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Optometric function in visually sensitive migraine before and after treatment with tinted spectacles

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Abstract

Optometrists frequently encounter patients with migraine and patients and practitioners sometimes suspect that visual stimuli or visual anomalies trigger headaches. There is a lack of evidence-based research on the issue, however. Some patients with migraine may be hypersensitive to visual stimuli, and it has been suggested that individually prescribed coloured filters might be an effective treatment to reduce symptoms from such stimuli. A recent randomised controlled trial showed such a treatment to be effective and the present paper reports on the optometric characteristics of the patients in this study. Twenty-one patients with neurologically diagnosed migraine were compared with 11 controls. No significant differences were found between the two groups with respect to refractive error, ocular pathology, colour vision, contrast sensitivity, accommodative function, strabismus and hyperphoria. The migraine group tended to be a little more exophoric, but by most criteria they were able to compensate for their exophoria as well as the control group. The migraine group were more prone to pattern glare than the controls ($p = 0.004$). The effects of precision tinted and control tinted lenses were investigated. The only variable to show a consistent and marked improvement with tinted lenses was pattern glare. The most likely mechanism for the benefit from individually prescribed coloured filters in migraine is the alleviation of cortical hyperexcitability (Wilkins *et al.* 1994) and associated pattern glare.

Keywords: migraine, headache, vision, tinted lenses

Introduction

At least 8% of the adult population suffers from migraine (Bates *et al.*, 1993) and UK male sufferers alone lose 4 million working days a year with an estimated productivity loss of £750 million. Headache is one of the most common symptoms reported by patients consulting optometrists with 8% of young patients seen in an optometric practice reporting this symptom (Barnard and Edgar, 1996). As migraine accounts for as many as 54% of all headaches (Leone *et al.*, 1994), this suggests that optometrists are likely to encounter patients with migraine very commonly.

The aetiology of migraine is not fully understood. Although the existence of various vascular, hormonal and neuronal correlates of the headache has been fairly well-established, the role of these factors, if any, in the causal mechanism of the headache remains unclear. The progress of an episode varies, but attacks are often precipitated by a trigger which can be visual.

There are two potential ways in which optometrists might help patients with migraine. First, through aiding the early diagnosis of the condition and referring for appropriate medical management. Most patients (70%) with migraine treat themselves and do not consult a medical practitioner (Bates *et al.*, 1993). Although non-prescribed analgesics are sometimes the only treatment that is required, many cases benefit a great deal more from prescribed medication. Most studies suggest that

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more than 50% of cases can be treated effectively with modern drugs for the acute treatment or prophylaxis of migraine (Tfelt-Hansen, 1996).

The second role of optometrists may be in relieving visual triggers (precipitating factors). Triggers for migraine include stress, dietary substances (e.g. alcohol and various foodstuffs), irregular sleep patterns and visual factors (Hay *et al*., 1994). It is surprising that despite a very large body of research on the neurophysiological correlates of migraine, there has been relatively little research on the precipitating factors. Putative visual triggers for migraine can be divided into two categories: optometric anomalies and stressful visual stimuli (stimuli that cause visual discomfort and/or visual perceptual distortions).

Optometric anomalies as a trigger for migraine

Turville (1934) argued that low convergent and divergent fusional reserves are correlates of migraine and that base in prisms are an effective treatment for many cases of severe classical migraine. Although he described 123 such cases, his study was not controlled and it seems likely that a referral bias was present in his clinical sample. He did not clearly establish whether binocular vision anomalies were correlated with migraine, nor whether base in prisms were more effective than a placebo.

In a study of 116 cases, Wilmut (1956) claimed that 91% of patients with migraine had a near exophoria that may have been decompensated, as assessed by a polarised test with a fusional lock that was only peripheral (see Evans, 1997a, pp. 52–61). Wilmut's (1956) study seems to be of a clinical sample and therefore suffered from a referral bias. Nonetheless, he did cite some data from a population of control subjects, and the type of exophoria that he found in 91% of the migraine group was present in only 25% of the controls. Few details of the control subjects were provided. It seems unlikely that this study investigated the effect of treatment with a randomised controlled design, but 47% of cases of migraine were said to be 'cured' with prisms.

A study by Waters (1970) avoided a referral bias by randomly selecting subjects who then underwent an ophthalmological investigation by an examiner who was unaware of the subjects' headache history. This study found a higher prevalence of hyperphoria in a group of patients with migraine. Unfortunately, the data on horizontal heterophoria in this study are difficult to interpret because: (1) esophoria and exophoria were grouped together, (2) these data were reduced to coarse subdivisions rather than being analysed as continuous variables, and the (3) Maddox rod test was used which assesses the full heterophoria rather than the decompensated element (Evans 1997a, pp. 43–64) and is therefore likely to correlate only relatively poorly with symptoms (Yekta *et al*., 1989).

Despite the lack of rigour of these studies, it is still commonplace for patients seeking a solution for their migraine to consult optometrists and it is not uncommon for optometric interventions, be they refractive or orthoptic, to be prescribed in an attempt to reduce the prevalence or severity of migraine attacks.

Stressful visual stimuli as triggers for migraine

People who suffer from migraine are more prone to photophobia than those who suffer tension headache or no headache. Photophobia is greatest when a headache is present, but even between attacks headache sufferers are still significantly more prone to photophobia than controls (Drummond, 1986). Photophobia is also common in children who suffer from migraine. Metsahonkala and Sillanpaa (1994) found that 3% of 3580 8–9-year-old children suffered from migraine and 94% of these had photophobia as a symptom.

A distinction should be drawn between symptoms from visual stimuli (e.g. photophobia) which occur at different times in the migraine cycle. For example, the photophobia may be associated with an initial trigger for a migraine attack, or occur during a migraine attack, or between episodes of migraine. Vincent *et al*. (1989) studied 165 patients suffering from chronic headaches, but did not investigate how many of their subjects had migraine. Bright light, reading, visual display units, and television precipitated headaches in 29, 16, 15 and 6%, and aggravated pre-existing headaches in 73, 55, 31 and 28%, respectively.

Wilkins *et al*. (1984) found that some visual stimuli can be stressful and can result in visual discomfort and migraine headaches. Striped patterns were found to be especially stressful and the term *pattern glare* was introduced as a description by Wilkins and Nimmo-Smith (1987). The latter authors showed that lines of printed text can form a striped pattern with spatial properties that might elicit pattern glare. Marcus and Soso (1989) found that pattern glare was particularly common in migraine sufferers. Wilkins (1991) hypothesised that visual discomfort from striped patterns, including text, could be reduced by restricting the area of the striped pattern, changing the typography of text, or using coloured overlays.

There have been several studies of visual function in patients with migraine, some supporting the idea that there exist visual deficits (e.g. Coleston *et al*., 1994; McKendrick *et al*., 2000), not all of them reliable (see Wray *et al*., 1995; vs Palmer and Chronicle, 1998). Some of the deficits have been taken as support for the notion of a cortical hyperexcitability (Wilkins *et al*., 1984; Wray *et al*., 1995). Whatever the basis for the visual

deficits, they are subtle, usually related to duration of illness (Khalil, 1991; Wilkinson and Crotogino, 2000) and involve colour vision (Shepherd, 1999). This may explain why Chronicle and Wilkins (1991) were able to show that people with migraine have colour preferences different from age- and sex-matched controls. These preferences may be the basis of reports of benefits from wearing coloured filters. Good *et al.* (1991) investigated 20 children with migraine. They found that coloured glasses significantly reduced the frequency of migraines and a rose tint was more effective than a blue tint. Wilkins *et al.* (1992) described a new instrument, the Intuitive Colorimeter, which could be used to find the colour of filter optimal for reducing a person's symptoms. This apparatus is used in conjunction with a range of 'precision tinted' lenses, which allow for the accurate specification and manufacture of individually prescribed tinted lenses.

Wilkins *et al.* (1992) described some case studies of individuals who had been successfully treated with this instrument, including two cases of severe migraine. Maclachlan *et al.* (1993) reported an open trial of 55 patients with visual discomfort, who had been treated with the Intuitive Colorimeter and Precision Tints. Seventy-six per cent of the patients had symptoms of visual discomfort, and 64% suffered from headache, although only 7% had received a neurologist's diagnosis of migraine. Eighty-six per cent of the total sample had a family history of migraine. A family history of migraine was twice as likely in those who found colour helpful. When followed-up after 6 months, 83% of the sample were still using their tinted lenses.

Wilkins *et al.* (1994) carried out a double-masked randomised controlled trial of the use of the Intuitive Colorimeter and Precision Tints for children with reading difficulties and asthenopia who had reported a benefit from coloured overlays. Individually prescribed coloured filters were found to significantly reduce symptoms of eyestrain and headaches although migraine was not specifically investigated. This syndrome of symptoms and benefit from individually prescribed coloured filters in people with reading difficulties has been described as Meares–Irlen syndrome (Evans, 1997b). The mechanism of the beneficial effect from the tinted lenses was investigated by Evans *et al.* (1995, 1996). They found that, although children with Meares–Irlen syndrome have slightly reduced fusional and accommodative amplitudes, the most likely explanation for the benefit from the filters was pattern glare. There is anecdotal evidence suggesting that at least some people with Meares–Irlen syndrome may be suffering from visually precipitated migraine (Evans *et al.*, 1999).

Chronicle (1993a) and Hay *et al.* (1994) noted that visual stimuli are common precipitants of migraine attacks and that the subjective discomfort of a pattern relates to the likelihood of its being a trigger for migraine. Chronicle (1993a) found that, on average, migraine patients reported greater discomfort with red light than with blue and performed significantly worse at a target identification task with red than with blue light.

Wray *et al.* (1995) hypothesised that 'what may be inherited in migraineurs is an abnormal biological threshold to a variety of visual stimuli'. Wilkins (1995) detailed a hypothesis that the mechanism for pattern glare is localised cortical hyperexcitability which can be ameliorated by coloured filters that change the distribution of normal neuronal activity in the cortex. In this way, individually prescribed coloured filters might help patients with photosensitive migraine and with photosensitive epilepsy. An open trial of the use of precision tinted lenses in photosensitive epilepsy found that 57% of patients report benefits and 18% report a reduction in seizures (Wilkins *et al.*, 1999).

There are therefore grounds for believing that visual stimuli, including text, can trigger visual discomfort and headaches in a proportion of migraine sufferers and that such cases could be treated with individually prescribed tinted lenses. To further investigate this an open trial was undertaken followed by a double-masked randomised placebo-controlled trial. The trial methodology and clinical findings relating to headache from this study are reported elsewhere (Wilkins *et al.*, in press). In short, these studies found that individually prescribed precision tinted lenses significantly reduce the frequency of migraines, in visually sensitive patients. The literature also provides anecdotal support for the hypothesis that certain optometric anomalies, especially decompensated exophoria, may be prevalent in migraine and it is possible that these anomalies might be related to the benefit from coloured filters. The present paper reports on a detailed optometric assessment of the subjects in the randomised controlled trial of Wilkins *et al.* (submitted), with the goals of determining: (1) whether any optometric factors are correlated with migraine in this sample, (2) whether any such correlates might need treatment, and (3) whether they might explain the benefit from coloured filters.

Methods

Subjects

The experimental subjects were 21 patients who were referred from various sources (neurologist, GP, optometrist). These sources were asked to refer patients with medically diagnosed migraine, no concurrent neurological pathology, at least two headaches every month, no change in medication for the last 3 months, and who were able to attend the Institute of Optometry. These patients were screened with coloured overlays (Wilkins,

1994) and, if they reported a benefit, they were given an overlay of their preferred colour to use as and when they wished.

The optometric/ophthalmological exclusion criteria for the study were that subjects: (1) had used their coloured overlay whilst reading for at least a month and reported that this improved their symptoms, (2) were not receiving any current ophthalmic or orthoptic treatment (if spectacles were about to be changed then entry to the study was postponed until after the patient had adapted to the new spectacles), and (3) did not already wear tinted spectacles (excluding the commonplace use of sunglasses). The latter exclusion criterion was necessary because participants who already wore glasses were provided with clip-over precision tinted lenses. Twenty-one patients met these criteria and were entered into the study. They had a mean age of 44 years (range 17–54 years) and 86% were female.

For the research, diagnoses of migraine were undertaken by a neurologist. Twelve patients had migraine with aura, and five had migraine without aura; according to the IHS criteria (Headache Classification Committee of the International Headache Society, 1988). Further details of subjects can be found in Wilkins *et al.* (submitted). The patients were instructed to continue their medication as usual during the trial.

Optometric data were available for all 21 experimental subjects, although only 17 completed the randomised controlled trial. The protocol stated that, after the initial optometric examination, three additional criteria had to be met for subjects to enter the randomised controlled trial phase of the study: (1) any appropriate refractive correction should be worn, (2) there should be no ocular disease or medical condition (other than migraine) likely to affect visual function, and (3) there should be no clinically significant anomaly of ocular motor function. No subjects were excluded from the clinical trial for any of these reasons.

When attending for the first research assessment, experimental subjects were asked to bring a friend of the same gender and of a similar age, but who did not suffer from migraines and who experienced no more than 12 headaches a year. Eleven of these control subjects attended.

Procedure

The design and procedure for the randomised controlled trial is described by Wilkins *et al.* (submitted), including details of the colorimetry assessment, tint characteristics, and symptom assessment. These methods are similar to those described by Wilkins *et al.* (1994). Experimental subjects were tested with the Intuitive Colorimeter, as described by Wilkins *et al.* (1992), to determine each subject's optimal chromaticity for reducing symptoms of visual discomfort and perceptual distortions. This chromaticity was later used to manufacture a pair of 'active tints', those that under a white halophosphate fluorescent light source (CIE Type F3) gave light with a matching chromaticity. For each subject, a pair of 'control tints' was also manufactured, of a similar saturation but approximately six JNDs different in chromaticity (Wilkins *et al.*, in press). The chromaticities of the active and control tints (under the equal energy illuminant) are shown in *Figure 1*, the active tints by square points, joined by lines to the chromaticities of the control tints.

Three weeks after the initial research appointment the subject was sent a pair of glasses (or clip-on lenses to wear over existing glasses) incorporating either the active or control tints, selected at random. As a result of colour adaptation, subjects were unaware of the exact colour that they selected in the Intuitive Colorimeter and were unable to tell whether the tinted lenses were the active or control colour. The experimenter was unaware of which tint had been sent.

Subjects wore the coloured filters as and when they wished for 6 weeks and then sent them back to the manufacturers. At least 2 weeks later the second pair (active or control) was posted to the patient and these were also available for wearing for 6 weeks. From the time of the first testing with the Intuitive Colorimeter to the end of the period when the second tints were worn, patients completed daily symptom diaries detailing any headaches and eyestrain (or eye pain) that they experienced.

At the time of the first colorimeter assessment, the experimental and control subjects were given a range of optometric tests, including visual acuities, refraction,

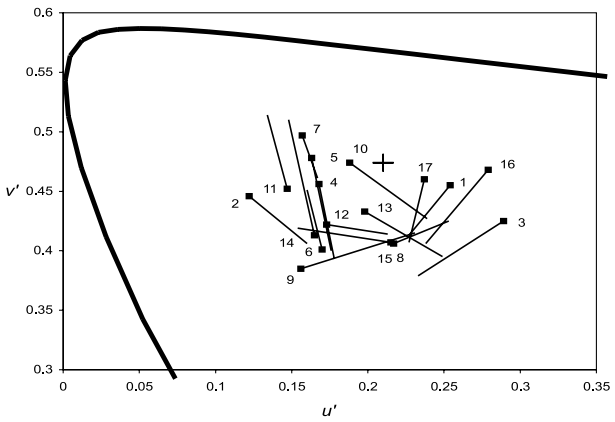

Figure 1. CIE 1976 UCS diagram showing the chromaticities of the tinted lenses used in Study 2. The chromaticity of each patients 'active' tint is shown by a square point and connected by a line to the chromaticity of the control tint. The distance from the cross is proportional to the saturation of the colour. The solid line shows the spectrum locus. The colour names are for guidance only.

orthoptic tests, contrast sensitivity testing and an assessment of pattern glare. The optometric assessment of the experimental subjects was repeated again at the end of the study three times: with the optimal tints, with the control tints and without any tinted lenses. Subjects were first tested with no tint, then with 'tint A' and then with 'tint B'. Tint A and B were randomly active or control and the experimenter did not know the identity of the tints at the time of testing.

Optometric tests

The optometric examination was the first meeting of the researcher (RP) with the subjects. The subjects who attended with a friend, to be a control, were asked in initial written instructions not to tell the optometrist which of them was the migraine sufferer and to 'toss a coin' to determine who was examined first. At the beginning of the eye examination, the optometrist explained that nothing the patient might say or do during the examination would prevent their trying out coloured lenses. The tests were carried out in the same order for all subjects.

All visual acuity, orthoptic, pattern glare and colorimetry tests were carried out with the patient wearing any refractive correction that they usually wore for tasks at the appropriate viewing distance. Lighting was a combination of conventional fluorescent strip lighting and an angle-poise incandescent spotlight with a 60-W bulb to give a luminance of 120 cd m^{-2} for the distance and near tests.

Ocular health was assessed by direct ophthalmoscopy and pupil reactions were assessed for symmetry, direct, indirect (consensual), near and afferent pupillary reflexes. Visual fields were tested using the suprathreshold 30° screening program with Henson CFA 3000 (Tinsley Medical Instruments, London, UK) and tonometry was checked as the mean of four readings per eye with the Pulsair 2000 (Keeler, Windsor, UK) noncontact tonometer.

The monocular and binocular visual acuities were recorded at distance with Bailey–Lovie LogMAR charts and at near with the similarly designed Lighthouse LogMAR charts. Refractive errors were assessed by conventional distance fixation retinoscopy and subjective refraction, but only the subjective results were statistically analysed.

The cover–uncover test (Evans, 1997a, pp. 15–20) was carried out at distance and near to identify strabismus using a target from the relevant LogMAR chart from the line above the patient's worse monocular acuity. Cover test recovery was scored according to the rapidity and smoothness of any phoria recovery movement as good, average, poor, or readily breaking down. Ocular motility was assessed with a white 4 mm target on black stick, using the star technique, with the target moved from the centre to the periphery in about 4 s (Evans, 1997a, pp. 22–23). The aligning prism (associated heterophoria) was assessed with the distance and near Mallett unit fixation disparity test, following the protocol recommended by Evans (1997a; Figure 4.3). The horizontal and vertical dissociated heterophoria was assessed at distance with a white Maddox rod carried out first with the rod in front of the left eye (right eye fixing) and then with the rod in front of the right eye. Assessing the dissociated heterophoria with each eye fixing in turn detects anisophoria which can be a sign of subtle incomitancy (Evans, 1997a, p. 229).

The near dissociated heterophoria was measured with a Maddox wing test, using a modified method to assess any binocular instability. The eye which sees the arrow was initially covered and the cover was then removed for 1 s and a note of the horizontal phoria was made. After the cover had been in place for a further 5 s, it was removed for 1 s for another measurement. This procedure was repeated until five measurements had been taken. The mean of the five readings was calculated, as well as the standard deviation (S.D.) to gain a measure of any binocular instability (Evans, 1997a, pp. 65–70). Still with the Maddox wing in place, a +2.00DS lens was then introduced before both eyes and, after the patient had adapted by focussing on the numbers for a few seconds, the cover was again removed and a further reading taken to calculate the AC/A ratio (Evans, 1997a, p. 28). The +2.00DS lenses were then removed and one reading of the vertical deviation was taken.

The near point of convergence was recorded with an RAF rule, with the target being moved at a speed such that the stimulus to accommodate was changed at an approximate rate of 1 D s^{-1}. The subject's eyes were observed to ascertain the objective break point.

Fusional reserves were measured at distance using a refractor head with binocular rotary prisms and at near with a variable prism stereoscope, using a small detailed target vertically placed on the visual axis. The prisms were adjusted at approximately 1Δ s, and the blur (if present), break, and recovery points were recorded. For each distance, two readings were taken of the divergent reserves and then, after a 30-s break, two readings of the convergent reserve. Each pair of readings were averaged for the data analysis and an additional variable of break minus recovery was calculated. Also, the fusional amplitudes were calculated (amplitude between convergent and divergent blur or, if there was no blur, break points).

Percival's and Sheard's criteria are two clinical methods of analysing whether a heterophoria is compensated (Evans, 1997a, pp. 51–52). Percival's criterion states that, at a given distance, the fusional

reserves (to break point) should be balanced so that one should not be less than half the other. Sheard's criterion states that, at a given distance, the fusional reserve (to blur point) that opposes the heterophoria should be at least twice the degree of the phoria. The extent to which the subjects met these criteria at each distance was calculated in two ways. First, in the conventional way as a simple pass/fail binary variable. Second, formulae were derived which calculated how adequately each subject passed each criterion, as a continuous variable on an interval scale. These continuous variables were termed Percival's value and Sheard's value.

Global stereopsis was assessed with the Randot (Haag-Streit UK, Harlow, UK) random dot shapes and local stereo-acuity was assessed with the contoured Randot circles, in the method recommended in the manufacturers instructions. Foveal suppression was measured at distance and near using the Mallett polarised letters test, as recommended by Evans (1997a, pp. 61–62).

The amplitude of accommodation was recorded using the RAF rule, for each eye and under binocular conditions. The patient fixed the N5 line of letters, or the smallest line visible at 30 cm and the target was moved in at the approximate rate of 1 D s^{-1}. The text was moved towards the patient until it was reported that the text was too blurred to read and it was then moved out until it became just clear enough to read. It was this amplitude to recovery that was recorded, in dioptres. Accommodative lag in each eye was assessed by the monocular estimate method (MEM) of dynamic retinoscopy (Cooper, 1987).

Colour vision was investigated with three tests under indirect natural daylight conditions or with an incandescent lamp with an appropriate filter to convert the output to a daylight equivalent. The colour vision tests that were used were the Ishihara (for each plate, the subject was scored as: correctly read/misread/no figure visible; Birch 1997), City University Test (Mark. 2), and Farnsworth D15.

Psychophysical tests

Spatial contrast sensitivity was assessed with the Vistech test at a distance of 30 cm, so that the spatial frequencies of the targets were 1, 2, 4, 8 and 12 cpd (Evans *et al*., 1994). All three cards were used (Kennedy and Dunlap, 1990; Evans *et al*., 1994) and the three results at each spatial frequency were averaged.

Pattern glare was assessed by asking patients about the symptoms of perceptual distortions that they experienced when binocularly viewing a 3 cpd square-wave grating (Wilkins *et al*., 1984). To control for suggestibility, patients were also asked the same questions whilst they viewed a control grating, of 0.5 cpd; a spatial frequency that would not be expected to induce pattern glare. The gratings were laser printed and were circular in outline with a diameter of 10 cm. They were orientated horizontally and were viewed at the testing distance of 0.4 m. The protocol stated that subjects with a history of epilepsy were to be excluded from the pattern glare testing, but none had such a history.

The seven questions that were asked to elicit any symptoms of pattern glare were 'Do you see a colour or colours?', 'Do the lines appear to bend?', 'Do the lines seem to blur?', 'Does the pattern flicker?', 'Do the lines wobble or shimmer?', 'Do parts of the pattern disappear and reappear?', and 'Do you see any other patterns, shapes, or glare? (please specify)'.

Subjects were asked to view each grating for 5 s and to fix a small dot in the centre of the grating. An ABBA design was used so that subjects were first shown the control grating and asked to answer the first question, then the experimental grating for the first question, then the experimental grating for the second question, then the control grating for the second question, then the control grating for the third question, and so on. Subjects were asked to quantify their response to each question as 'none' (scored as 0), mild or 'a little' (scored as 1), and severe or 'a lot' (scored as 2).

Follow-up appointment

To assess whether the baseline optometric status had changed, many of the tests described above were repeated at the follow-up appointment by the same optometrist as had carried out the initial examinations (RP). Variables were statistically tested according to *a priori* hypotheses which are explained in the Results section.

Results

The randomised controlled trial showed that the frequency of headaches was significantly lower when the optimal tint was worn, compared with the control, and this aspect of the study is reported in detail elsewhere (Wilkins *et al*., in press). The present paper concentrates on the optometric variables.

Binary variables (e.g. yes/no; pass/fail) were analysed with the χ^2-test, with continuity correction. Other comparisons used the unpaired *t*-test or, for data that were not normally distributed, the Mann–Whitney *U*-test. Two-tailed *p*-values were calculated for all statistics. Horizontal heterophoria data were considered both for sign (eso-deviations needing base out prisms as positive, exo-deviations requiring base in prisms as negative) and as unsigned variables (magnitude of deviation only). Vertical heterophorias were coded for magnitude only.

One subject wore monovision contact lenses (Evans and Thompson, 1991) and his data from some orthoptic tests (distance fixation disparity, distance dissociation test, near foveal suppression test, near fusional reserves, stereo-acuity) were excluded because of suppression.

First appointment

Optometric tests. Pupil reactions and ophthalmoscopic findings were within normal limits, except for one patient who had mild changes in the retinal vasculature suggestive of early arteriosclerosis. This patient was referred to his general practitioner (GP) for a cardiovascular investigation. Ocular tensions were in the normal range (10–21 mmHg) for all patients except three of the experimental group and two of the control group who had ocular tensions in the range 22–26 mmHg. This mild ocular hypertension was not of any clinical significance since visual fields and optic disc cupping were within normal limits in these and in all other patients.

The migraine group did not differ significantly from the controls in the monocular and binocular distance and near visual acuities (Mann–Whitney, $p > 0.25$). The monocular mean spherical component of the refractive error did not differ significantly in the two groups (*t*-test, $p > 0.12$). The degree of astigmatism was slightly higher in the migraine group ($n = 6$ in each group; *t*-test, right eye $p = 0.057$, left eye $p = 0.094$). The strength of near additions was not significantly different in the two groups (*t*-test, $p = 0.78$). The proportion of subjects who wore spectacles did not differ significantly in the two groups, whether for distance or near (χ^2, $p > 0.1$).

None of the subjects had a heterotropia (strabismus) at distance or near on cover testing. Only one subject (migraine group) had a poor recovery movement on the distance cover test and all near cover test recovery results were graded as good. No abnormalities were detected on ocular motility testing.

No subjects had a vertical fixation disparity at distance or near. A distance horizontal aligning prism (1Δ) was needed by just one member of the control group (aligning prism 3Δ out) and in three of the migraine group (one with an aligning prism of 2Δ in, two with 1Δ in). The difference between the two groups approached significance (Mann–Whitney, $p = 0.074$), but the absolute (unsigned) size of the aligning prism was not significantly different in the two groups (Mann–Whitney, $p = 0.69$). At near, only two members of each group manifested a significant (1Δ) horizontal aligning prism and both the signed and unsigned data were not significantly different in the two groups (Mann–Whitney test, $p > 0.5$).

The two groups did not differ significantly in the horizontal (signed, Mann–Whitney, $p = 0.46$; unsigned, *t*-test, $p = 0.54$) or vertical (Mann–Whitney, $p = 0.90$) distance dissociation test results, nor in horizontal or vertical anisophoria (Mann–Whitney, $p > 0.13$). The signed mean of the five readings of near horizontal dissociated heterophoria was a little more exophoric in the migraine group (mean 3.5Δ exophoria in migraineurs, 2.5Δ exophoria in controls), but this difference was not statistically significant (*t*-test, $p = 0.57$). The unsigned mean dissociated horizontal heterophoria at near was not significantly different in the two group (*t*-test, $p = 0.14$). The standard deviations of the five readings of the near horizontal heterophoria were not significantly different in the two groups (*t*-test, $p = 0.49$), nor was the AC/A ratio at near (Mann–Whitney, $p = 0.82$) and nor was the vertical near dissociated heterophoria (Mann–Whitney, $p = 0.62$).

The near point of convergence did not differ significantly in the two groups (Mann–Whitney, $p = 0.86$). The distance divergent fusional reserves were significantly lower in the migraine group, for blur (*t*-test, $p = 0.032$), break (*t*-test, $p = 0.047$), and recovery (*t*-test, $p = 0.019$), but not for break–recovery (*t*-test, $p = 0.28$). However, the equivalent distance convergent fusional reserves and fusional amplitude were not significantly different in the two groups (*t*-test, $p > 0.14$). Most importantly, at distance neither Percival's nor Sheard's values or criteria were significantly different in the two groups (*t*-test, $p > 0.7$), confirming that decompensated heterophoria at distance was not a feature of migraine in this sample.

All near divergent and convergent fusional reserve variables and near Percival's value were not significantly different in the two groups (*t*-test, $p > 0.17$). However, Sheard's value at near was significantly worse in the migraine group (*t*-test, $p = 0.032$), suggesting that decompensated heterophoria at near may be a feature of migraine in this sample. When Percival's criterion was treated in the conventional way, as pass/fail instead of a continuous variable, the two groups again did not differ significantly (only three of the controls and five of the migraine group failed Percival's criterion; χ^2 $p = 1.0$). When Sheard's criterion at near was treated in the conventional way, significantly more of the migraine group (10 subjects) than the control group (one subject) failed the criterion (χ^2 $p = 0.046$).

On the test of global stereopsis (Randot random dot shapes), all subjects achieved the test ceiling of 250″ except one control, who achieved the other available level of 500″. On the test of local stereo-acuity (Randot circles), the migraine group had slightly better stereo-acuity than the control group (Mann–Whitney, $p = 0.086$). No subjects had any foveal suppression at distance and only one subject had foveal suppression at near, but of an insignificant degree of 2 min of arc (for details of scoring, see Evans, 1997a, pp. 61–62).

The amplitude of accommodation did not differ significantly in the two groups (right, left, both eyes; Mann–Whitney, $p > 0.52$). Similarly, the accommodative

lag in either eye did not differ significantly in the two groups (Mann–Whitney, $p > 0.15$).

No subjects made any errors on the Ishihara colour vision test. One subject, from the control group, made one error (tritan) on the City University (Mark 2) colour vision test, but this subject made no errors on the Ishihara or Farnsworth D15 tests. One subject in the experimental group made two errors on the Farnsworth D15 test (four and five were interposed and 10 and 11 were interposed), but this subject made no errors on the Ishihara or City University tests. No errors were made by any of the other subjects in either of the three tests.

Psychophysical tests. The contrast sensitivity functions were similar in the two groups (*Figure 2*) and were transformed to log values for testing by analysis of variance (ANOVA). The main effect of subject group was not significant ($F = 1.0$, $p = 0.42$) and the two groups did not differ significantly at any spatial frequency ($F < 1.3$, $p > 0.25$).

Pattern glare data were not obtained from one of the experimental subjects because the experimental grating made her feel nauseous. Only one subject (from the experimental group) reported any illusions on viewing the control (0.5 cpd) grating. This subject only reported a mild degree of one of the symptoms on the control grating, yet had a high score of perceptual distortions with the experimental grating. The data from the control grating therefore seems to confirm that reports of pattern glare did not result from increased suggestibility.

When viewing the 4 cpd grating, the migraine group reported significantly more pattern glare than the control group (*t*-test, $p = 0.004$).

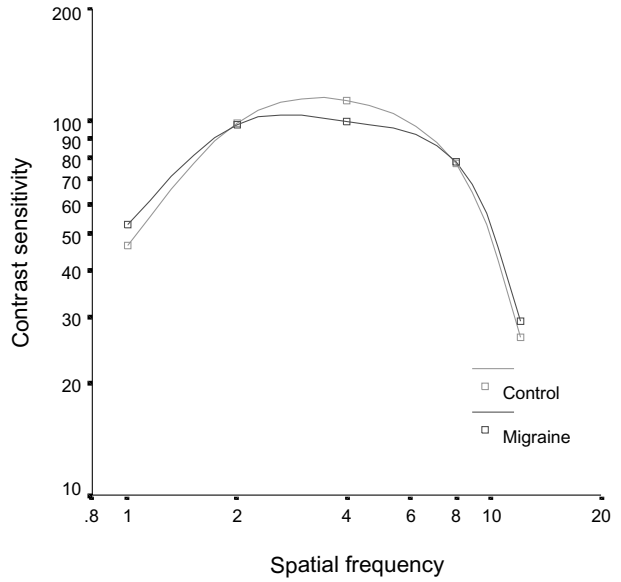

Figure 2. Spatial contrast sensitivity functions of control and migraine groups.

Follow-up appointment

At the follow-up appointment the optometric and psychophysical tests were repeated under three conditions: no tint, preferred tint and control tint. Friedman's non-parametric repeated measures ANOVA was used because of the non-parametric nature of some of the variables. To reduce the risk of a Type 1 error, it was decided not to analyse all the optometric and psychophysical variables but instead to concentrate on the measures (and any associated variables) which were significantly different in the two groups at the first, pre-treatment, appointment.

The variables that were selected to be analysed were the distance divergent fusional reserves (blur, break, recovery), distance aligning prism (this approached significance at first appointment and may be linked to the distance divergent fusional reserves), near Sheard's criterion (treated both as pass/fail and as a continuous variable) and associated variables (near dissociated heterophoria and fusional reserves), and pattern glare.

The distance divergent fusional reserves blur and recovery points were not significantly different under the three conditions ($p > 0.23$). The distance divergent fusional reserve break point showed a significant (Friedman, $p = 0.002$) trend to increase in the order of no tint, control, active. However, the reserve with the active tint was not significantly higher than that with the control tint (Wilcoxon, $p = 0.18$).

None of the subjects had a distance aligning prism under any of the three conditions.

Sheard's criterion is calculated from the dissociated heterophoria and fusional reserves. The mean near dissociated heterophoria did not differ significantly under the three conditions ($p > 0.1$). However, the S.D. of the five readings of near dissociated heterophoria did vary significantly under the three conditions (Friedman, $p = 0.002$). The findings were counter-intuitive: the variability of the heterophoria decreased in the order active tints, no tints, control tints *(Figure 3)*. The near dissociated heterophoria was significantly more variable with the active than with the placebo tints (Wilcoxon, $p = 0.004$).

The near divergent fusional reserves did not differ significantly under the three conditions (blur, break, recovery: $p > 0.10$). The near convergent fusional reserve blur point did not differ significantly under the three variables ($p > 0.8$), and the recovery point showed a tendency to vary significantly under the three conditions ($p = 0.081$). The near convergent fusional reserve break point varied significantly under the three conditions ($p = 0.033$), with the highest fusional reserve being with no tint and with the fusional reserve with each tint being very similar. Similarly, the near fusional amplitude varied significantly under the three conditions

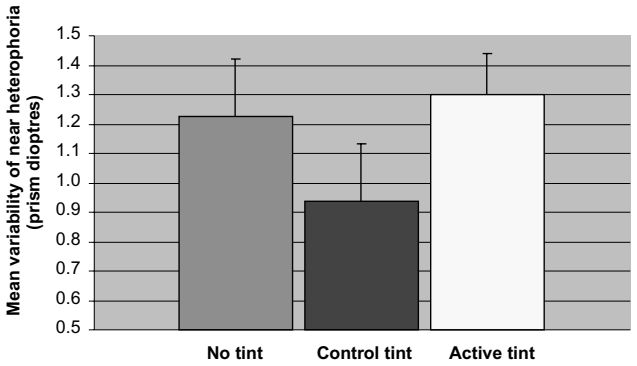

Figure 3. Mean variability (in prism dioptres) of near heterophoria under the conditions of no tint, control tint, and active tint. Error bars show the standard error of the mean.

($p = 0.006$), with the highest fusional reserve being with no tint and with the fusional reserve with each tint being very similar (*Figure 4*).

Percival's criterion at near did not differ significantly in the three conditions, whether treated as a continuous variable (Friedman, $p > 0.7$) or as pass/fail (χ^2, $p > 0.9$). When Sheard's criterion at near was treated as pass/fail then the three conditions did not differ significantly (χ^2, $p = 1.0$). When treated as a continuous variable there was a tendency for the conditions to differ (Friedman, $p = 0.10$), with subjects doing best at Sheard's criterion with no tint, and having worse performance with either tint. The results with the tints were very similar to one another.

The mean near aligning prism was 0.1Δ of esodeviation for the no tint condition, 0.16Δ of exodeviation with the control tint, and 0 for the active tint. This trend approached significance (Friedman, $p = 0.091$), but lost significance when the unsigned values were used (Friedman, $p = 0.1$).

None of the subjects reported any pattern glare with the control grating under any of the conditions. Subjects reported significantly increasing degrees of visual perceptual distortions in the following order (*Figure 5*): active tint, control tint, no tint (Friedman test, $p < 0.001$), but the pattern glare with active tints was not significantly less than with the control tints (Wilcoxon test, $p = 0.62$).

Discussion

As migraine can have many triggers, it was important to ensure that we were investigating subjects whose migraine potentially had a visual trigger. The subjects for this study therefore were pre-selected as finding a coloured overlay helpful. This means that the data from the present study cannot be used to predict the prevalence of visual anomalies in unselected patients with migraine. The present study does allow conclusions to be drawn on the optometric profile of patients who feel that visual factors may be involved in the precipitation of their migraine. This permits some speculation on the mechanism of the visual trigger in these patients.

Optometric characteristics of the migraine group

Although there was a tendency, of border-line significance, for astigmatism to be higher in the migraine group, visual acuities, refractive errors and spectacle use are not strong correlates of migraine in the present sample. None of the subjects manifested a heterotropia (strabismus) or incomitant deviation.

Waters (1970) found a high prevalence of hyperphoria in migraine, but this was not found in the present study. The two groups also did not differ significantly in distance or near horizontal dissociated heterophoria, AC/A ratio, stability of near heterophoria, or near point of convergence.

Wilmut (1956) claimed that a decompensated near exophoria was a cause of migraine. Symptomatic heterophoria is usually described as decompensated (Evans, 1997a, p. 43) and there are three clinical methods of assessing compensation. The most reliable of these is the Mallett aligning prism, but Sheard's and

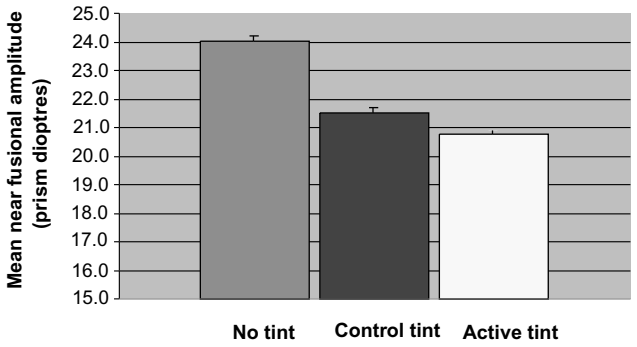

Figure 4. Mean fusional amplitude (in prism dioptres) under the conditions of no tint, control tint and active tint. Error bars show the standard error of the mean.

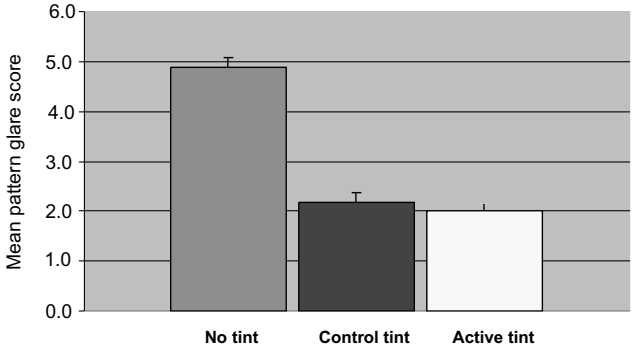

Figure 5. Mean pattern glare score (see text) under the conditions of no tint, control tint and active tint. Error bars show the standard error of the mean.

Percival's criteria can also provide useful information (Evans, 1997a, pp. 45–70).

At distance, there was a tendency, of border-line significance, for the Mallett aligning prism to be more exophoric in the migraine group, but Sheard's and Percival's criteria were not significantly different in the two groups. The distance divergent fusional reserves were significantly lower in the migraine group, but the distance convergent fusional reserves and fusional amplitudes were not significantly different in the two groups. As it is the convergent fusional reserve that is used to overcome any exophoria, these results suggest that the tendency for the migraine group to have a more exophoric distance aligning prism is unlikely to be clinically significant.

At near, the aligning prism and Percival's criterion of the two groups were not significantly different, but there was a significant tendency for more of the migraine group to fail Sheard's criterion. This latter finding does provide some support for the findings of Turville (1934) and Wilmut (1956). However, the present study was, to the best of our knowledge, the first to assess the Mallett aligning prism in a migraine population. The findings with this test suggest that decompensated heterophoria is not a strong correlate of migraine. This is supported by the data for the near convergent and divergent fusional reserves, neither of which differed significantly in the two groups.

Compared with the control group, the migraine group did not manifest any deficits of foveal suppression, stereoacuity, accommodative function, colour vision and contrast sensitivity. Statistically speaking, the strongest correlate of migraine was pattern glare, and data from the control condition confirmed that this was not attributable to heightened suggestibility in the migraine group.

It was noted above that the protocol was to exclude subjects with a clinically significant ocular motor (accommodative or binocular) anomaly. It is interesting that, although group averages identify subtle differences in ocular motor function in the migraine group, these were not felt to be clinical significant in any individual case. The literature shows that the criteria for diagnosing clinically significant ocular motor anomalies are controversial (Evans, 1997a), and the optometrist who carried out the eye examinations made the clinical decision based on her test findings and clinical experience. In the present study, an holistic approach was taken, rather than considering individual optometric test results in isolation. For example at distance fixation, the one migraine subject with poor cover test recovery had no aligning prism on the Mallett unit and met Sheard's and Percival's criteria; and the subjects who failed Sheard's and Percival's criteria all had good cover test recovery and no aligning prism. Similarly, the migraine subjects with an aligning prism at near all had good cover test recovery. This approach, of considering performance at a range of tests, has both clinical (Evans, 1997a, pp. 62–64) and statistical (Bowling, 1998, pp. 152–153) validity. Nonetheless, we accept that some practitioners might have adopted less conservative criteria and treated more patients with vision therapy or with refractive or prismatic correction. We are currently evaluating ocular motor function in larger samples of unselected migraine and control patients.

Follow-up appointment

The divergent fusional reserve break point was significantly influenced by the tints, with a higher (better) reserve with the active tint than with no tint. Other measures of distance fusional reserve, and the distance aligning prism, were not significantly different in the three conditions.

At near, the aligning prism and Percival's criterion did not vary significantly under the three conditions. There was a tendency, of border-line significance, for subjects to do worse at Sheard's criterion with tints than without. This was probably attributable to the finding that the near convergent fusional reserve and fusional amplitude were higher without the tints than with them.

Again, the statistically strongest result related to pattern glare. There was a very significant effect of tints, with least pattern glare with the active tint and most with no tint (*Figure 5*). Although there was less pattern glare with the active tint than with the control tint, this difference did not reach significance. This may be unsurprising since the control tints were not necessarily inactive: they were selected as being of a colour that was similar to the preferred colour, but suboptimal. It is therefore possible that the control improved symptoms compared with no tint, but to a lesser extent than the active tint. Although this reasoning would explain *Figure 5*, it should be noted that an alternative hypothesis is that the coloured filters alleviate pattern glare by reducing stimulus luminance. We think it more likely that the subtle difference in colour between the active and control tint meant that the effect on a fairly brief test of pattern glare did not reach statistical significance, although the more prolonged outcome of using the tints in everyday life did reveal significantly less symptoms with the active tint (Wilkins *et al.*, in press). It should be noted that other research has shown a colour-specific effect of coloured filters on pattern glare in patients with migraine (Chronicle, 1993b).

Mechanism for the visual trigger

All of our sample had demonstrated an interest in research on vision and migraine and reported a benefit from using coloured overlays. The sample is therefore

likely to have a high concentration of people who have a visual trigger for some or all of their headaches.

There were a few clinical signs of decompensated heterophoria in our migraine subjects, but other tests suggested that decompensated heterophoria was not a strong correlate of migraine in our sample. It should also be noted that, in view of the fairly large number of comparisons made in this study, some of the just significant differences between migraine and control groups may be attributable to a type 1 error. Nonetheless, it seems to be a sensible precaution for eyecare practitioners to carefully look for the clinical signs of decompensated heterophoria in patients whose migraines appear to have a visual trigger.

Wilkins *et al.* (in press) showed that individually prescribed coloured filters significantly reduced the symptoms of migraine patients in the present study. One possibility is that the patients who benefit from tints do so because they have photophobia resulting from a binocular vision anomaly (exo-deviations are sometimes associated with photophobia; Wiggins and von Noorden, 1990). This is not supported by the present data and would not account for the finding that the tint needs to be selected with a high degree of precision (*Figure 1*). Indeed, some of the data from the follow-up appointment suggests that the tints may have marginally worsened the performance of some of our subjects at certain orthoptic tests. This worsening was slight and was not clinically significant, but adds support to the notion that the mechanism for the benefit from the tints was not through the correction of ocular motor problems.

The most likely mechanism for the visual trigger in our subjects is pattern glare. This was the strongest correlate of migraine in our sample, and was the variable that improved most when subjects were using coloured filters. Turville (1934) noted that lights and patterned stimuli (white railings) can be a trigger, and several authors have associated pattern glare with migraine (Wilkins *et al.*, 1984; Marcus and Soso, 1989; Wilkins, 1991). Chronicle and Wilkins (1991) and Chronicle (1993a,b) linked this pattern sensitivity to the benefit from colour. The present study reveals that the mechanism for the benefit from individually prescribed coloured filters in migraine is very likely to be through the alleviation of cortical hyperexcitability (Wilkins *et al.*, 1994) related to pattern glare. Pattern glare can result from everyday stimuli, including text (Wilkins and Nimmo-Smith, 1987).

Our subjects were pre-selected as reporting a benefit from coloured overlays. It is therefore possible that there is a separate subset of migraine sufferers who have visual triggers yet who do not find coloured filters to be helpful. It is conceivable that these patients might have a higher than usual prevalence of decompensated heterophoria. If, as in some patients in the present sample, coloured filters caused a slight deterioration in the orthoptic status of these subjects then they might have been prevented from entering the study because they failed to find coloured overlays helpful. More than 65 years after Turville's original paper, there is still a need for a rigorous controlled trial to investigate the optometric correlates of migraine in a large, unselected, sample. Our results confirm that this study should investigate pattern glare as well as binocular vision variables, and such a study is underway.

In conclusion, the benefit that some patients with migraine derive from individually prescribed coloured filters is likely to be related to pattern glare. Of course, many patients with migraine do not report any association between visual tasks and their headaches or other symptoms and would therefore not be expected to benefit from any optometric intervention. On average, some measures of binocular co-ordination were slightly worse in our sample with migraine than in controls. Although these ocular motor factors do not seem to provide an explanation for the benefit that the migraine group derived from coloured filters, they might play a role in certain cases. When eyecare practitioners encounter migraine patients whose headaches might be related to visual tasks then they should exclude the possibility of a conventional visual trigger (e.g. binocular vision anomaly) and should investigate the effect of coloured filters. A wide range of coloured filters need to be tried, and the tint needs to be precisely defined. The Wilkins (Intuitive) Colorimeter and Precision Tints were found to be effective tools for this purpose.

Acknowledgements and declaration of interest

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