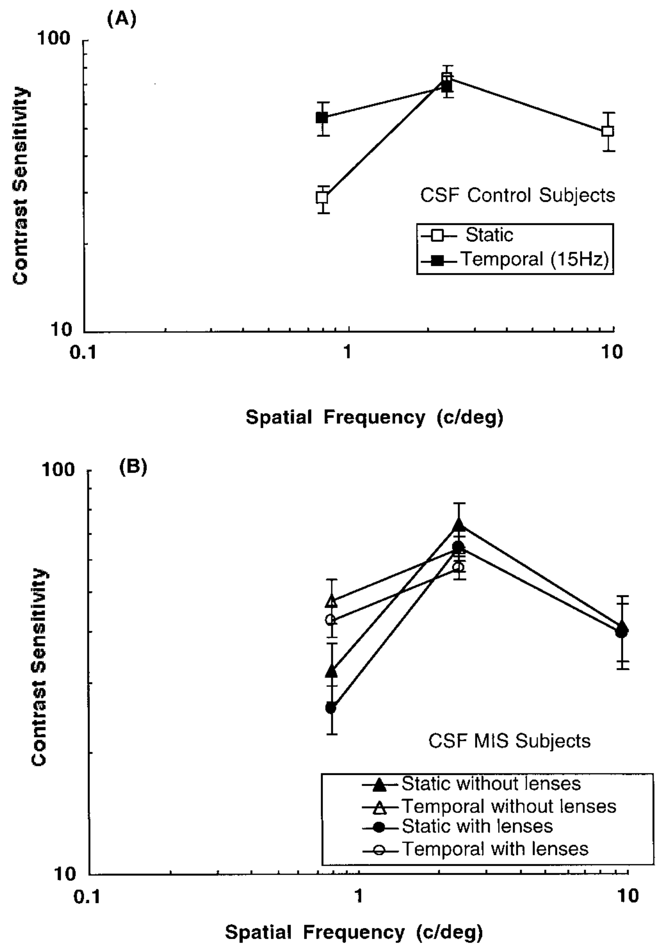

FIGURE 2. Spatiotemporal contrast sensitivity curves in (**A**) control subjects and (**B**) subjects with MIS, with and without tinted lenses. Error bars represent ±1 SEM.

RESULTS

For ease of interpretation, the results of this study have been divided according to task.

Spatiotemporal Contrast Sensitivity

Contrast sensitivity functions can be seen in Figure 2 for both the control (Fig. 1A) and MIS subject groups (Fig. 1B) for both static and counterphase flickering stimuli. No selective loss could be demonstrated in the MIS subject group. A two-factor analysis of variance (ANOVA) revealed a significant effect of spatial frequency ($F_{4,141}$ = 10.27, P = 0.001), no significant effect of viewing condition (normal versus MIS with lenses, versus MIS without lenses; $F_{8,141}$ = 1.02, P = 0.36), and no significant interaction ($F_{8,141}$ = 0.44, P = 0.89) demonstrable.

Contrast Increment Thresholds

In all viewing conditions, contrast discrimination thresholds increase with spatial frequency of the stimuli.[23] Figure 3 shows the results plotted for both the control (Fig. 3A) and MIS (Fig. 3B) subject group to reveal the effect of standard contrast. With a standard contrast of 64%, discrimination thresholds are somewhat higher, and this was true for both subject groups. However, at each standard contrast, a two-factor ANOVA revealed a significant effect of spatial frequency ($F_{4,530}$ = 32.91, P = 0.0001), no significant effect of subject group (F_{1530} =

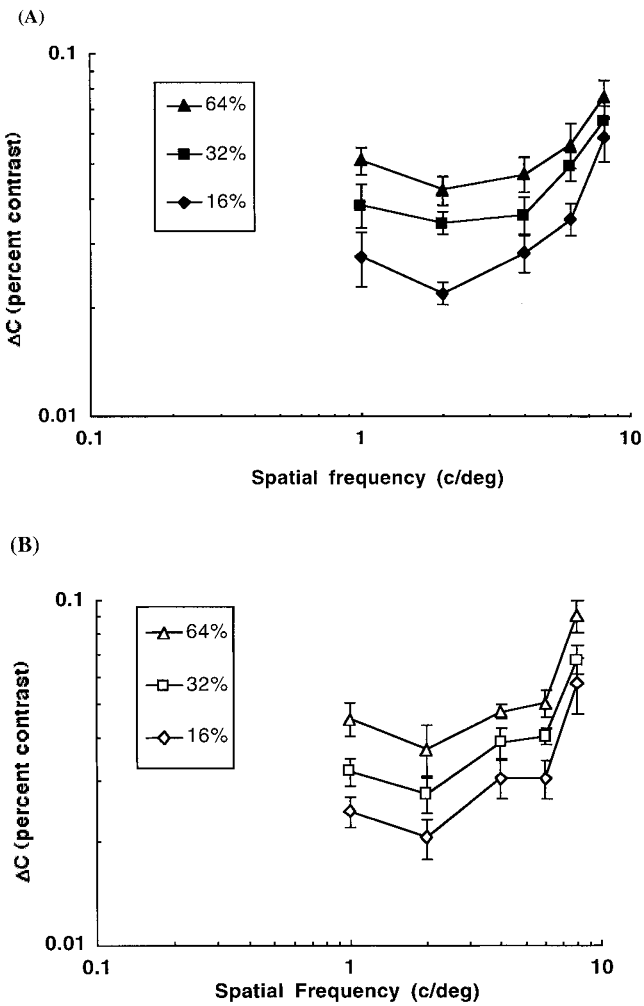

Figure 3. Contrast increment plots in (**A**) control subjects and (**B**) subjects with MIS, without tinted lenses. Error bars represent ±1 SEM.

0.55, $P = 0.46$), and no significant interaction ($F_{4,530} = 1.36$, $P = 0.26$).

Figure 4 shows the same data replotted to reveal the effect of the tinted lenses. No significant difference in contrast discrimination thresholds was evident in the MIS subject group, with or without lenses. ANOVA again revealed a significant effect of spatial frequency ($F_{4,470} = 37.96$, $P = 0.0001$), no significant effect of viewing condition ($F_{1,470} = 0.59$, $P = 0.44$), and no significant interaction ($F_{4,470} = 1.83$, $P = 0.12$).

Motion Perception

Measures of D_{min} are presented in Figure 5 for both the control (Fig. 5A) and MIS (Fig. 5B) subject groups. Factorial analysis of variance revealed a significant effect of spatial frequency ($F_{4,300} = 179.77$, $P = 0.0001$), no significant effect of subject group ($F_{2,300} = 2.56$, $P = 0.07$), and no significant interaction ($F_{8,300} = 0.08$, $P = 0.99$).

Coherence thresholds also demonstrated no significant difference between subject group (normal versus MIS; $F_{1,41} = 0.14$, $P = 0.72$) or indeed viewing condition (with versus without lenses; $F_{1,41} = 1.37$, $P = 0.25$). These results are illustrated in Figure 6.

Discussion

If it is assumed that the reduction in unpleasant somatic and perceptual symptoms with the use of tinted lenses is based on

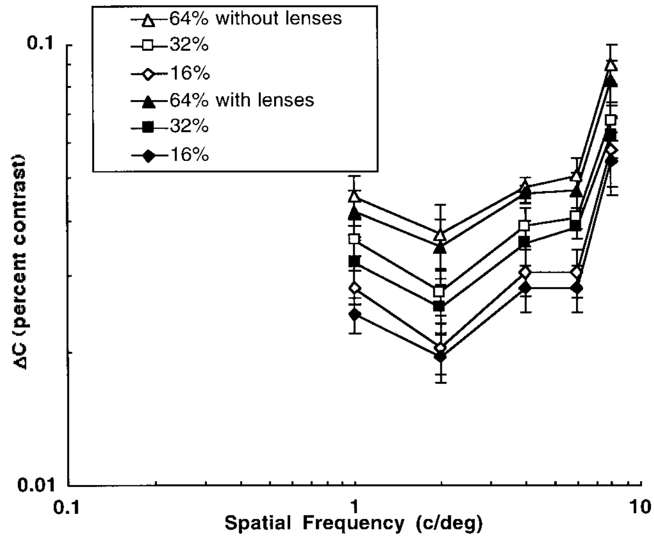

Figure 4. Contrast increment plots in subjects with MIS, with and without tinted lenses. Error bars represent ±1 SEM.

response changes in the early stages of visual processing rather than at later cognitive stages or through a placebo effect, then it should be possible through task-specific psychophysical assessment of visual function to reveal the underlying physiological basis for this apparent improvement.

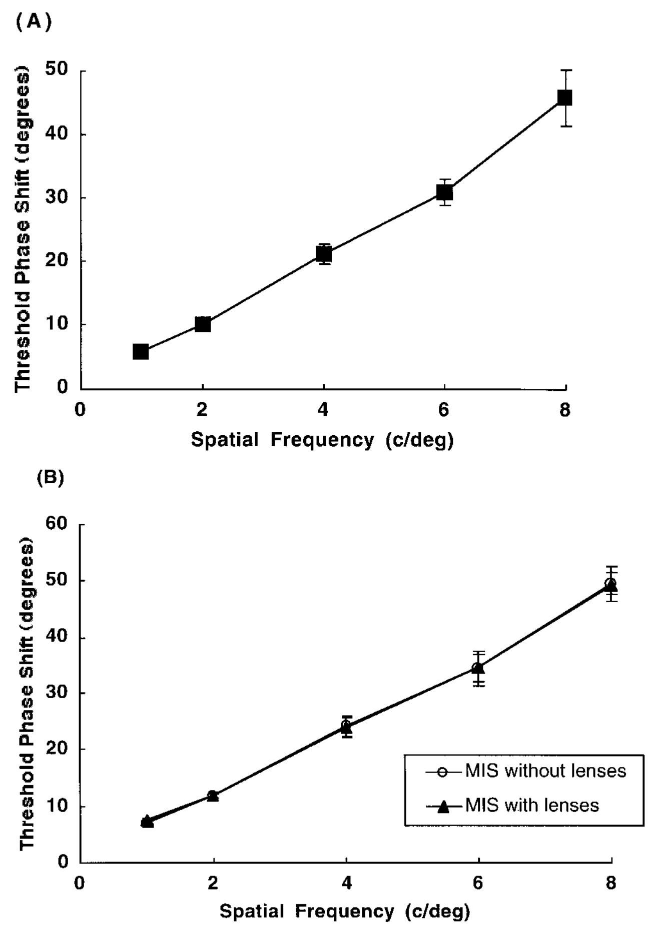

Figure 5. D_{min} scores in (**A**) control subjects and (**B**) subjects with MIS, without the use of tinted lenses. Error bars represent ±1 SEM.

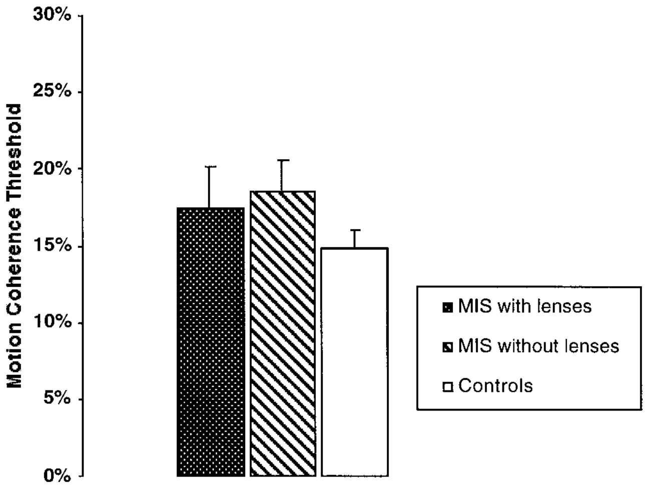

FIGURE 6. Coherence threshold scores in percentages in control subjects and subjects with MIS, with and without tinted lenses. Error bars represent ±1 SEM.

A spatial model alone does not appear adequate to explain the dynamic distortions in subjects with MIS, but information combined from both spatial and temporal channels may well suffice. The current series of experiments were designed to compare the ability of subjects with MIS with that of age-matched control subjects in a range of spatiotemporal tasks.

The significant main and interaction effects for the spatiotemporal contrast sensitivity data reflect well-established norms for contrast sensitivity. Visual inspection of data reveals a peak at 2.4 cyc/deg for both the static and counterphase (15 Hz) stimuli in both subject groups (Fig. 2). If we are to believe that MIS-affected children comprises a group of poor readers, these nonsignificant differences in contrast sensitivity between the static and counterphase stimuli contradict previous findings of a transient system deficit in specific reading disability groups,[24,25] reflecting both the inhomogeneous nature of MIS and its dichotomy in dyslexia.

To evaluate the effect of what appears perceptually as oversaturated stimuli, we investigated contrast thresholds over a range of spatial frequencies at three standard contrast levels. At each standard contrast no significant difference in contrast discrimination thresholds was evident either in either subject group (MIS versus normal observers) or viewing condition (with versus without lenses).

None of the participants in this study reported adverse perceptual or somatic effects from viewing the stimuli, although these stimuli had a spatial frequency, contrast, and angular subtense previously shown to be aversive.[4,7,26,27] Our stimuli, however, had a duration of 1 second, which is a considerably shorter presentation time than had previously been used.[3]

If indeed these individuals have a phenomenological experience of an unstable visual world, a measurable difference might be expected in motion discrimination thresholds compared with those in visually normal observers. However, on both measures of motion discrimination, the performance of subjects with MIS (with versus without lenses) was similar to that of control observers. Again, these nonsignificant results are not consistent with recent research in which specific reading disability groups and normal readers have been differentiated through measures of motion coherence.[28,29] The noncorrelation of findings in this and other studies may be due to methodological differences. In our study all random dots had a limited lifetime, ensuring that tracking of the stimuli would not be possible. Also the stimuli comprised both black and white dots on a gray background compared with black on white or vice versa. This prevents the detection of motion based on low-frequency components in the stimuli.

However, it should also be acknowledged that the transient system deficit in specific reading disability groups is described as small and correlated with the severity of the disability. Many subjects with MIS may simply not fit into this category, and if indeed a transient system deficit is ultimately shown to be at the basis of specific reading disability, it would still fail to provide a complete explanation for the atypical benefits reported from the use of tinted lenses.

In conclusion, the present results show typical patterns of visual sensitivity in normal observers and those with high visual stress across a range of psychophysical measurements, demonstrating the sensitivity of the techniques used. They nevertheless fail to show any difference between subject group (control versus MIS). This finding is consistent with the absence of any objectively demonstrable visual benefit achieved through the use of tinted lenses in the group with MIS. It remains possible that other tests of visual performance may be more sensitive,[30] but this must be demonstrated with more rigorous psychophysical procedures.

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