Ophthal. Physiol. Opt. 2008 **28:** 295–309

# The Pattern Glare Test: a review and determination of normative values

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**Abstract**

Pattern glare is characterised by symptoms of visual perceptual distortions and visual stress on viewing striped patterns. People with migraine or Meares–Irlen syndrome (visual stress) are especially prone to pattern glare. The literature on pattern glare is reviewed, and the goal of this study was to develop clinical norms for the Wilkins and Evans Pattern Glare Test. This comprises three test plates of square wave patterns of spatial frequency 0.5, 3 and 12 cycles per degree (cpd). Patients are shown the 0.5 cpd grating and the number of distortions that are reported in response to a list of questions is recorded. This is repeated for the other patterns. People who are prone to pattern glare experience visual perceptual distortions on viewing the 3 cpd grating, and pattern glare can be quantified as either the sum of distortions reported with the 3 cpd pattern or as the difference between the number of distortions with the 3 and 12 cpd gratings, the '3–12 cpd difference'. In study 1, 100 patients consulting an optometrist performed the Pattern Glare Test and the 95th percentile of responses was calculated as the limit of the normal range. The normal range for the number of distortions was found to be <4 on the 3 cpd grating and <2 for the 3–12 cpd difference. Pattern glare was similar in both genders but decreased with age. In study 2, 30 additional participants were given the test in the reverse of the usual testing order and were compared with a sub-group from study 1, matched for age and gender. Participants experienced more distortions with the 12 cpd grating if it was presented after the 3 cpd grating. However, the order did not influence the two key measures of pattern glare. In study 3, 30 further participants who reported a medical diagnosis of migraine were compared with a sub-group of the participants in study 1 who did not report migraine or frequent headaches, matched for age and gender. The migraine group reported more symptoms on viewing all gratings, particularly the 3 cpd grating. The only variable to be significantly different between the groups was the 3–12 cpd difference. In conclusion, people have an abnormal degree of pattern glare if they have a Pattern Glare Test score of >3 on the 3 cpd grating or a score of >1 on the 3–12 cpd difference. The literature suggests that these people are likely to have visual stress in everyday life and may therefore benefit from interventions designed to alleviate visual stress, such as precision tinted lenses.

**Keywords:** cortical hyperexcitability, Meares–Irlen syndrome, norms, pattern glare, visual stress

## Introduction

In everyday life, many people experience discomfort when looking at repetitive striped patterns, as when ironing striped shirts or using escalators (Wilkins, 1995). The intensity of the effect varies according to the parameters of the pattern and individual susceptibility. For susceptible people, these patterns induce eyestrain; headache; and illusions of colour, shape and motion. The symptoms of discomfort (visual stress) and visual perceptual distortions have been given the name 'patterned glare' (Wilkins and Nimmo-Smith, 1984) and subsequently 'pattern glare' (Evans and Drasdo, 1991).

Pattern glare is typically tested with square wave gratings. To elicit maximum pattern glare, the gratings should have the following properties: a spatial frequency

*Received*: 14 November 2007
*Revised form*: 21 March 2008
*Accepted*: 30 March 2008

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doi: 10.1111/j.1475-1313.2008.00578.x

of about 3 cycles per degree (cpd), even width and spacing (duty cycle 50%), high contrast and be viewed binocularly (Wilkins *et al*., 1984; Wilkins, 1995).

### *Reading and pattern glare*

Wilkins and Nimmo-Smith (1984, 1987) investigated whether the pattern of stripes formed by text was sufficient to induce pattern glare and visual discomfort in susceptible subjects. They showed that the contrast, spatial frequency and duty cycle of text were all within the range required to produce visual discomfort, and they proposed that text could produce pattern glare. Wilkins *et al*. (1984) showed that the most unpleasant patterns give rise to the most illusions and that people who experienced more illusions suffered from more headaches. When asked to describe the effects they experienced, participants reported: colours, diamond shaped lattice, shimmer, blurring, dazzle, glare, bending, flashing, blobs and flickering (Wilkins *et al*., 1984). The above effects are thought to be due to cortical hyperexcitability and the patterns need to be specific to induce symptoms (Wilkins *et al*., 1984; Wilkins, 2003).

Reading performance has been the subject of further studies on pattern glare. One study used reading-like visual tasks and showed that sensitive subjects took significantly longer because of the pattern formed by the lines on the page (Conlon *et al*., 1998). This pattern glare can cause visual discomfort during reading (Wilkins and Nimmo-Smith, 1984) and may account for the benefit from coloured filters (Evans *et al*., 1994, 1995, 1996, 2002) in a condition that has been called Meares–Irlen syndrome (Evans, 1997) or visual stress (Wilkins, 1995). This condition is described hereafter with the acronym MISVIS (Meares–Irlen syndrome/visual stress).

A more recent study showed that a group with high visual discomfort was less efficient at both conscious and automatic attention tasks regardless of the background pattern (Conlon and Humphreys, 2001). This indicates that the reduced reading efficiency is probably not just a result of an increased level of global interference of patterns, such as from lines of text (Conlon and Humphreys, 2001). It had previously been suggested that the high visual discomfort group had reduced efficiency of the parvocellular system (Conlon *et al*., 2001). In the Conlon and Humphreys (2001) study, it was argued that poorer performance could be the result of an overload in the magnocellular system, resulting in reduced efficiency of the attentional spotlight or alternatively less efficient spatial attention via the parvocellular system. Evans (2001) suggested a model that links pattern glare in some cases of dyslexia with a deficit of visual attention and indirectly with a magnocellular deficit.

### *Migraine and pattern glare*

As long ago as 1934, it was noted anecdotally that a small number of migraine sufferers could have migraine episodes triggered by glare from bright light or patterns. For example, driving past railings or looking at a flickering flame could precipitate an attack (Turville, 1934). More recently, a strong correlation has been found between migraine and pattern glare (see Harle and Evans, 2004; for review) and some patients with migraine find that precision tinted lenses reduce the frequency of their attacks (Wilkins *et al*., 2002), probably because of pattern glare (Evans *et al*., 2002).

Schoolchildren with migraine have been found to lose more than double the number of schooldays to illness compared with their counterparts without migraine (Abu-Arefeh and Russell, 1994). On days when adults are going to have headaches, and up to 24 h before, susceptibility to pattern glare is increased (Nulty *et al*., 1987). Where the headaches are on one side the distortions tend to be greater in one visual hemifield (Wilkins *et al*., 1984) and in migraine sufferers the distortions tend to be on the same side as the aura (Khalil, 1991). A recent controlled study of optometric function in visually-sensitive migraineurs found pattern glare to be the strongest optometric correlate of migraine (Evans *et al*., 2002).

### *Epilepsy and pattern glare*

A series of experiments (Wilkins *et al*., 1984) pointed to neurological processes in common between epilepsy and pattern glare. These researchers demonstrated that the spatial properties of patterns that elicit epileptiform electroencephalographic abnormalities in a group of people with photosensitive epilepsy are similar to the spatial properties that make patterns uncomfortable for people who do not suffer from epilepsy.

Four per cent of patients with epilepsy suffer from visually induced seizures caused, for example, by flicker or steadily illuminated patterns such as stripes (Wilkins, 1995). Experiments in 1975 and 1979 by Wilkins showed that striped patterns can provoke epileptiform EEG activity (Wilkins, 1995). Meldrum and Wilkins (1984) hypothesised that the photosensitive epileptiform abnormalities are because of a minor failure of GABAergic cortical inhibition and so these findings support a relationship between migraine headache and cortical dysinhibition noted elsewhere in the literature (Palmer *et al*., 2000).

### *Aetiology of pattern glare*

The cells of the visual cortex are organised into columns that are responsive to gratings of a specific orientation

and spatial frequency. Therefore, gratings should produce a concentrated excitation within the nerve network (in a few cortical columns having appropriate orientation sensitivity) compromising the shared inhibitory processes. The inhibitory interneurons are shared between columns so the synthesis and reuptake of the inhibitory neurotransmitter may be insufficient to meet demand under conditions of strong excitation. Patterns of stripes may therefore cause a high level of cortical stimulation leading to a breakdown in cortical inhibition. If the discharge does not spread but remains local, the neural excitation could be responsible for visual perceptual distortions without being sufficient to induce electrical activity measurable at the scalp (Meldrum and Wilkins, 1984).

It has been shown that some cortical cells respond more to gratings than edges or bars and that the linearity of the contour is more important than the total number of contours, so that stripes are more epileptogenic (Meldrum and Wilkins, 1984) and more likely to cause pattern glare (Wilkins *et al*., 1984) than checks.

Further evidence that the illusions associated with pattern glare are triggered in the cortex is provided by the observation that the effect is greater under binocular than monocular conditions (Wilkins *et al*., 1984). The input from the two eyes remains separated until it reaches the cortex. The cortex is arranged functionally into orientation specific and ocular dominance columns that overlap. The input from the two eyes is combined through interneurones whose neurotransmitter is GABA (Kandel *et al*., 1995). Monocular occlusion can be used as a treatment for photosensitive epilepsy because it has been shown to reduce the photosensitive response to flicker (Wilkins, 1995). Monocular occlusion may help some dyslexic children (Evans, 2001), possibly because of the fact that pattern glare is reduced by covering one eye (Wilkins *et al*., 1984).

### *Alternative explanations for pattern glare*

The evidence reviewed above all points to a cortical mechanism for pattern glare (Wilkins *et al*., 1984). Less likely non-cortical explanations for pattern glare include the small eye movements that occur during fixation and also accommodative fluctuations. If these mechanisms were correct then less specific tasks would lead to pattern glare. An investigation into the effect of spatial frequency on accommodation using sinusoidally modulated vertical gratings of 1.67, 5 and 15 cpd on pre-presbyopic subjects found that an over-accommodation occurred with the highest spatial frequency and that accommodation was most stable at 5 cpd (Ward, 1987). It has also been suggested that flicker at higher spatial frequencies may result from involuntary eye movements (Wade, 1977). However, later work by Wilkins and Neary (1991) found that coloured lenses, which reduce pattern glare (Evans *et al*., 2002), had idiosyncratic effects on ocular motor balance and their results suggested it was unlikely that accommodation had a role. This conclusion was supported by Evans *et al*. (2002), and Simmers *et al*. (2001) found increased accommodative micro-fluctuations in MISVIS but concluded that these were most likely a correlate rather than a cause.

### *Methods for reducing pattern glare*

The literature reviewed above establishes that pattern glare can be a significant factor in people's lives, but how can pattern glare from text be minimised? Changing the spacing of the lines, the length of the lines (Wilkins and Nimmo-Smith, 1987) or the number of lines visible at one time can reduce the striped effect produced by text (Wilkins and Nimmo-Smith, 1984). One way of doing this is to use a typoscope. This is simply a card with a rectangular slot positioned so that only a few lines of text are visible at one time.

A controlled study using reduced contrast reading material (half of the text was printed on medium grey paper to do this) concluded that the score for the learning difficulty students was 10% higher on the pages with reduced contrast compared with the pages of full contrast (Giddings and Carmean, 1989).

One controlled study assessing the benefit of using the DEX frame (a combination of a typoscope, magnifier and coloured filter) for children with specific learning disability found no benefit compared with the control group (Taylor *et al*., 1992). However, although MISVIS is correlated with dyslexia, most people with dyslexia do not have MISVIS (Kriss and Evans, 2005; White *et al*., 2006) and studies of MISVIS in dyslexic populations will therefore suffer from reduced statistical power.

It has also been suggested that the use of the Visual Tracking Magnifier (VTM) can help children with learning difficulties. This is a magnifier of up to 1.5× magnification. Either side of a central clear strip (approximately 0.7 cm wide) are patterned areas intended to reduce distortions from the surrounding text. There are two designs and the widest is 11.5 cm long. The magnifier is placed flat on the text and moved along the lines. A major disadvantage of this magnifier is the small field of view and we have not been able to find any randomised controlled trials of this intervention. However, the use of magnifiers is known to reduce reading speed in fully sighted people (Bowers, 2000).

Pattern glare seems to be the mechanism, or one of the mechanisms, underlying the visual stress that is a core feature of MISVIS. MISVIS is defined as symptoms, on viewing text, of asthenopia and visual perceptual distortions that are alleviated by using individually

prescribed coloured filters (Evans, 1997, 1999). This condition, the use of coloured filters and the relationship with pattern glare will now be described in more detail.

### *Meares–Irlen syndrome, coloured filters and pattern glare*

Meares (1980) first described the symptoms of MISVIS. She noted that some children's reading abilities were influenced by the characteristics of their reading material and that their reading could be improved by changing the size of the print, the contrast or using coloured paper. Irlen (1991) called this Scotopic Sensitivity/Irlen Syndrome and described this as a visuo-perceptual syndrome in which sufferers experience eyestrain and perceptual illusions with reading which could be alleviated with the use of coloured filters.

A study of 20 patients wearing Irlen coloured glasses found that coloured lenses reduced discomfort when looking at gratings (Wilkins and Neary, 1991). Several theories have been proposed to explain why the coloured lenses helped, including pattern glare (Wilkins and Neary, 1991). Binocular uncoordination or accommodative dysfunction are sometimes associated with MISVIS and, although these problems are not usually the explanation for the benefit from coloured filters, people with MISVIS need careful optometric evaluation and differential diagnosis (Wilkins and Neary, 1991; Evans *et al*., 1995, 1996; Scott *et al*., 2002; Evans, 2005).

It has been hypothesised that the magnocellular deficit which is widely believed to be a correlate of dyslexia might explain the benefit from coloured filters (Chase *et al*., 2007). However, a magnocellular deficit is unlikely to explain the highly individual and specific nature of the required coloured filter, which has been demonstrated in two randomised controlled trials (Wilkins *et al*., 1994; Robinson and Foreman, 1999), and three studies have found magnocellular function to be normal in MISVIS (Evans *et al*., 1995; Simmers *et al*., 2001; White *et al*., 2006).

The symptoms of pattern glare and MISVIS are very similar (Evans and Drasdo, 1991; Wilkins *et al*., 1991). Patients who benefit from coloured overlays or spectacles often experience pattern glare (Evans *et al*., 1995, 1996). In matched control group studies, pattern glare has been found to be the strongest correlate of a benefit from coloured filters in people with reading difficulties (Evans *et al*., 1995) and migraine (Evans *et al*., 2002). The aetiology of MISVIS is not known for sure, but it seems very likely that pattern glare from cortical hyperexcitability is at the core of the condition (Wilkins and Neary, 1991; Evans, 2001; Wilkins, 2003). Coloured lenses have also been found to be beneficial in photosensitive epilepsy again suggesting some common neurological link with MISVIS and, therefore, pattern glare (Wilkins *et al*., 1999).

In conclusion, precision tinted lenses seem to be an effective intervention for MISVIS (Evans, 2001). Although pattern glare appears to be a correlate of reading difficulties (e.g. dyslexia; Kriss and Evans, 2005), migraine (Harle and Evans, 2004), epilepsy (Wilkins *et al*., 1999) and autism (Ludlow *et al*., 2006) only a proportion of people with these conditions are likely to have MISVIS and therefore to benefit from precision tinted lenses. When the symptoms are centred on text based activities then coloured overlays can be used to screen for the benefit from colour (Wilkins, 1994, 2002). But there are some patients with migraine whose symptoms of visual stress are not specific to text, occurring, for example, more generally under fluorescent lighting or in the office. It was felt that it would be useful to develop a tool that would help to identify these cases. As reviewed above, pattern glare is a strong correlate of MISVIS, and is probably a manifestation of the underlying aetiology of cortical hyperexcitability. In research studies, pattern glare testing had been found to be a simple procedure and anecdotal comments of those who had used these research tests suggested that a test of pattern glare for use by eyecare and possibly other professionals might be useful.

### *The Wilkins and Evans Pattern Glare Test*

The Wilkins and Evans Pattern Glare Test was published in 2001 to allow practitioners to assess pattern glare (*Figure 1*). The test is based on the literature on pattern glare and the instructions give guidance on how to interpret the results (Wilkins and Evans, 2001). However, neither the effectiveness of the test nor the precise test norms have yet been established.

The test is designed to induce visual perceptual distortions in susceptible patients. There are three high-contrast grating patterns, each with a duty cycle of 50%, which are viewed binocularly. Each grating pattern subtends an angle of 13.63° at the eye when viewed at the testing distance of 40 cm. The orientation of the gratings is horizontal so that it mimics text. For each grating, patients are asked to report which, if any, of the following visual perceptual distortions are perceived: colours, bending of lines, blurring of lines, shimmering/flickering, fading, shadowy shapes, others. For each pattern, the number of these distortions is summed to give a Pattern Glare Score (maximum 7), in line with previous research (Wilkins *et al*., 1984; Conlon *et al*., 1999).

Pattern 1 is a control with a low spatial frequency (0.5 cpd) that is expected to trigger relatively few distortions, which are not likely to be associated with headaches and eye strain (Wilkins *et al*., 1984). The main purpose of pattern 1 is to detect patients who are highly suggestible and might respond 'yes' to almost any

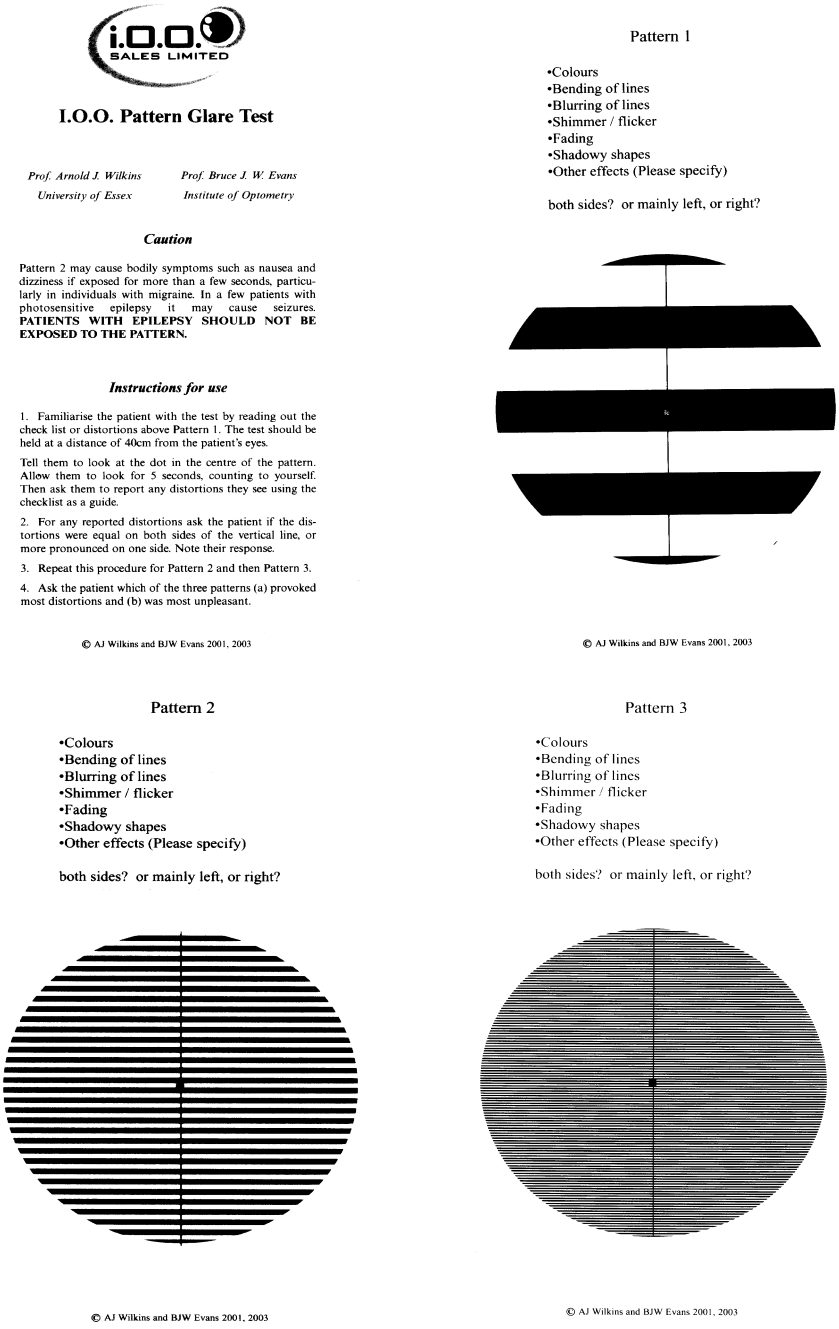


**Figure 1.** The Pattern Glare Test. The actual test is larger than illustrated. Courtesy of i.O.O. Marketing Ltd, London.

question about visual perceptual distortions. As revealed in the literature reviewed above, the spatial frequency (3 cpd) of Pattern 2 will maximally elicit pattern glare and individuals who complain of many symptoms of visual stress in everyday life should report more distortions in response to Pattern 2 compared with gratings that have higher (Pattern 3) and lower (Pattern 1) spatial frequencies. Pattern 3 is another form of control, with a higher spatial frequency grating (12 cpd) and would be expected to elicit less distortion than Pattern 2. Distortions from Pattern 3 would be expected to be of a different nature to those from Pattern 2, reflecting a greater contribution from optical as opposed to neurological factors (Conlon *et al.*, 2001). According to the work of Conlon *et al.* (2001), individuals with relatively low visual discomfort would be expected to report more distortions in response to Pattern 3 (12 cpd) than Pattern 2, although they may report fewer distortions overall. The anticipated pattern of results in patients with pattern glare compared with the normal result is summarised in *Table 1*, which is reproduced from the test manual (Wilkins and Evans, 2001).

**Table 1.** Possible relationship between the Pattern Glare Test results and the degree of visual discomfort likely to be experienced in everyday life

| | Discomfort and distortions in response to | | |
|---|---|---|---|
| **Visual discomfort in everyday life** | **Pattern 1 (0.5 cpd)** | **Pattern 2 (3 cpd)** | **Pattern 3 (12 cpd)** |
| Low/moderate | + | ++ | +++ |
| High | + | ++++ | +++ |

Reproduced with permission from the Pattern Glare Test instructions (Wilkins and Evans, 2001).

In summary, pattern glare would be suggested by a patient having a high score with Pattern 2 (3 cpd) and/or a score with Pattern 2 which is higher than the score with Pattern 3. It is not clear which of these results is the best indicator of pattern glare so both were considered in our analyses.

The common practice of describing square-wave gratings as having a specific spatial frequency is an over-simplification. The quoted spatial frequencies are the fundamental spatial frequency, but a Fourier analysis would also reveal the presence of higher spatial frequency components from the sharply defined edges of the square-wave gratings. Nonetheless, in Fourier terms overwhelmingly the most powerful component will be the fundamental spatial frequency of each grating as described above.

## Study 1: Norms for the Pattern Glare Test

The goal of Study 1 was to determine the norms for the Pattern Glare Test for a typical optometric clinic population. The effects of age and gender were also investigated.

### *Methods*

*Participants.* The participants were 100 clinical patients visiting the researcher's (SS) optometric practice for an eye examination and meeting the following selection criteria: over 10 years of age; binocular near visual acuity (with any correction habitually worn) of 6/12 equivalent or better; and no personal history of epilepsy. Patients meeting these criteria were pseudo-randomly selected by age stratification to represent a cross-section of the population based on the 2001 census. The researcher does not specialise in the assessment of people with reading difficulties, migraine or any other particular condition. The participants are therefore likely to resemble a fairly typical cross-section of members of the public consulting a community optometric practice.

*Procedure.* Immediately following their eye examination, suitable patients who had given written informed consent completed a brief questionnaire. This was designed so that the participants could answer the questions on their own and they were asked about gender, whether they had experienced six or more headaches in the last year that had prevented them carrying out normal activities, whether they had been diagnosed by a doctor as suffering from migraine, and finally whether they had received a psychologist's diagnosis of dyslexia.

The Pattern Glare Test was carried out exactly as described in the test instructions (Wilkins and Evans, 2001). Each participant was familiarised with the test and read out the list of visual perceptual distortions described above. The patient was then asked to look at the dot at the centre of the grating and to count to five slowly so that they fixated the centre spot for about 5 s. This is sufficient to induce symptoms in someone who is sensitive to pattern glare. Participants used any spectacles that were habitually worn more than 50% of the time when reading.

The participants were shown the approximate distance at which to hold the test and were allowed to hold it themselves. They then viewed each grating starting with Pattern 1, then 2 then 3 and recorded any distortions seen on the record sheet. The record sheet required only yes or no answers for simplicity and the participants were left alone to answer the questions.

### *Results*

*Norms for the Pattern Glare Test.* The data from the normative population are illustrated in *Figure 2*. The pattern glare score was obtained for each participant for each of the three gratings and for the difference between the Pattern Glare Score for Pattern 2 (3 cpd) and Pattern 3 (12 cpd); this is described below as the '3–12 difference'. The distributions of the Pattern Glare Scores were tested for normality by inspecting frequency distributions and using the Kolmogorov–Smirnov test and this indicated that the data for 0.5, 3 and 12 cpd gratings do not closely follow a normal distribution, although the data for the 3–12 variable are normally distributed (*Figure 2*).

The literature reviewed in the introduction demonstrates that only a high test score is clinically significant, so the 95th percentile ranking was calculated (Bland, 1987) as the limit of the normal range. The 95% confidence intervals (CI) of the 95th percentile rankings were also calculated, using the method of Bland (1987). This gives the normal range for the 3 cpd grating as less than 4 (CI 3–6). For the 3–12 variable, the upper limit of the normal range is 1 (CI 1–3). These, and other descriptive data, are given in *Table 2*.

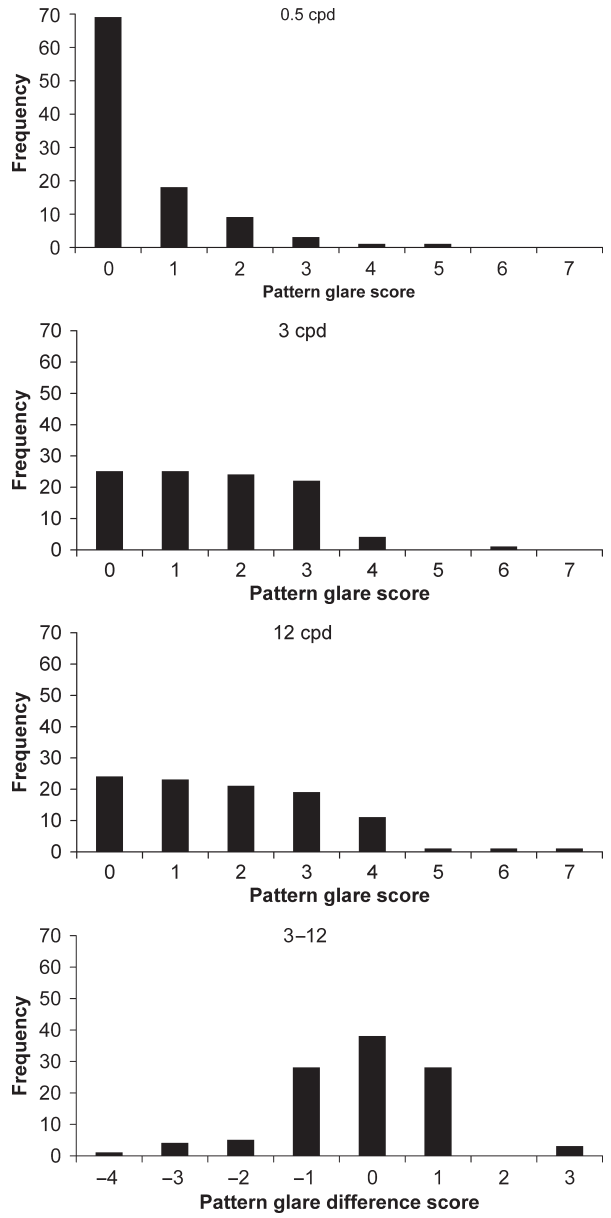


**Figure 2.** Frequency distributions of Pattern Glare Scores obtained by the 100 participants in Study 1 on Patterns 1, 2 and 3, and for the difference between Pattern 2 and Pattern 3 (the 3–12 difference).

**Table 2.** Descriptive data for Pattern Glare Scores for the full normative sample of 100 participants in Study 1

| | 0.5 cpd | 3 cpd | 12 cpd | 3–12 |
|---|---|---|---|---|
| Mean | 0.53 | 1.59 | 1.82 | −0.23 |
| Median | 0.00 | 2.00 | 2.00 | 0.00 |
| Range | 5.00 | 6.00 | 7.00 | 7.00 |
| Percentiles | | | | |
| 25 | 0.00 | 0.50 | 1.00 | −1.00 |
| 50 | 0.00 | 2.00 | 2.00 | 0.00 |
| 75 | 1.00 | 3.00 | 3.00 | 0.50 |
| 95 | 2.90 | 3.90 | 4.00 | 1.00 |

*Effect of gender.* Pattern glare is a correlate of migraine and females are more likely to suffer from migraine. To investigate the effect of gender, we therefore removed all participants in the normative sample who reported headaches (as defined in the Methods section) or migraine. This left 34 males and 43 females. The Pattern Glare Scores of the male and female groups did not differ significantly for the scores from any of the three gratings (Mann–Whitney *U*-test, $p > 0.20$). However, the groups did differ significantly for the 3–12 variable (*t*-test, $p < 0.044$): the males have relatively more pattern glare for the 3 cpd and less for the 12 cpd than the females. All the *p*-values quoted throughout this paper are two-tailed.

The mean ages of the males (48 years, S.D. 25) were slightly higher than the females (41 years, S.D. 22). Therefore, we randomly deleted the data of some younger participants from the female (larger) group so as to match the ages of the groups. In this, and subsequent experiments, when participants' data were deleted to create new subgroups the deletion took place without any consideration of the Pattern Glare Scores. This deletion left 33 females, with similar mean, S.D. and range of ages (48 ± 21; 12–82 years) to the males (48 ± 25; 10–90 years). The two modified groups still did not differ in the Pattern Glare Score for each grating and now no longer differed significantly (*t*-test, $p = 0.097$) in the 3–12 variable.

*Effect of age.* Returning to the full 100 participants we then looked at the effect of age. For the 50 oldest participants exactly half were males, but for the 50 youngest participants only 28% were males. To balance the genders, males were randomly deleted from the older group and females from the younger until there were 38 participants, 34% of whom were male, in each group. The mean age of the older group was 61 years (S.D. 13, range 43–86 years) and of the younger was 26 years (S.D. 10, range 10–42 years). There was no significant difference in the number of migraineurs in the two groups ($p = 0.29$).

The effect of age is illustrated in *Figure 3*. Mann–Whitney *U*-tests showed that at 0.5 cpd the older participants were not significantly different from the younger participants ($p = 0.39$) but there was a significant difference at 3 cpd ($p = 0.044$) and 12 cpd ($p < 0.0001$). However, the 3–12 variable was not significantly different in the two groups (*t*-test, $p = 0.11$).

The effect of age was further investigated by calculating, for the 76 participants described above, the correlation coefficients (Pearson, $r$; Spearman, $r_s$) between age and the pattern glare variables. The correlation for the 0.5 cpd grating was weak ($r_s = -0.20$, $p = 0.092$), but there was a significant

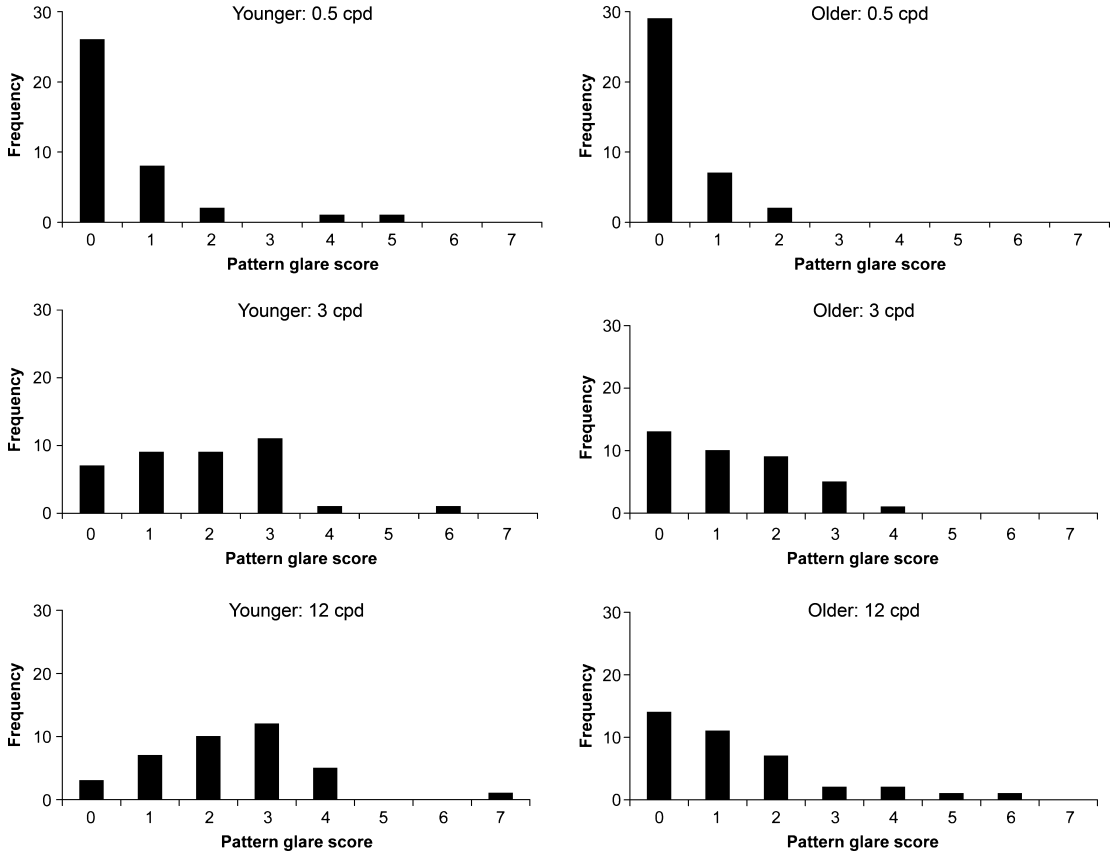


**Figure 3.** Frequency distributions for Pattern Glare Scores for Patterns 1, 2 and 3 in the younger (left panel) and older (right panel) groups in Study 1.

inverse correlation between age and the Pattern Glare Score for the 3 cpd ($r_s = -0.26$, $p = 0.022$) and 12 cpd ($r_s = -0.45$, $p < 0.0005$) gratings. The 3–12 variable was positively correlated with age ($r = 0.24$, $p = 0.035$). These data indicate that younger participants had more pattern glare than older participants with both the 3 cpd and the 12 cpd gratings. *Figure 3* shows that the younger participants tended to have more distortions with the 12 cpd grating than with the 3 cpd grating, whereas the older participants tended to have more distortions with the 3 cpd than with the 12 cpd grating.

*Discussion*

As expected, very few distortions were recorded for the control grating of 0.5 cpd, showing that it was an effective control. The results show that the average number of distortions was slightly higher for 12 cpd than 3 cpd, which is in line with previous research (Conlon *et al*., 2001).

Ninety-five per cent of the sample experienced less than four distortions on viewing the 3 cpd grating and had a 3–12 score of 1 or less. Therefore, patients consulting an optometrist with symptoms of visual discomfort with reading such as asthenopia or headache and reporting four or more distortions on pattern 2 of the pattern glare test or scoring two or more for 3–12, are more likely to suffer from pattern glare and visual discomfort. They may benefit from further investigation to alleviate their symptoms, such as testing with the Intuitive Colorimeter and precision tinted lenses.

When participants with migraine and headaches are excluded and groups are matched for age, pattern glare does not appear to differ significantly between the genders.

*Effect of age*. The results show a significant decrease in the number of distortions reported on viewing gratings with age. There is a greater decrease with the 12 cpd grating than the 3 cpd grating resulting in a small overall increase in 3–12 cpd difference with age. To the best of our knowledge, this finding has not been reported before.

The contrast sensitivity function (CSF) has been shown to reduce with age at higher spatial frequencies (>4 cpd; Owsley *et al*., 1985). One possible cause is lens changes in the ageing eye. However, comparisons of CSF in phakic eyes and eyes that have undergone cataract extraction and intra-ocular lens implantation,

have failed to find a significant difference (Owsley *et al*., 1985), suggesting that lens clouding is not a significant factor until it is extensive. Other optical factors include increased aberrations as a result of structural changes in the ageing eye. However, this occurs in both the cornea and the lens and one may compensate for the other, although the balance may change with age (Guirao *et al*., 1999). Guirao *et al*. (1999) demonstrated a deterioration of retinal image with age as a result of increased optical aberrations and showed that optical performance of the eye decreased linearly with age. Bleeker *et al*. (1986) also demonstrated a significant linear increase in autofluorescence of the lens with age. Owsley *et al*. (1985) suggested that senile pupillary miosis may be a greater factor in reduced CSF with age because it leads to reduced retinal illuminance and poorer image quality. A later study found an age-related reduction in contrast sensitivity at low luminance levels (Sloane *et al*., 1988a). However, in this study measurements relating pupil size to contrast sensitivity showed that senile miosis might increase contrast sensitivity. Overall, there are many age-related optical changes in the eye and these will reduce the level of light reaching the retina and might influence the results of the Pattern Glare Test.

Neural factors are also important. There is a breakdown of myelin in monkey primary cortex with age. This is not thought to have a direct effect on visual function, but to influence cognition through slowing axonal conduction, which results in a loss of synchrony (Peters *et al*., 2000). Synchrony contributes to cortical hyperexcitability (Meldrum and Wilkins, 1984) and so a loss of synchrony will reduce cortical hyperexcitability and, therefore, pattern glare and visual discomfort. Regardless of the mechanisms, however, there seems to be a reduction in cortical excitability with age, consistent with the reduction in susceptibility to headache with age (Stovner *et al*., 2006).

Cortical reorganisation also occurs during normal ageing. This has been demonstrated for short-term memory by measuring spatial frequency discrimination thresholds for sine wave gratings (Bennett *et al*., 2001). Functional magnetic resonance imaging has shown a reduction in the amplitude of the haemodynamic response of the visual cortex in older adults (Buckner *et al*., 2004). Sloane *et al*. (1988b) found evidence of a neural contribution to the reduction in contrast sensitivity with age. The loss of sensory acuity with age may explain the decrease in pattern glare that we have found.

## Study 2: Effect of order of testing in the Pattern Glare Test

When the Pattern Glare Test was developed there were no available data on the order of testing and this was therefore arbitrarily set in the order of ascending spatial frequency. In view of the lack of previous work on this topic, it was decided to investigate the effect of order of testing in Study 2.

### *Methods*

Thirty participants were chosen using the same criteria as study 1 but with the additional criterion that they had to be aged between 50 and 71 years (mean age 60 years, S.D. 6), which is the most common age range seen at the practice where the research was carried out. As in Study 1, these participants used their reading spectacles for the Pattern Glare Test, if they normally used spectacles for reading.

The Pattern Glare Test was performed in exactly the same way as in Study 1 except that the test was carried out in reverse order. The data from a subgroup of Study 1 participants acted as controls. These participants were selected purely on the basis of age to be age-matched with the participants in study 2. There were 27 members of this group with age range also 50–71 years (mean age 60 years, S.D. 7).

### *Results*

The effect of testing order is illustrated in *Figure 4*. The normal order group did not differ significantly from the reversed order group at 0.5 or 3 cpd (Mann–Whitney *U*-test, $p > 0.19$), but did differ at 12 cpd (Mann–Whitney *U*-test, $p = 0.003$). This grating is usually presented last but was presented first in Study 2 when the testing order was reversed. The 3–12 difference score was not significantly different in the two groups (*t*-test, $p = 0.078$). *Figure 4* shows that the 12 cpd grating generates more pattern glare when it is presented after the 3 cpd grating, as in the normal order of testing.

To investigate the reason for this, the matching of the samples was checked. In the group from study 1 (usual order), the proportion of males, headache sufferers and migraine sufferers was slightly higher (48%, 15% and 30%, respectively) than in the study 2 (reversed order) participants (44%, 3% and 10%, respectively). From the research on migraine reviewed in the introduction, we would have expected this group to report more pattern glare with the 3 cpd grating and less with the 12 cpd grating but in fact our results found this group to have more pattern glare with the 12 cpd grating. This suggests that this effect is the result of order of testing.

### *Discussion*

Study 2 again confirmed that the 0.5 cpd grating is an effective control for suggestibility and only rarely generates any reports of pattern glare. The amount of pattern glare with the 3 cpd grating was largely

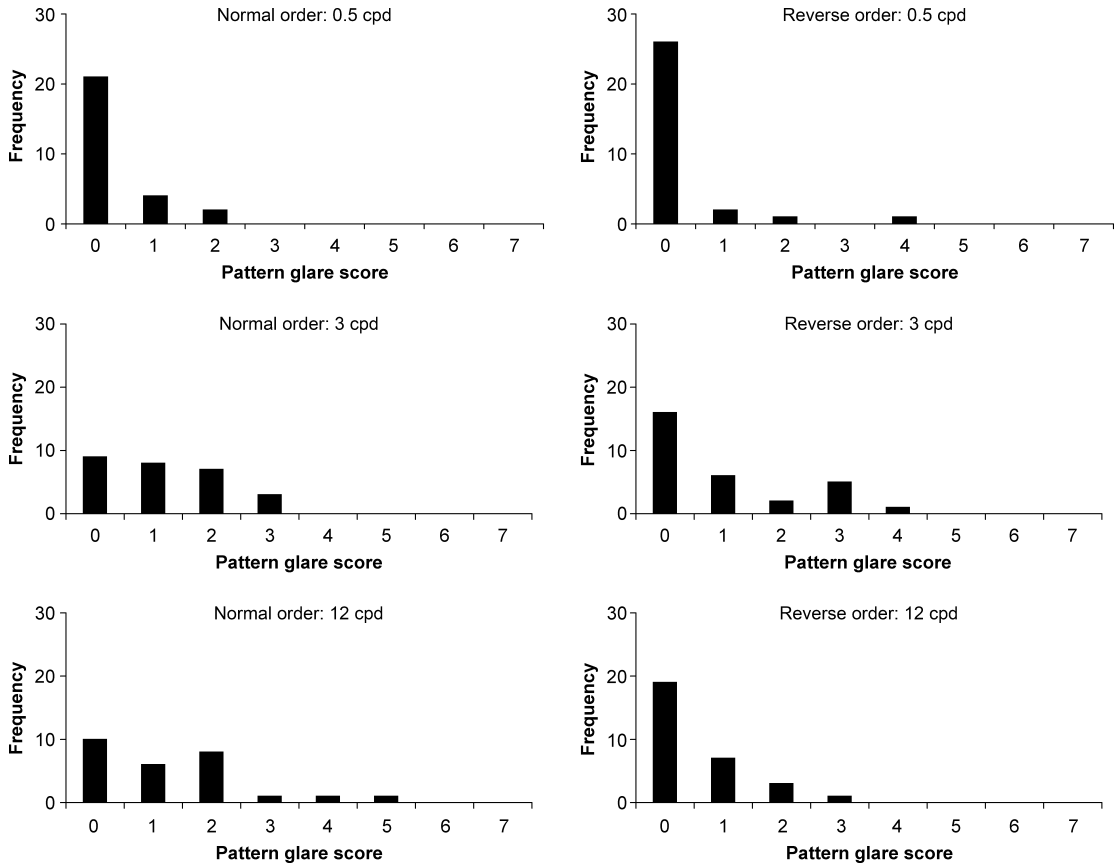


**Figure 4.** Frequency distributions for Pattern Glare Scores for Patterns 1, 2 and 3 in the participants in Study 2 who were administered the test in the reverse order (12 cpd grating first, 0.5 cpd grating last; right panel) and the matched control group from Study 1 who were administered the test in the normal order (left panel).

independent of order of testing, and there was no significant order effect on the 3–12 result. However, there was a significant effect of order with the 12 cpd grating and possible explanations for this will now be considered.

It is possible that when participants experience visual perceptual distortions on viewing the 3 cpd grating then this may disrupt the accommodative and/or convergence system. These effects may then persist when looking at the 12 cpd grating and therefore give more optical distortions with this grating.

There may also be cognitive effects. Once the participant has seen the distortions with the 3 cpd grating they may then have a heightened awareness of distortions and be looking for these when viewing the 12 cpd grating. Thus, the 3 cpd grating may act as a prime. An example of this memory effect is recognising a word that has been seen previously. However, an investigation into the repeatability of the Pattern Glare Test (Stevenson, 2004) did not result in significantly more distortions for the Pattern Glare Test the second time. This test was repeated about half-an-hour after the first presentation so if the order effect does result from priming then the priming must be short lived.

Another explanation is biases transferred from the first presentation. Not only are there biases resulting from the previous target seen but also from the previous judgements made (Poulton, 1979). Other research has shown that the previous trial can have an inhibiting or augmenting effect on the current results in word and non-word trials (Iacoboni *et al.*, 1997).

We think that a more likely explanation of the effect of order relates to cortical hyperexcitability. When the 3 cpd pattern is viewed then high levels of cortical hyperexcitability from this grating may saturate the system and enhance the cortical excitation with the 12 cpd grating. When the 12 cpd grating is viewed first the level of stimulation is lower and, therefore, there is no resultant enhancement of the 3 cpd grating.

Conlon investigated spatial frequencies between 1 and 16 cpd. No detail was included as to the order of presentation and so the assumption is that the order was the same for all participants (Conlon *et al.*, 2001). Wilkins varied the order of presentation of seven square wave gratings of spatial frequency 0.5–32 cpd that were presented in paired combinations, giving 21 combinations (Wilkins *et al.*, 1984). The participants simply chose

which pattern of the pair was more pleasant. There were effects as a result of the order of testing but this did not influence the results of spatial frequency and so order effects were not investigated further (Wilkins *et al.*, 1984).

It would be useful for further research to look into the effect of order in more detail with an experimental design to look at all possible combinations of order. Pattern glare is detected as a high score on the 3 cpd plate or a high 3–12 difference score. The order of testing did not have a statistically significant effect on either of these variables and so the usefulness of the test is not adversely affected by the interesting order effect that we have discovered.

## Study 3: An investigation into pattern glare in migraine sufferers

The literature reviewed in the introduction suggests that pattern glare is a correlate of migraine. We sought to investigate this in a further group of migraine sufferers.

### *Methods*

A further 30 participants were selected who all reported having received a medical diagnosis of migraine, in addition to meeting the same selection criteria as used in Study 1. They performed the pattern glare test exactly as in Study 1. The participants chosen were not aware of why they had been chosen specifically and were given the same information as those in Study 1.

For controls, we matched data from a subset of the study 1 population to the migraineurs as follows: 84 participants from study 1 were selected, eliminating all participants who had either suffered from six or more headaches in the last year that had prevented them from carrying out normal activities or had been diagnosed by a doctor as suffering from migraine. The mean age of the migraine group ($n = 30$) was 41 years (S.D. 18, range 11–73 years). To match the groups for age, all controls under 11 years and over 73 years were eliminated. This left a control group ($n = 71$) with a similar mean age, S.D. and range (40, 19, 11–73 years, respectively) to the migraine group. In the migraine group, 26% were male, compared with 39% in the control group. So, males were deleted in the control group, selected pseudo-randomly to keep the ages of the two groups similar. This resulted in a headache-free control group of 57 participants (mean age 40 years, S.D. 20, range 11–73 years), 26% of whom were males.

### *Results*

*Figure 5* shows that the migraine group experienced more distortions with all gratings, particularly the 3 cpd grating. However, the difference in pattern glare score between the groups did not reach statistical significance for any of the three gratings (Mann–Whitney *U*-test, $p \geq 0.08$). The difference between the two groups for the 3–12 variable was, however, statistically significant (*t*-test, $p = 0.041$) with the migraine group reporting relatively more pattern glare with the 3 cpd grating than the 12 cpd (*Figure 5*).

### *Discussion*

Marcus and Soso (1989) found that 82% of participants with migraine were sensitive to striped patterns compared with 6.2% of participants without migraine. No difference was found between migraine groups with and without aura (Marcus and Soso, 1989). Another study found that women who suffer from migraine with aura were more affected by glare, flicker and patterns than those with migraine without aura (Hay *et al.*, 1994). Evans *et al.* (2002) found that migraine sufferers who reported a benefit from coloured filters experienced significantly more pattern glare than controls with a 4 cpd grating. They concluded that the benefit that some patients with migraine derive from individually prescribed coloured filters is likely to be related to pattern glare. In a study using the Wilkins and Evans Pattern Glare Test to compare a group of migraine sufferers with controls, Harle *et al.* (2006) found that the migraine group had more pattern glare with the 3 cpd grating and a higher '3–12 difference' score.

*Figure 5* does demonstrate that, as the literature suggests, the migraine group has more pattern glare, especially with the 3 cpd grating. However, in the present sample the difference between the two groups only reached significance for the 3–12 cpd difference. It should be noted that the diagnosis of migraine was by self-report of medical diagnosis and was not checked, so it is likely that some of the participants may not have met strict criteria for the diagnosis of migraine (Headache Classification Subcommittee of the International Headache Society, 2003). Furthermore, our data did not allow us to sub-classify migraine into those with aura and without aura. It is also possible that our migraine group did not include many migraine sufferers who are visually sensitive and, with hindsight, it would have been useful to ask questions about this. Indeed, one of the main uses of the test is to detect patients whose migraines are likely to be visually precipitated and the results of Evans *et al.* (2002) and of Harle *et al.* (2006) suggest that the test is likely to be useful for this.

It should also be noted that our control group in Study 3 were not a normal cross-section of the population. They were patients consulting a community optometric practice and were selected as having infrequent or no headaches and no history of medically diagnosed migraine.

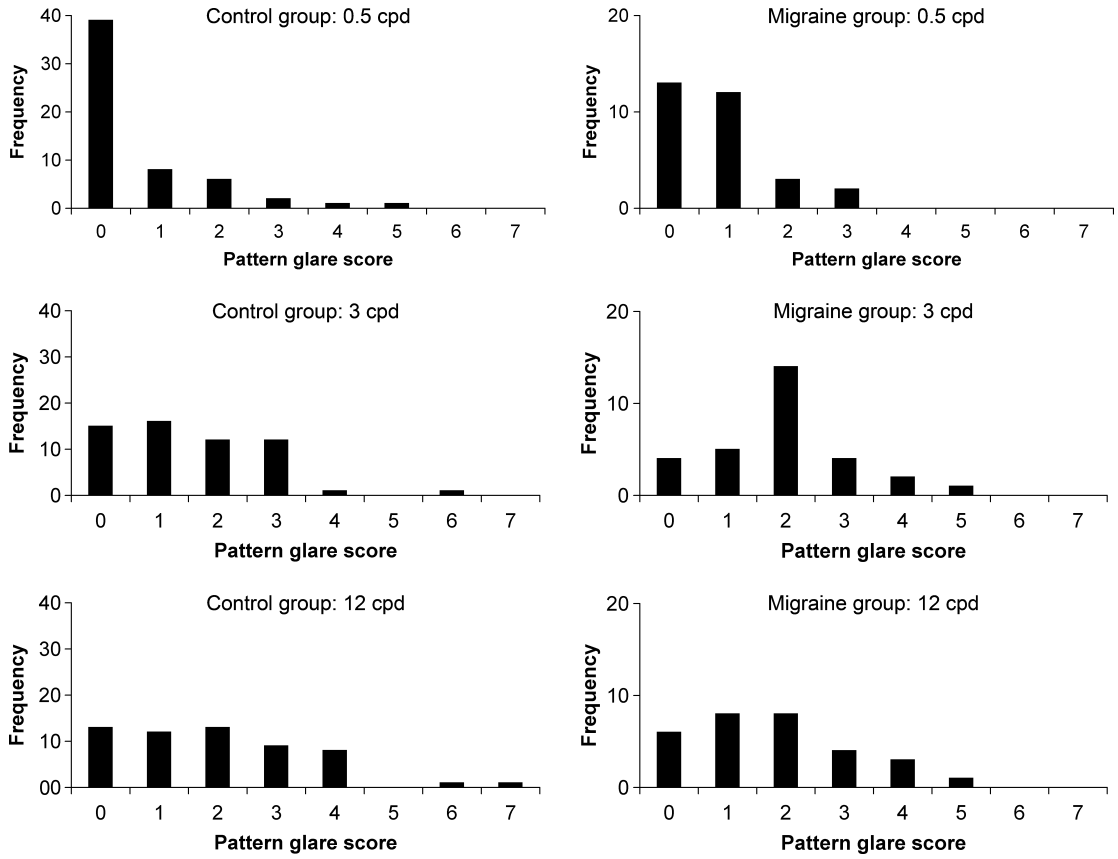


**Figure 5.** Frequency distributions for Pattern Glare Scores for Patterns 1, 2 and 3 in the migraine group from Study 3 (right panel) and the matched control group from Study 1 (left panel). Note: the vertical axes of the graphs for each group are different but have been scaled to be approximately proportional to the number of participants in each group.

## General conclusions

This research has shown that certain groups are more susceptible to pattern glare and has provided norms for the Wilkins and Evans Pattern Glare Test. For Pattern 2 (3 cpd), 95% of a typical optometric population will have a Pattern Glare Score less than 4. For the 3–12 cpd difference, 95% of our population scored less than 2. This is a slightly stricter cut-off than that used by Harle *et al.* (2006).

Pattern glare is of similar prevalence in males and females, decreases with age and is correlated with migraine. The Pattern Glare Test can be performed by patients unsupervised, provided instructions are given and that patients with epilepsy are excluded. The order of testing has a significant effect on the number of distortions recorded on the 12 cpd grating. We have speculated on the explanation and significance of this, but this order effect should be investigated with further research. However, there was no significant effect of testing order on the results with the 3 cpd grating or the 3–12 variable and so this order effect does not appear to change the clinically significant outcomes of the test.

A limitation of our studies is that they use an optometric population, which may be different to a cross-section of the general population. In particular, people with refractive errors are undoubtedly more likely to visit optometrists. But, we are unaware of any evidence to suggest that pattern glare or MISVIS is correlated with refractive errors. The Pattern Glare Test is likely to be used in optometric practices, so norms based on an optometric population are useful. Nonetheless, it would be interesting to compare our data with that from non-clinic populations, ideally using larger sample sizes.

We have not considered the optometric characteristics of our participants (e.g. the results of tests for visual acuity, ocular pathology, refractive error and binocular vision anomalies). The literature review in the Introduction did not indicate that there is likely to be a high correlation between these variables and pattern glare. Astigmatism is one obvious candidate for a confounding variable, but as all three gratings were horizontally orientated then we think that it is unlikely that astigmatism would have confounded the pattern of results that we obtained with different gratings. It is also

possible that horizontal gratings might have caused a decompensation of horizontal heterophoria, which could result in symptoms similar to those of pattern glare. However, there is considerable evidence that the symptoms of MISVIS are likely to result from pattern glare independently of binocular vision anomalies (Wilkins and Neary, 1991; Evans *et al*., 1995, 1996; Scott *et al*., 2002; Evans, 2005). Nonetheless, it would be interesting for future research to investigate the relationship between pattern glare and conventional optometric variables.

Lines of text have been shown to trigger pattern glare, which in turn causes visual discomfort (Wilkins and Nimmo-Smith, 1984). As a result of the visual discomfort, task performance is reduced (Conlon *et al*., 1998) and, therefore, people who are sensitive to these patterns may experience reading difficulties or may not read to a level that is commensurate with their full potential.

The norms that we have obtained for the Pattern Glare Test facilitate the assessment of pattern glare in clinical practice. If a patient is found to have high levels of pattern glare, the practitioner can go on to advise how to minimise the effects of pattern glare. It has been shown that those suffering from severe visual discomfort take significantly longer to perform visual search tasks and are, therefore, less efficient readers (Conlon *et al*., 1998). It has also been shown that pattern glare sensitivity is associated with light sensitivity and 'words jumping around' when reading (Evans *et al*.,1996). The literature suggests that people with high degrees of pattern glare are likely to have visual stress in everyday life and may therefore benefit from interventions designed to alleviate visual stress, such as precision tinted lenses.

## Acknowledgements

We are grateful to the patients who freely gave their time for the research. We are also grateful for a dissemination grant awarded to BJWE by EyeNET, the primary care eye research network supported by the London NHS Executive. The views expressed in this publication are those of the authors and not necessarily those of the NHS Executive. We also thank Professor Arnold Wilkins for his helpful comments on an earlier draft of the manuscript. The research described forms part of an MSc in Clinical Optometry by SS. The Pattern Glare Test is marketed by i.O.O. Sales Ltd, which raises funds for the Institute of Optometry. A royalty is paid to BJWE as an 'Award to Inventors'.

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