Some visual, optometric and perceptual effects of coloured glasses

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We examined 20 individuals who had worn coloured glasses (Irlen filters) for a period of at least 3 months and who claimed to find them beneficial. Sixteen had a history of reading difficulties. The performance of a variety of visual tasks was compared: (1) using the coloured lenses; (2) using neutral density filters of similar photopic transmittance; and (3) using trial lenses to correct any residual refractive error. The coloured lenses appeared to reduce discomfort and susceptibility to anomalous perceptual effects upon viewing grating patterns. They also improved the speed of visual search by a small amount. The lenses had idiosyncratic effects on ocular muscle balance and acuity. They did not affect contrast sensitivity at a spatial frequency of 4 c/deg.

The Irlen Institute (California, USA), founded by Helen Irlen, supplies tinted spectacles for patients with 'scotopic sensitivity syndrome'[1,2], which is the name she uses to describe a variety of complaints, many of which would typically be regarded as reflecting asthenopia, photophobia or visual discomfort. The name is not intended to imply a hyperactivity of rod cells in the retina.

Many, but by no means all, of the clients seen by the Institute have a history of reading difficulty. They report anomalous visual effects when viewing text, such as the apparent motion of letters, and these effects can sometimes be reduced when the text is covered by a tinted overlay. Overlays appear to improve visual processing[3], but for reasons that remain obscure, and may well include placebo effects[4,5].

The clients are assessed initially by the use of overlays; and, if the tints seem beneficial, are subsequently invited to compare a variety of tinted lenses, choosing a combination of trial tints that best reduces perceptual distortion. Lenses are then dyed to have a spectral transmission similar to that of the chosen combination. There is no strong correlation between the colour preference expressed for overlays and for spectacles[6]. A weak correlation would be anticipated for at least two reasons:

1. The overlay absorbs light twice, once before and once after reflection from the page, and as a result the spectral absorption is multiplied by two.
2. The perception of the colour of an object such as an overlay is the result of a neutral computation that takes into account the spectral properties of the illuminating source, as estimated from the spectral power distribution of light reflected from surrounding objects. When tinted glasses are worn, however, the tint has the effect of contributing to the colour of the illuminating source, and is thereby discounted.

The present studies examined only clients selected by the Irlen Institute as having experienced beneficial effects from the tinted glasses supplied. The selection of subjects meant that any negative results that might be obtained could not be attributed to the selection of non-responsive clients (cf. Reference 6). In the first study, the visual effects of the tinted glasses were compared with the effects of: (1) neutral density filters having individually-matched photopic transmission; and (2) no lenses (or untinted trial lenses if a refractive error was present). In a follow-up study, some volunteers from the original sample were asked to mix coloured lights so as to make text and other patterns appear clearer or more comfortable.

First study

Subjects

The Irlen Institute in London provided the names of 28 individuals who had been assessed and prescribed tinted lenses at the Institute, and who were willing to participate in a study investigating the effectiveness of the lenses. These individuals were invited to the Applied Psychology Unit. (Children were accompanied by their parents.) The volunteers were asked to bring with them any glasses or reading aids they might have. Seventeen males and three females attended; 19 of the 20 were aged 18 years or younger (mean age 13 years, range 7–41 years). Several participants were members of the same family. At the time of examination all subjects had been wearing their lenses for at least 3 months.

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Procedure

The subjects were given an optometric examination that included an ophthalmic history, measurements of Snellen acuity at distance and near, push-up amplitude of accommodation, near point of convergence, retinoscopy, subjective refraction, and tests of ocular muscle balance at distance (Maddox Rod) and near (Maddox Wing; Clement Clarke International, London), fixation disparity at near (Mallet test; Hamblin, London) and stereopsis (Titmus test; Titmus Optical Company, Inc., Petersburg, VA). Colour vision was assessed by the City University Colour Vision Test (Keeler, London), and binocular contrast sensitivity was measured with the Cambridge Low Contrast Gratings (Clement Clark International, London).

Subjects were questioned about:

1. Any difficulties with reading, including preferences in the use of left and right hands for various activities, for example, writing, drawing, eating and throwing (Edinburgh Handedness Inventory).
2. Headaches, including details concerning the severity, frequency, and duration of the pain, its nature and location, any symptoms preceding or accompanying the pain and any family history of migraine. Subjects were asked whether headache characteristics had changed since the tinted lenses were worn.
3. Eye-strain, including how often they suffered from irritation, dryness or redness of the eyes, blurring or narrowing of vision, spots or shapes in front of the eyes, pain in response to light, colours surrounding objects, a feeling of fullness in the eyes, or any other visual problems. Subjects used a 10-point scale from 'never' to 'more than once a day'. They were asked whether eye-strain characteristics had changed since the tints were worn.

To assess the effect of the Irlen filters on aspects of visual function, a variety of tests was performed under two or more of the following viewing conditions:

1. With Irlen filters.
2. With neutral density filters of similar photopic transmittance.
3. With no filters or with untinted trial lenses if needed to correct any residual refractive error. (The photopic transmittance was measured individually to the nearest 0.1 log units with room illumination, and used together with refractive correction if present in the Irlen filters.)

The Cambridge Low Contrast Gratings were used to measure binocular contrast sensitivity with Irlen filters or neutral density filters before the eyes. The test comprises a series of 10 pairs of square plates. The pairs were presented one above the other at a distance of 6 m, at which distance each plate subtended 2 degrees × 2 degrees. They were illuminated by the light from a tungsten filament lamp and had a mean luminance of 100 cd m^{-2}. A grating with square-wave luminance profile and spatial frequency of 4 c/deg was present in the top or the bottom plate at random. Subjects were required to choose whether the top or the bottom plate contained the grating, guessing if necessary. Four series of presentations of successive pairs with decreasing contrast were presented, and each series terminated when the first error was made (see Reference 7 for scoring method).

A specially constructed test was used to compare near acuity using the Irlen filters and using neutral density filters. Upper-case letter Es were designed from a 5 × 5 matrix of square pixels so that the top, central and bottom arms were 5 pixels in length. Nine such letters were arranged in a 3 × 3 matrix separated from one another by a distance equivalent to the width of the letters. Each letter in the matrix was oriented randomly up, down, left or right. The subjects' task was to report the orientation of the Es, guessing if necessary. The charts were viewed from 0.4 m, but the size of the letters was chosen to be close to each subject's acuity threshold, as determined by the following procedure. Without any tint, but with trial lenses if necessary to correct for any refractive error, subjects were presented with a series of E charts, in which the height (and width) of the Es decreased by a factor of 0.707 on each successive chart, ranging from 10.8 to 2.7 minutes arc, until two or more errors in orientation discrimination were made on a chart. The letter size on that chart was used in the subsequent assessment in which 12 charts were presented in the order ABBABAABABBA with the Irlen filters assigned to the A position. The charts were illuminated by overhead conventional fluorescent lighting from cool white halophosphate lamps (or, in the case of subject 7, incandescent lighting), so that the mean luminance was about 50 cd m^{-2}.

Susceptibility to anomalous visual effects was assessed by asking the subjects to look at stressful striped patterns and subsequently report any illusions they saw. The patterns were of a kind that produces illusions that are thought to be cortical in origin and reflect a susceptibility to eye-strain and headache[8]. The patterns were gratings with square-wave luminance profile, Michelson contrast 0.7, spatial frequency 3 c/deg, circular in outline and with radii of 1.8, 3.6, 7.1 and 14.0 degrees, presented in order of increasing radius. They were illuminated by the light from a tungsten filament lamp and had a mean luminance of 100 cd m^{-2}. A spot 1 mm in diameter in the centre of the pattern was fixated from a distance of 0.4 m for 5 s. Subjects were then required to report whether they saw illusions, prompted by the following list: 'blurring, bending of stripes, shimmering, flickering, shadowy shapes, red, green, blue, yellow, or any other illusion'. Note that illusions of shape and movement were prompted before those of colour, so that any changes in perception of illusions of colour as a result of wearing tinted glasses would not affect reports of illusions of shape and motion. The subjects observed the patterns with refraction only, with Irlen filters, and with neutral density filters in that order.

Visual search was assessed under the same three viewing conditions. Under the light from cool white fluorescent lamps, subjects viewed 10 lines of black lower case letters which, from the viewing distance of 0.4 m, subtended 11.5 degrees wide × 5 degrees high and had a mean luminance of about 50 cd/m^{-2}. The sequence of letters was generated by random sampling from the 26 letters of the alphabet with the constraint that no letters were repeated in immediate succession. The letters were arranged in strings 1–7 letters in length, with a space between each string, so as to resemble a passage of text. The length of string was chosen randomly with equal probability for the seven lengths. The subject's task was to report, as quickly and as accurately as possible, the letter immediately following each x. The total number of errors and mean time to complete each passage were recorded. Nine different passages were presented in randomized order, three for each of the three viewing conditions.

For subjects with poor binocular control at near (an exophoria of more than 4 D, or an esophoria or fixation disparity), the Maddox Wing and Mallett tests were repeated with the subjects viewing through their Irlen filters.

The colour appearances of the filters were noted. Measurements of the transmission at intervals of 10 nm between 400 and 700 nm were obtained and from these the colour coordinates and photopic transmission were calculated. The extent to which the filter affected the peak–peak modulation from halophosphate fluorescent lamps was also calculated after the methods recently described[9], using linear interpolation to obtain the necessary 5 nm resolution.

Results

Table 1 shows the subjects' gender and age and relevant details of history. *Table 2* shows the results of the optometric examination and *Table 3* the colour appearance, and, where available, the colour coordinates and transmission of each lens. *Figure 1* shows the spectral transmissions of the lenses and *Figure 2* summarizes their minima. *Tables 4* and *5* summarize for each subject the main findings of the additional tests.

Sixteen of the 20 subjects had previously been assessed by education professionals (not Irlen staff) as 'dyslexic'. (It is beyond the scope of this paper to discuss the controversy surrounding the use of this term.) Questioning about headaches and eye-strain revealed that 17 had a family history of migraine. Headaches and/or eye-strain were reportedly reduced by the wearing of tints in 17 of the subjects.

One subject (number 12) was deutan deficient but the remainder had normal colour vision (within the limits of the City University Colour Vision Test). Twelve of the 20 subjects wore pink or rose-tinted lenses, three blue, two yellow, one green, one amber and one brown.

Table 2 shows that 19 of the 20 subjects had 6/6 binocular visual acuity at near and far without refractive correction, 18 had a near point of convergence of less than 0.1 m, and 19 had stereopsis of at least 40 sec arc. Most subjects had only small refractive errors, the majority being hyperopic, and only one subject (number 10) had a refractive correction incorporated into his Irlen glasses. Push-up amplitude of accommodation, measured without the refractive correction, was reduced (<10 D) in eight subjects, but improved to normal levels for five of these eight when trial lenses to correct the refractive error were worn. Nine subjects revealed an ocular muscle imbalance without correction at far and five at near, while five revealed fixation disparity at near. Five subjects had undergone treatment for binocular vision problems: one (subject number 10) squint surgery and four (subjects 9, 17, 18 and 20) orthoptic therapy.

Table 4 shows for each subject the results for the contrast sensitivity, visual acuity, illusion sensitivity, and visual search tests used to evaluate the effectiveness of the Irlen filters. There were no significant differences across subjects between binocular contrast sensitivity when wearing the Irlen filters compared with that when wearing neutral density filters of similar transmittance (paired Student's *t*-test, two-tail, t (df 17) = 0.78; $p = 0.45$). There were, however, significantly fewer illusions of movement and shape reported with the Irlen filters than with the neutral density filters (t (df 19) = 4.5; $p = 0.002$) or the refraction lenses (t (df 19) = 4.8; $p = 0.0001$). When the illusions of colour were included in the analysis similar results were obtained.

The visual search task showed no significant differences between the total number of errors made under the three different viewing conditions, but the task was performed significantly more quickly with the Irlen filters than either the neutral density filters (paired t (df 19) = 2.09; $p = 0.05$,

Table 1 Details of subjects

Subject	*Gender*	*Age (years)*	*Headache frequency/severity*	*Headache reduced with Irlen*	*Migraine in family*	*Eye-strain, no. of symptoms*	*Eye-strain reduced with Irlen*	*Dyxlexia*	*Handedness*
1*	F	17	1 monthly, severe	N	Y	6	N	N	A(R)
2*	M	13	3 weekly, mild	N	Y	4	N	Y	R
3*	M	13	1 monthly, severe	N	Y	2	N	Y	R
4†	M	10	1 weekly, mild	Y	Y	4	Y	Y	R
5†	M	13	1 weekly, severe	Y	Y	5	Y	Y	R
6	M	10	1 daily, severe	Y	Y	8	Y	Y	A(R)
7	F	16	1 daily, severe	Y	Y	6	Y	Y	R
8	M	13	1 yearly, mild	N	N	3	Y	Y	A(L)
9	M	9	1 weekly, severe	Y	Y	6	Y	Y	A(R)
10	M	14	1 monthly, severe	Y	Y	4	Y	Y	R
11	M	9	3 weekly, severe	Y	Y	4	Y	NT	R
12	M	10	3 yearly, mild	N	N	1	Y	Y	R
13§	M	10	2 daily, mild	N	Y	8	Y	Y	A(L)
14§	M	41	1 monthly, severe	Y	Y	NT	NT	N	A(R)
15	M	7	3 weekly, mild	Y	Y	5	Y	Y	R
16	F	11	1 monthly, mild	N	Y	5	Y	Y	R
17‡	M	13	5 yearly, mild	Y	Y	3	Y	Y	R
18‡	M	10	1 yearly, mild	N	Y	3	Y	Y	A(L)
19‡	M	8	1 daily, severe	Y	Y	4	Y	Y	A(L)
20	M	11	1 yearly, mild	N	N	3	Y	NT	R

A = Ambidextrous (dominant hand in parentheses); NT = not tested.
*†‡ siblings.
§ Father and son.

Table 2 Results of optometric examination

Subject	*Visual acuity (binocular)* Near	Far	*NPC* (cm)	*Accommodation* (D)	*Muscle balance* (D) Far	Near	*Fixation disparity* (D)	*Stereoacuity* (sec arc)	*Supplement*	*Refraction*
1	6/6	6/6	15	10	0.5 ex	2 ex		≥40		R plano L plano
2	6/6	6/6	<10	10	1 hypo			≥40		R + 0.75 L + 0.75
3	6/6	6/6	<10	9		2 ex		≥40		R + 0.50 L + 0.25
4	6/6	66	<10	7				≥40		R + 0.50/ − 0.25 × 90 L + 0.50/ − 0.25 × 90
5	6/6	6/6	<10	14				≥40		R − 0.25/0.25 × 180 L − 0.25
6	6/6	6/6	<10	6				≥40		R + 0.25 L + 0.25
7	6/6	6/6	<10	10	5 es		1 es	≥40		R plano L plano
8	6/6	6/6	<10	10	0.5 es	12 ex		≥40		R plano L plano
9	6/6	6/6	<10	5				≥40	R internal	R + 1.0/ − 0.75 × 90 L + 1.0/ − 1.0 × 90
10	6/6	6/60	<10	11	1 hypo	6 ex		100		R − 2.25 L − 2.75
11	6/6	6/6	<10	10				≥40		R + 0.5/ − 0.25 × 90 L + 0.25/ − 0.25 × 90
12	6/6	6/6	10	12	2 es	2 ex		≥40	R & L internal	R + 0.25/ − 0.25 × 90 L + 0.25
13	6/6	6/6	<10	6	2 es 1 hypo			≥40	L internal	R + 0.75/ − 0.25 × 90 L + 0.5/ − 0.25 × 90
14	6/6	6/6	<10	4.5			1 es	≥40		R − 0.25 L − 0.25
15	6/6	6/6	<10	15				≥40		R + 0.25/ − 0.25 × 90 L + 0.25
16	6/6	6/6	<10	8	3 es 2 hypo	3 es	1 es	≥40		R + 0.50 L + 0.50
17	6/6	6/6	<10	12		1 ex		≥40	R internal	R + 0.25 L + 0.25
18	6/6	6/6	<10	12		3 Hyper	1 Hyper	≥40		R + 0.50 L + 0.25
19	6/6	6/6	<10	9	2 ex	8 ex		≥40		R + 0.5/ − 1.0 × 65 L + 0.25/ − 0.50 × 90
20	6/6	6/6	<10	5			1 ex	≥40	L internal	R + 0.50 L + 0.50

NPC = Near point convergence.

two-tail) or the refraction only (t (df 19) = 2.24; $p = 0.04$) conditions. The mean time taken to complete the visual search task did not differ significantly between the neutral density filters and the refraction lenses (t (df 19) = 0.70; $P = 0.49$).

A within-subject analysis revealed that three of the 20 subjects (1, 6 and 14) made significantly fewer errors on the acuity task when wearing their Irlen filters (two-tail t-tests, $p < 0.05$). In a group of 20 individuals, one might expect one significant ($p < 0.05$) effect by chance, but the probability with which three such events occur by chance is 0.076 (Binomial test).

Table 5 shows the effect of the Irlen filters on near binocular control in the eight subjects with an ocular muscle imbalance or fixation disparity at near. The Irlen filters appeared to decrease the fixation disparity in four of the five subjects, and reduce muscle imbalance in three. The effects of chromatic aberration could not easily account for these improvements in binocular control. For example, three of the subjects were esophoric and wore pink/rose tints. Because long wavelength light is refracted less than short, one might anticipate that accommodation would be increased in order to maintain a clear image. Any such increase would presumably lead to an increased convergence of the visual axes and a consequent increase in the esophoria.

Fourteen of the 20 subjects had positive refractive errors (in seven subjects the errors were spherical in both eyes and in seven the errors were astigmatic in at least one eye). Of these 14 subjects, seven were wearing red or rose tints, indicating that the tint colour was not chosen solely on the basis of refractive error.

Follow-up study

Ten of the volunteers returned for a second assessment 1 year after the first. All were still wearing the tints. They underwent a more extensive examination of the effects of the Irlen glasses (all planar) on binocular control and, in an environment free of surface colours, they mixed coloured illuminants for maximum clarity and comfort.

Binocular coordination

The Maddox wing and Mallet test at near were performed under three or more of the following conditions: (1) with

Table 3 Characteristics of Irlen filters and colour mixtures. Photopic transmission of filter is that under D65 standard illuminant. The peak–peak modulation (%) of light from a halophosphate cool white fluorescent lamp (CIE type F2) as transmitted by the filter is shown in the last column. This may be compared with a value of 28.3% for unfiltered light

Subject	*Colour appearance of filter*	*Colour coordinates of filter*		*Transmission of filter (%)*	*Colour coordinates and luminance* (cd m^{-2}) *of first colour mixture*			*Luminance modulation from F2 lamp (%)*
		x	*y*					
1	Rose	0.342	0.285	45	0.52	0.211	44	26.2
2	Rose	0.360	0.310	67	0.64	0.33	46	25.4
3	Rose	0.389	0.315	40				23.6
4	Yellow	0.423	0.459	54	0.285	0.58	56	26.6
5	Blue	0.236	0.255	34	0.483	0.483	127	36.7
6	Amber	0.563	0.359	27	0.704	0.279	11	16.1
7	Pink	0.393	0.316	26	0.68	0.28	6	24.2
8	Rose	0.363	0.278	40				24.7
9	Rose	0.550	0.342	28				15.8
10	Pink	0.347	0.334	34				27.8
11	Blue	Not available	Not available	Not available				
12	Pink	0.333	0.225	18				25.0
13	Brown	Graduated	Graduated	Graduated	0.234	0.599	99	23.6
14	Rose	0.345	0.331	77	0.451	0.355	108	27.4
15	Green	0.345	0.370	76				28.8
16	Pink	0.421	0.298	20				21.3
17	Rose	0.354	0.296	52				25.4
18	Yellow	0.352	0.358	86				39.5
19	Rose	0.378	0.270	28				22.8
20	Blue	0.269	0.320	45				34.3

Table 4 Results of initial tests

Subject	*Contrast sensitivity*		*Acuity, no. of errors*		*No. of illusions*			*Visual search*					
								No. of errors			*Mean time* (s)		
	Irl	*ND*	*Irl*	*ND*	*Irl*	*ND*	*Rx*	*Irl*	*ND*	*Rx*	*Irl*	*ND*	*Rx*
1	48	48	4	13	5	8	5	9	7	12	36	37	36
2	42	41	9	12	4	6	5	11	13	21	39	34	33
3	41	41	15	8	7	8	7	8	4	7	50	50	50
4	42	32	17	24	4	6	4	14	13	10	36	37	41
5	26	27	12	10	4	4	5	7	11	11	43	42	43
6	37.5	33.5	2	26	1	12	10	9	8	12	49	54	47
7	41	42	10	6	1	2	8	2	2	1	40	52	59
8	40	33.5	27	22	4	3	5	13	17	12	63	68	68
9	34	34	18	15	0	4	4	4	1	4	64	64	76
10	32	30	4	9	3	3	4	7	2	7	42	42	48
11	42	44	2	6	0	5	5	3	0	4	45	52	47
12	44	45	16	7	4	6	8	5	2	4	44	49	51
13	32	37	3	3	4	10	13	7	6	8	42	43	41
14	39	38	3	12	2	5	5	2	2	1	42	43	43
15	–	–	5	3	0	1	2	18	15	16	61	76	68
16	37	36	6	4	1	4	5	6	8	6	60	61	54
17	41	41	17	15	1	1	2	10	11	11	36	34	38
18	–	–	11	9	1	5	7	9	8	9	43	43	44
19	32	36	6	13	1	4	1	15	11	14	70	67	68
20	39	39	5	6	0	3	6	0	8	5	57	59	68
Mean	38.31	37.67	9.60	11.15	2.35	5.00	5.55	7.95	7.45	8.75	48.1	50.35	51.2
SD	5.34	5.49	6.80	6.66	2.03	2.82	2.78	4.69	5.02	5.08	10.6	12.21	12.5

Irl = with Irlen filter fitted; ND = with neutral density filter; Rx = shown in *Table 2*.

Irlen filters; (2) with neutral density filters of similar photopic transmittance, measured individually; (3) with no lenses; (4) with refractive correction only. The order of viewing conditions was randomized. For the Maddox Wing test of horizontal phoria the subjects were instructed to report the number to which the white arrow was pointing every 2 s for 10 s. For the Mallet test, prisms were used to correct any fixation disparity, and if intermittent suppression was present the subject reported when either bar disappeared over a 2-min period. The testing was performed under high-frequency (32 kHz) full-spectrum fluorescent lighting (Tru-lite: Durotest; 100 lx at test surface).

Colour mixing

Subjects were seated facing an aperture in a box with matt black surfaces. Peripheral vision was shielded by a black curtain around the head and shoulders. At the base

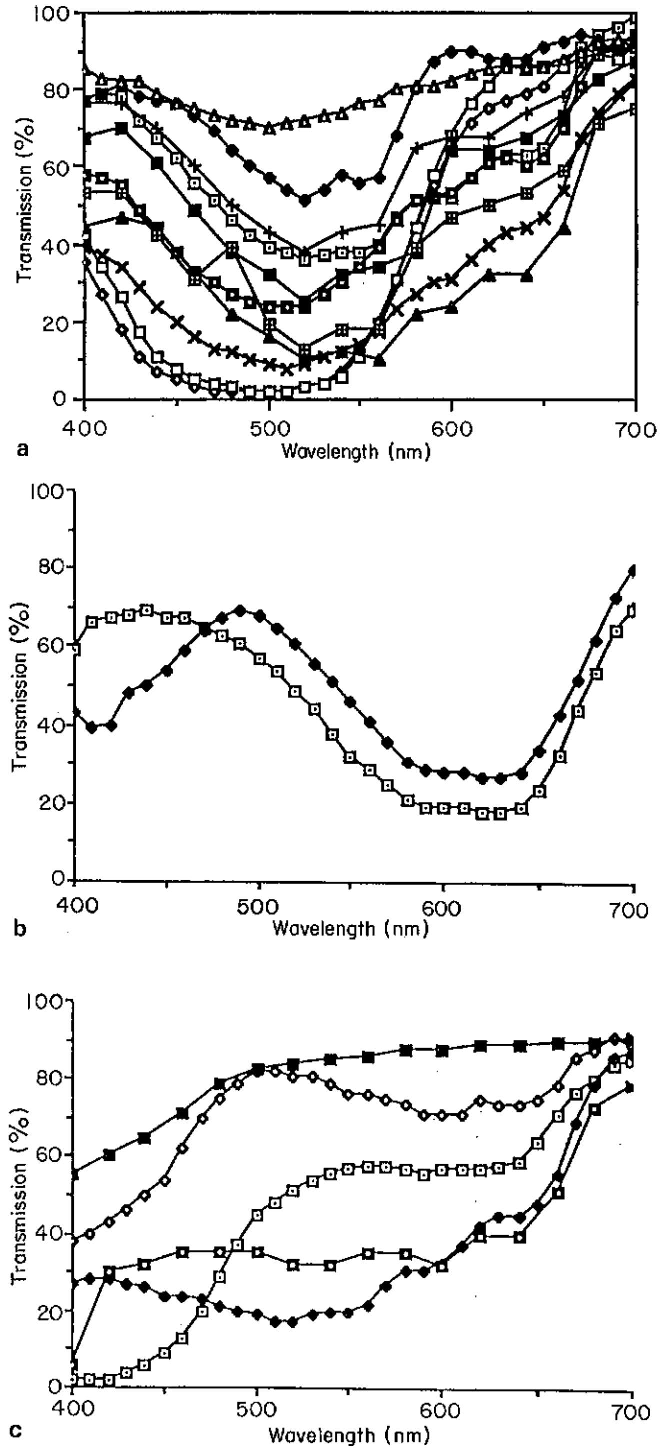

Figure 1 Transmission curves for the Irlen lenses of the 18 subjects for whom data were available. (*a*) Curves with minima near 500 nm. Subject: ⊡ = 1, ◆ = 2, ◘ = 3, ◇ = 6, ■ = 8, □ = 9, ▲ = 12, △ = 14, x = 16, + = 17, ⊞ = 19. (*b*) Curves with minima near 600 nm. Subject: ⊡ = 5, ◆ = 20. (*c*) Curves with no obvious minima. Subject: ⊡ = 4, ◆ = 7, ◘ = 10, ◇ = 15, ■ = 18

of the box a black surface inclined 20 degrees from the horizontal towards the subject was illuminated by the light from three projectors, one with a red filter (Lee 164) in the light path, one with a green (Lee 124) and one with blue (Rosco 79), so that for luminances less than 15 cd m^{-2} a gamut of colour mixtures defined by the x, y colour coordinates (0.73, 0.27), (0.23, 0.61) and (0.13, 0.13) could be obtained. (Owing to the low transmittance of

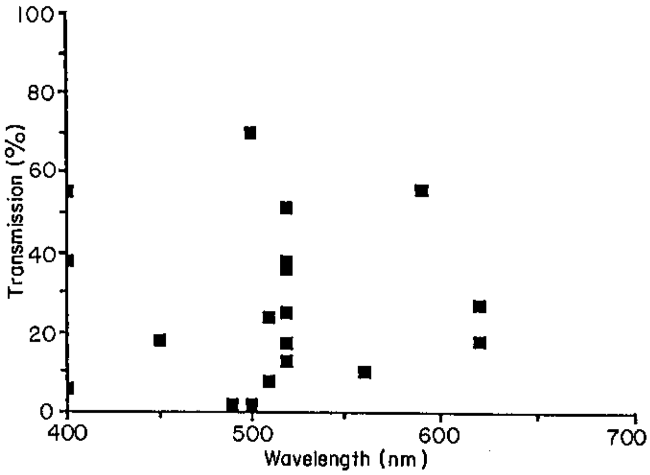

Figure 2 Transmissions and wavelengths of the minima of the transmission curves shown in *Figure 1*

the blue filter, luminances higher than 10 cd m^{-2} could be obtained only by adding light from the red and green projectors, restricting the gamut.) The surface was viewed from a distance of 0.4 m and on it was presented a passage of text or a pattern of horizontal striped lines. The text consisted of 31 lines without paragraph from *Small House at Allington* by A. Trollope, laser printed in black ink on white matt paper with sansserif fount and ragged right margin. The body of the text measured about 0.15 m wide × 0.13 m high and was centred on paper 0.21 m wide × 0.19 m high. The patterns were gratings with square-wave luminance profile, contrast 0.7, square in outline, each side subtending 14 degrees. They were printed in black ink on white paper with a white border 6.7 degrees wide.

The light from each projector was controlled by the wheel of a potentiometer connected to a thyristor circuit. The three wheels were mounted in front of the illuminated surface where they could easily be reached by the subject's hands, although the hands were covered by black curtain to prevent any clues from skin colour. With the passage of text in place, the subjects were introduced to the methods of mixing the light from the three projectors to produce white, red, green, blue, yellow, turquoise and magenta and then instructed to mix a colour that made the text as clear as possible, and then as comfortable as possible. The settings were made initially at a luminance of the subjects' choice, and subsequently with the luminance of the page constrained by verbal instruction to be about 40 cd m^{-2} and then about 10 cd m^{-2}. The text was replaced by a grating with a spatial frequency of 2.8 c/deg and separate settings obtained for clarity and comfort, initially without and subsequently with constraints on luminance, as before. The grating was then replaced by one with a spatial frequency of 0.7 c/deg and the procedure repeated.

The space-averaged luminance of the page was measured using a spot photometer with V-lambda correction (Minolta model LS-100). The colour coordinates were obtained using a Minolta TV colour analyser (Model TV2130). The probe was directed towards the pojectors in order to capture sufficient light for reliable readings. The chromaticity coordinates obtained when the probe was directed at the page via an aluminium tube were compared with those obtained when the probe was

Table 5 Results of muscle balance testing. In the follow-up study the means of 5–30 observations are shown with standard deviations in parentheses

	Maddox Wing				*Mallett*			
Subject	*No Rx*	*Rx*	*Irl*	*ND*	*No Rx*	*Rx*	*Irl*	*ND*
				FIRST STUDY				
7	Ortho	(plano)	NT		1 eso		Ortho	
8	2–12 exo		6–11 exo		Ortho			
10	6 exo	4 exo	Ortho		Ortho	Ortho		
14	Ortho	NT			1 eso	NT	Ortho	
16	3 eso	Ortho	Ortho		1 eso	Ortho	Ortho	
18	3 hyper	3 hyper	1–3 hyper		1 hyper	1 hyper	0–1 hyper (less movement)	
19	8 exo	8 exo	8 exo		Ortho	Ortho		
20	Ortho	Ortho			1 exo	1 exo	1 exo	
				FOLLOW-UP STUDY				
1	3.9 exo (1.4)	(plano)	4.4 exo (1.5)	4.2 exo (1.47)	Ortho	NT	NT	NT
2	2.6 exo (1.5)	4.8 exo (1.1)	1.5 exo (1.3)	1.9 exo (1.65)	Ortho	NT	NT	NT
3	0.2 exo (1.23)	0.4 exo (1.07)	1.4 exo (2.0)	1.9 exo (2.2)	Ortho	Ortho	NT	NT
4	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	Ortho	Ortho	NT	NT
5	2.8 exo (1.2)	1.0 exo (1.1)	3.7 exo (1.6)	2.7 exo (0.89)	Ortho	Ortho	NT	NT
6	0.1 exo (0.66)	0.7 exo (0.54)	0.2 eso (0.59)	0.0 (0.57)	Ortho	Ortho	NT	NT
7	0.3 eso (0.43)	(plano)	0.3 eso (0.43)	0.0 (0.0)	1.0 eso (0.0)	NT	0.0 (0.0)	0.8 eso (0.27)
11	0.2 eso (0.48)	0.1 eso (0.18)	0.0 (0.0)	0.0 (0.13)	12.5/min	10.5 min^{-1} (suppression rate min^{-1})	0 min^{-1}	6.5 min^{-1}
13	3.6 eso (3.9)	4.1 eso (6.4)	3.7 eso (6.0)	7.6 eso (7.7)	Ortho	Ortho	NT	NT
14	0.6 eso (2.0)	NT	0.1 eso (0.25)	1.0 eso (1.15)				

NT = not tested; Irl = with Irlen filter fitted; ND = with neutral density filter; Rx = shown in *Table 2*.

directed toward the projectors. The difference was small. The coordinates tabulated incorporate the small correction necessary to provide estimates of the chromaticity coordinates of the page itself.

Results

Two of the ten subjects (numbers 2 and 11) showed a significant ($p < 0.05$, two-tail t-test) reduction in ocular muscle imbalance with the Irlen filters. Two (numbers 3 and 5) showed an increase. Subjects 6, 7 and 11 showed a significant reduction in muscle imbalance with neutral density filters as compared with no lenses. The one subject showing fixation disparity improved significantly with both neutral density and Irlen filters.

Table 3 shows the colour coordinates of the colour mixtures initially chosen and those calculated from the transmission spectrum of the volunteers' spectacles. There are few data but sufficient to indicate that the colour coordinates of the mixture did not bear a strong relationship to the colour coordinates of the tint in the spectacles, although both sets of coordinates were generally within the same region of colour space. The coordinates shown are those first produced, that is, under the instruction to make the text as clear as possible. In all subjects except two (numbers 1 and 2) the coordinates and luminance produced under the instruction to make the text as comfortable as possible were similar. When the luminance of the mixture was constrained by verbal instruction to be near 40 cd m^{-2} the colour coordinates were significantly closer to equal energy white than when the luminance was near 10 cd m^{-2}. Work is currently under way to determine whether this was simply an artefact of the more restricted gamut available at high luminances or due to the fact that the higher the luminance of a coloured surface, the more colourful it appears[10]. The colour mixtures produced for the two striped patterns were in general similar to those for the text stimuli (with the exception of subject 5 whose mixture for these stimuli was blue). In some cases the mixtures had high levels of hue saturation. Such extremes are occasionally seen in mixtures produced by normal subjects (unpublished data).

General discussion

There were modest improvements in the speed of visual search, and reduction in the anomalous perceptual effects induced by striped patterns. In three subjects the filters improved visual acuity significantly. There were apparent improvements in binocular control in five subjects at the first examination. The second examination included a more detailed investigation of the effects of the tints on binocular control, and showed modest but idiosyncratic changes, some of which were adverse. Only two of the subjects in the second examination had shown poor binocular control at near when first examined.

The subjects reported reductions in eye-strain and/or headaches as a result of wearing their Irlen filters. The improvements are subjective and difficult to substantiate, particularly in view of the reports of psychoneurosis in patients who wear tinted glasses[11]. However, liability to certain types of headache is known to be associated with susceptibility to perceptual distortions in certain visual stimuli, notably gratings with a square-wave luminance profile and a spatial frequency close to 3 c/deg. The distortions are thought to be cortical in origin[8]. Persons who report many illusions in such patterns tend to suffer frequent headaches[8], particularly migraine[12], and in the 24 hours before the onset of a headache susceptibility to the distortions increases[13]. In view of these data, it is of interest: (1) that the volunteers in the present study reported more illusions than one might have expected on the basis of previously published data from normal observers[8]; and (2) that when the Irlen filters were worn the subjects saw fewer perceptual distortions, even when illusions of colour were ignored.

The improvements in headaches and perceptual distortions were, of course, subjective. An objective test, visual search, also showed small improvements when the Irlen filters were worn, but it is possible to argue that the improvements were secondary to changes in motivation occasioned by placebo effects or changes in visual comfort. However, not all the observed improvements in ocular muscle balance can readily be explained by placebo effects, given that subjects were unaware what 'good' performance might be. These effects are also difficult to interpret in terms of accommodation and its links with vergence. They are consistent with the improvements in stereopsis reported by Fricker[14] who used a test of stereopsis more sensitive than the Titmus test used here.

The measured improvements were small, despite the selection of subjects who claimed benefit. Other subjects are therefore unlikely to show larger effects than those found here, at least on the visual tests used. Only a small proportion of the tests showed improved performance with the filters, which raises the possibility that a similar number of tests, but perhaps different ones, might prove statistically significant in any replication of this study. If the improvements observed are secondary to some more central effect, such as reflected in subjective visual comfort or indeed motivation, then small inconsistent but generally positive findings would, of course, be anticipated.

Some of the selected volunteers mixed a red, green and blue light to illuminate text or patterns on an otherwise colourless surface. When asked to choose an illuminant maximizing comfort and clarity they chose similar mixtures for both types of stimuli. The mixtures were only broadly similar to the colours that the Irlen tints would provide under common forms of illumination. The Irlen tints were selected under conditions in which coloured objects were visible in the field. These are realistic viewing conditions in which the mechanisms of colour constancy may play an important role, affecting the choice of tint, provided, of course, that choice is determined by colour perception rather than by wavelength.

The most obvious explanations of the effects of tinted glasses involve some aspect of accommodation. Accommodation is a dynamic process, and it is quite possible that the tints affected accommodative load in some constructive way. Despite the variety in the colour appearance of the tints, all had high transmission above 650 nm (a feature of the dyes used with CR39 plastic lenses). The majority had a minimum transmission in the range 500–500 nm (see *Figures 1* and *2*) although the photopic transmittance (with CIE illuminant D65) varied considerably (see *Table 3*). If accommodation were the sole mechanism for any efficacy of the tints, one might not expect the principal absorption to be in the middle of the visible spectrum. Two alternative explanations perhaps therefore deserve consideration. The first concerns the effects of the temporal modulation of light, and the second the spatial.

Temporal effects

The light from a fluorescent lamp (controlled by conventional circuitry) pulsates in brightness twice with each cycle of the electricity supply; in the UK at a frequency of 100 Hz. The pulsation is too rapid to be seen as flicker but affects the firing of neurons in subcortical visual structures, including the retina (in humans)[15] and the lateral geniculate nucleus (in cats)[16]. When the pulsation is electronically removed under double-blind conditions the incidence of headaches and eye-strain amongst office workers is halved[17]. People with migraine frequently complain of fluorescent lighting[18], and the pulsation might explain these complaints. Nearly all the subjects in the present study had a family history of migraine, and may therefore have been unusually susceptible to the effects of light pulsation. Rapid and imperceptible pulsation of light has a small effect on ocular motor control[19] and may perhaps also affect accommodation[20], suggesting that reading might be affected. Many of the subjects in the present study had reading difficulty. Persons with reading difficulty have a selective deficit on psychophysical tasks that assess the function of the transient system[21]. The subjects might have been unusually susceptible to the effects of light pulsation for this reason as well.

The common halophosphate fluorescent lamps show little pulsation at the red end of the spectrum. Most of the pulsating light has a wavelength less than 550 nm (Reference 9). It follows that the pulsation can be reduced by tinted glasses that preferentially transmit wavelengths greater than 550 nm. *Table 3* shows for a halophosphate lamp the peak–peak pulsation of light (half the difference between maximum and minimum luminance, expressed as a percentage of the time-averaged luminance) for a typical halophosphate fluorescent lamp (CIE type F2) after the light has been filtered by the Irlen tint. Most of these values are less than the pulsation that occurs without any tint (28.3%), suggesting that the tint usually acts to reduce the peak–peak pulsation in luminance. The reduction is usually small, suggesting that the effects of the tint on the pulsation from fluorescent lamps is unlikely to be the only, or even the principal explanation for any beneficial effects that there may be. Further, there is no evidence to suggest that the beneficial effects are confined to conditions in which the subject is exposed to fluorescent light.

Spatial effects

Wilkins and Nimmo-Smith[22,23] applied a neurological theory of visual discomfort[8] to the perception of the clarity of text. They demonstrated that printed text resembles a pattern of stripes – some texts more so than others. The 'stripes' can have aversive effects, including asthenopia, headaches and pattern-sensitive epilepsy. Covering the lines above, and below those being read using a simple mask reduced the 'stripes' and thus the aversive effects (both epileptic and non-epileptic). For observers susceptible to the anomalous visual effects in striped patterns, such as those with migraine[11], the mask improved the clarity of text[23]. As has already been stressed, most of the volunteers in the present study had a family history of migraine. Most were susceptible to adverse effects from striped patterns and the Irlen filters appeared to reduce their susceptibility.

Coloured filters have, from time to time, been reported as benefiting individual patients with photosensitive epilepsy[24] and, for reasons that are poorly understood, people with migraine sometimes prefer a particular tint. Weston[25] made the observation that:

> 'it is ... possible for acute strain to be caused by repetitive patterns. ... For example, a dress fabric

having very narrow black and white stripes of equal width – forming what is known as a dazzle pattern – has proved so trying to work with as to be intolerable except for quite short periods. In such cases it is *sometimes* possible to lessen the strain by wearing *coloured* glasses which *appear* to subdue the glaring contrast of the pattern.'

The choice of the italicized words (authors' italics) seems particularly apposite, especially the use of the word coloured, implying a very strong tint, similar to that of many of the Irlen filters.

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