

The Aetiology and Measurement of Colour Preference and its Association with Light Sensitivity, Reduced Contrast Sensitivity and Binocular Deficiency

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Abstract

Objective: This paper aims to show that a colour preference where none would normally be expected is a physiological characteristic specific to a sport (occupation) and to an individual, which is related to light sensitivity, reduced contrast sensitivity and Binocular deficiency.

Apparatus: The test consists of 7 lorgnettes glazed with approximately 65% light transmission factor (LTF) tints representing 6 colours of the rainbow and neutral density grey acting as a control or placebo.

Method: Two groups of athletes were tested; Netball Panel Umpires (former National or International players) average age 43 and the Junior British Rifle Squad and 8 of their coaches from the National Small Bore Rifle Association (NSRA), average age 21 and 42. The lorgnettes were presented in random order asking subjects if they liked or disliked the colour. The best and worst tints were then determined by successive forced choices.

The data for the two groups were analysed using the Chi Squared Test and the pairings Blue-Teal and Yellow-Tan, which were found to be mutually exclusive.

Results: When the data for both groups were combined colour choice was not random ($p = 0.00074$) this appeared to be particularly true for Blue, Teal (blue/green), Yellow and Tan (Orange). Observed and expected results for grey were the same. When the best and worst responses to the pairings of colours (Blue/Teal and Yellow/Tan) were compared separately for each group the differences (NSRA $p = 0.00001147$, Netball $p = 0.00613$) were significant. Both groups tended to favour either a blue or teal tint over yellow or tan; this was a stronger effect in the Umpires.

Conclusion: Colour preference was a defining characteristic for the two groups. Individuals show a non-random preference for particular coloured tints. A preference for blue associated with a strong dislike of yellow is likely to indicate clinically significant light sensitivity associated with poor binocularity. A pathological or physiological reduction (amblyopia) in contrast sensitivity is likely to cause individuals to favour the contrast enhancing effect of yellow.

Previous methods of measuring colour preference, which did not separate the variables of hue and saturation, may have led to misleading conclusions on the aetiology of colour preference. This could have affected the understanding of visual stress and the cause of reading difficulties. It appears that highly saturated tints give rise to a phenomenon, which might be called "Differential Chromatic Occlusion" diagnostic of a measurable and correctable binocular deficiency, which predisposes to dyslexia.

Keywords: *The Eye Bright Test; Colour Preference; Light Sensitivity; Net Ball Panel Umpires; British Junior Rifle Squad; NSRA; Autonomic Nervous System; Sympathetic; Parasympathetic Colorimeter; Irlen Syndrome; Meares Irlen; Coloured Overlays; Contrast Sensitivity; Dyslexia; Visual Stress; Binocular Vision; Suppression; Depth of Suppression Test; The Use of Tints; Aligning Prism; Differential Chromatic Occlusion*

Abbreviations

UV: Ultra Violet; IR: Infra Red; EBT: Eye Bright Test, Patent GB2374428; NHS: British National Health Service; NSRA: National Small Bore Rifle Association; LTF: Light Transmission Factor; SVUK: Sport and Schoolvision United Kingdom Ltd

Introduction

Colour is a powerful communicator. The transcendence of the visual system [1] makes it arguably the finest discriminator at the highest level of sensory perception.

It warns of the danger in red berries or fire and the sting of insects with yellow and black bodies. It shows the difference between a pink flush of emotion and the pallor of anger, fear or poor health; it is a powerful tool in engineering, physics or electronics and an essential analytical tool in chemistry and many other sciences.

The ability to distinguish between wavelengths in the electromagnetic spectrum is useful in industry, where colour coding is used to convey information quickly [2,3]. Lack of colour discrimination can be a disadvantage in some professions [4] for about 8% of the male population who are colour deficient. For that 8% it has been proposed that a red tinted lens improves hue discrimination by increasing the relative brightness of red [5]. A more recent development in the treatment of colour deficiency has given a better understanding of the difference between types of Red/Green colour “blindness”. These patented lenses separate the sensitivities of red and green photoreceptors which are congenitally too closely aligned, restoring colour vision in the most common types of colour deficiency, deuteranomaly and protanomaly [6]. The effect of colour deficiency on colour preference was beyond the scope of this research.

Choice of colour, or colour preference is deeply rooted in psychology and evolution. It may not be a coincidence that the natural colours of fields and forests and the blue of the sky and the sea are calming. This may be why colour has a powerful effect on the autonomic nervous system, for instance orange or yellow will energise the sympathetic even in the absence of danger, equally blue and teal will facilitate relaxation by stimulating the parasympathetic.

Colour preference can also be affected by pathological conditions like cataract, The French impressionist Monet was deeply disturbed by the effect cataract had on his colour perception. Macular degeneration and systemic disorders, which affect cone function, are also likely to have an effect. Looking through a coloured material can affect complicated “neurological” disorders like dyslexia and associated conditions, migraine and epilepsy [7].

The hazards of colour

The colour of light is an indication of wavelength and in some cases an associated danger. Blue light and Ultra violet (UV) are implicated in posterior sub capsular cataract formation and macular degeneration [8-11]. The eye does not deal easily with shorter wavelengths, UV causes the crystalline lens to fluoresce and blue light is focused in front of the retina, both contributing to a veiling luminance and reduced contrast sensitivity [12]. A yellow tint (with a UV filter), which absorbs blue light can improve contrast and mitigate any damaging effects.

Infra red (IR) can cause cortical cataracts in blast furnace workers [13] It may be the heat associated with IR, which increases the prevalence of cataract in people with brown eyes over the age of 45 [14], the iris acting as a heat sink on top of the lens, which then “cooks” the underlying protein of the crystalline lens causing a cuneiform cataract.

When light is intense in the orange/yellow part of the spectrum, to which the eye is most sensitive, it can lead to disability glare. Although filters will not necessarily increase the contrast thresholds [15] they will save the retinal photoreceptors from excessive metabolic demand as they bleach and regenerate with a damaging effect on dark adaptation and long-term macular dysfunction [11].

Understanding the physical effects of tinted lenses is important when it comes to the final dispensing of spectacles [16], but the usefulness of tints is not fully understood [17,18].

In the hospital eye service tints may be seen as clinically necessary for well established reasons like albinism, aniridia and trabeculectomy damage, or symptomatic age related macular degeneration, cataracts and aphakia.

On Health Service examination (NHS England) claim forms tints have to be justified in a way, which other parts of the prescription are not; there is a lack of guidance about the frequency of prescribing tints, which colour is best and why. When there is no professional consensus funding authorities will tend to be the final arbiter.

Given these facts and the potential of tinting to relieve symptoms and prevent disease, there needs to be a convenient way of measuring colour preference in general practice.

Measurement of colour preference

The measurement of colour preference has been established. Teacher Olive Meares described how pupils with visual perceptual difficulties found these reduced when the page was covered with sheets of coloured plastic [19].

Psychologist Helen Irlen later described how her students reported fewer visual distortions when aided by coloured filters [20]. The choice of colour seemed specific to the subjects, who were each given a number of different sheets from which to choose.

Anecdotally some practitioners believed that tints should never be prescribed and have little value in the treatment of reading difficulties, this may have contributed to the scepticism of early work with coloured overlays and reading disability. The beneficial effects can be explained by the physical properties of light and the absorption characteristics of the overlays [17]. For example someone with reduced contrast sensitivity will find a yellow overlay helpful. Changing the background of the print on the page from white to yellow increases the contrast of the black letters against their background. Yellow is at the peak sensitivity of the visual system.

Similarly, someone who is light sensitive will do well with a blue or green overlay, which reduces the glare from white light reflected off the page. For the same reason students' work is sometimes printed on blue or sepia paper. The choice of colour can be predicted to some extent by the subjects' degree of light sensitivity; the more light sensitive they are the closer their colour choice will be to the short wavelength end of the visible spectrum and the more yellow light it will absorb [17].

Wilkin's intuitive colorimeter

The Irlen tints were used in overlays and were not tested for use in spectacles [21]. One of the drawbacks of the overlays was that they prevented writing on the page. Wilkins [22] Lightstone and Evans [23] investigated the Irlen effect to establish a scientific measure of colour preference (hue) and saturation (light transmission of the tint), which would enable spectacle lenses to be tinted. Research with the Wilkin's Intuitive Colorimeter established scientifically that individuals have distinct and precise combinations of colour and saturation preference, which significantly increased reading speed [24,25]. These precision tinted lenses were often highly saturated.

This measurement of reading speed was based on random word recognition and excluded subjects who were unable to read any of the 15 words selected. Cleverer subjects may have been able to recognise random words by their first and last letters especially after a practice trial. This would make it harder to differentiate the effect of intelligence from the building block of reading speed, which is rate of individual character recognition [26]. Another potential drawback to this method of assessing the effect of coloured overlays or tinted lenses is that it does not take into account the differential effect of serif and non-serif fonts which can be associated with particular refrac-

tive and binocular vision difficulties [26]. The binocular vision difficulties themselves would also have to take into account eye dominance to fully understand and account for their effect [27].

For this reason a broad conclusion that coloured filters could relieve symptoms that were not attributable to conventional errors of refraction or binocular vision anomalies [28] may be premature. This could add to the importance of colour preference in so far as any colour preference when hue is fixed could be an indication of some underlying refractive or binocular vision anomaly and that no preference is normal. Otherwise research is left with the problem of explaining why colour preference is inconsistent [21] and why coloured overlays or precision tinted lenses improve reading.

Inter colour discrimination

Around the same time Chromagen was developing the use of different coloured contact lenses to improve colour discrimination in people who had a deficiency. Subjects chose from a range of eight different colours [29]. The effect on colour discrimination was equivocal, but serendipitously these lenses also had a positive effect on reading difficulties [30]. Like precision tinting these were also mostly heavily saturated lenses. This coincidence does raise the possibility that saturation is causing an effect, which is separate from hue.

Fixation disparity

It is understood that symptomatic binocular vision anomalies can be resolved refractively with aligning prisms [31]. A fixation disparity test is used to quantify the amount of prism required [32] where the nonius bars often show up the characteristic signs of compromised binocular balance. Typically one of the bars may be displaced laterally and appear faded or intermittently turned off and on when viewed through a polarized visor. The bars are shown below in the distance version of the Mallett Test (See figure 1). This is an adaptive process caused by the brain's ability to suppress an image in order to prevent double vision.



Figure 1: The distance mallett fixation disparity “OXO” Test showing the red nonius bars.

The depth of suppression

The depth of suppression can be measured in strabismus, for example by placing red or neutral density filters of increasing saturation in front of the good eye until the suppressing or amblyopic eye switches on and takes up fixation [33,34], or causes double vision.

The effect of colour saturation

It would be interesting to know if a similar effect takes place with deeply saturated lenses where there is underlying suppression in heterophoria. If the increasingly saturated tint were placed in front of both eyes, the eye with the tendency to suppress would be the first to switch off. This would effectively make the subject monocular thereby removing any binocular conflict and mitigating the effect of an unstable dominant eye [27]. A pilot study confirmed that the same improvement in individual rate of character recognition [26] with precision tinted lenses could be achieved with non-tinted lenses in prismatically corrected spectacles [35].

The importance of colour preference

The measurement of colour preference has demonstrated its importance but the mechanisms underlying the benefit remain uncertain [36-38]. It is interesting that neither Meares nor Irlen were optometrists so would not necessarily have been able to quantify the effect of visual disability on colour preference. Optometrist Geraint Griffiths (the author) has proposed that a preference for blue or green can be indicative of light sensitivity due to a binocular deficiency and a preference for yellow or tan can be related to reduced contrast sensitivity caused by impeded visual development [17,26].

Dyslexia and reading difficulties

The complexity (an almost infinite choice of hue and saturation) of the Colorimeter and precision tinting make it difficult to explain how the improved reading performance was achieved when Irlen had already demonstrated this effect with a limited range of hue and saturation. This has led to speculation about the cause of dyslexia and whether this is a separate condition to reading or learning difficulties, unrelated to vision, refractive or binocular deficiency [39-41].

Separation of hue and saturation

This argues the case for a simpler measure of colour preference to separate colour preference (hue) from saturation. Combining these two variables may have inhibited the consideration of vision and visual correction in the measurement of reading speed and its association with dyslexia.

Definition of colour

It may not be necessary to define colour precisely when considering its broader therapeutic use, so a more simply defined and reduced range of colours was proposed. These would be relatively light in saturation have a fixed hue with limited effect on colour constancy [42] and contrast sensitivity. A limited range of colours with fixed saturation (See table 1) might make it easier to understand how and why tinting works and what is the role of saturation.

Objective of the Study

The study aimed to show that:

- Only six colours with fixed hue and grey are needed to determine colour preference.

- Colour preference where none would normally be expected shows a non-random distribution, which is specific to the individual and the population (occupation) from which the sample is taken.
- Preference for particular parts of the visible electromagnetic spectrum and its association with light sensitivity may be an indication of visual disability.
- Colour choice from this limited range of tints can be a basis for prescribing.

Materials and Methods

Materials

The colour preference test consisted of 6 pairs of coloured lenses as described above and a control or placebo neutral density filter (grey), mounted in lorgnettes (See figure 2 Colour Preference Set). The light transmission factor was about 65% for each pair of lenses.



Figure 2: The colour preference set (The Eye Bright Test - EBT).

The colours were evenly spread across the visual electromagnetic spectrum (the colours of the rainbow). The precise wavelength of each colour was not considered to be important as long as it was at about the middle of the range generally accepted to be the colour indicated (See table 1 colours used and wavelength guide).

Wavelength	Colour ~ LTF 65%						
Guide (nm) (Mid range values)	Pink	Tan (Orange)	Yellow	Teal (Blue /Green)	Blue	Fuchsia (Purple)	Grey
Jalie [15]	640	610	580	540	480	420	Neutral
Fincham [43]	640	606	584	545	482	420	Neutral
Freeman [44]	629	605	568	520	470	408	Neutral

Table 1: Proposed colours and wavelength guide.

Subjects

Two groups of subjects from elite sport were tested:

1. All England Netball Association Panel Umpires, most of whom were former National or International players
 - a. Screened at Nottingham University 6.9.98.
 - b. N = 64.
 - c. Average Age 44.3.

2. British National Smallbore Rifle Association (NSRA) Junior Squad and eight of their coaches
 - d. Screened at Chesterfield 25.5.97 and Aldersley 21.4.00.
 - e. N = 35.
 - f. Average Age 20.5 (coaches average age 42).

Method

Independent assessors (some of the athletes) tested the umpires in an indoor sports hall with no outside windows. The author tested the shooters (NSRA), in a large room in a sports centre, which was open to the daylight.

The subjects were asked to look at a distant object in the prevailing ambient light (ideally relevant to their sport like a target in shooting). Each lorgnette was presented at random. Subjects were asked to say if they liked or disliked the colour of the lenses or had no preference. The question was not specific about why they liked it or not, so that their answer could be a summation of all the things that influence a person's choice of colour, a gut reaction. The favoured tints were placed in one pile on the examiner's right and the least favoured on the left. Undecided tints were placed in the middle.

If there were more than one lorgnette in the least and most favoured piles the subject was then asked to make a forced choice between successive pairs of lorgnettes, asking if it was better with one or two. The first choice was retained and compared with the next one in the pile until a single lorgnette in each pile remained. It was very rare for a subject not to be able to decide which were the best and worst tints.

The subjects with no colour preference fell into two groups:

- All colours liked indicating no preference and good tolerance of colour distortion.
- All colours disliked, indicating intolerance of any colour distortion.

Recording the Results

The codes for each lorgnette and choices of all or none are shown in table 2.

Colour	Teal	Yellow	Blue	Orange	Grey	Pink	Fuchsia	All	None
Code	1	2	3	4	5	6	7	8	9

Table 2: Choice codes.

The codes were recorded on a data sheet, one for each subject (See table 3).

	Colour Preference			
	Best	Worst	All	None
Code				

Table 3: Colour preference data sheet

Statistics

The Chi squared Test for non-parametric data was used to test the distribution of colour choice, the null hypothesis being that it would be random in each of the conditions tested. Probabilities (p) of 0.05 (5.00E-02) or less were deemed significant where p was the probability that the choice of colour was random.

Results

When the data for both groups were combined colour choice was not random (p = 0.00074) this appeared to be particularly true for blue, teal, yellow and tan. The data for pink and fuchsia, all and none had to be summed because there were insufficient data points separately. Observed and expected results for grey, pink/fuchsia and all/none were similar (See table 4).

Observed	Teal	Yell	Blue	Tan	Grey	Pink/Fuchsia	All /None	Totals
Best	15	19	20	8	15	11	9	97
Worst	5	34	6	21	12	11	7	96
Totals	20	53	26	29	27	22	16	193
Expected								
Best	10.05	26.64	13.07	14.58	13.57	11.06	8.04	
Worst	9.95	26.36	12.93	14.42	13.43	10.94	7.96	
p	0.00074							

Table 4: NSRA and netball results combined (Pink/Fuchsia, All/None, amalgamated).

The unexpected findings were for Teal, yellow, Blue and tan, which seemed to be contributing most to the significance of the test.

Rifle results

During the data collection Teal and Blue tended to be mutually exclusive to Yellow and Tan (only one subject put blue and yellow into the pile of liked tints). For this reason when data had to be combined to satisfy the criterion of the Chi Squared Test (expected values 5 or greater) Teal was combined with Blue. The data for yellow and tan were also combined although the results showed that these two colours had different properties judged by their frequency of choice. The distribution of these pairings was not random (p = 1.1467E-05 see table 5).

Obtained	Teal/blue	Yell/Tan	Totals
Best	15	7	22
Worst	1	21	22
Totals	16	28	44
Expected			
Best	8	14	
Worst	8	14	
p	1.1467E-05	(0.0000115)	

Table 5: Teal/blue and yellow/tan pairing frequency compared for rifle.

To confirm that they were appropriate the pairings were changed to teal/yellow and blue/tan, which showed significant differences although much reduced ($p = 0.033$).

The frequencies of blue/yellow and teal/tan were then compared and showed no significance ($p = 0.36$). This suggested that these colours are true opposites whose effects are cancelled out when they are paired.

In the first pairing (teal/yellow and blue/tan), Teal and Yellow aren't complete opposites because the green component in Teal absorbs some blue light, giving it a contrasting effect similar to yellow. Tan and blue share similar properties of yellow light attenuation.

Netball results

When Teal/Blue was paired against Yellow/Tan the difference was significant ($p = 0.0092$) but less so than the Rifle Shooters ($p = 0.0000115$).

The probability of a random distribution of colour preference in the Umpires for the pairing of Teal/Tan and Yellow/Blue was 0.76, confirming again that pairing the opposite colours cancelled out the significant difference between them as found in the rifle shooters.

Comparison of frequencies for rifle and netball

Inspection of the observed data showed differences between the two groups. For instance twice as many Umpires disliked yellow as liked it. In rifle the split was about 50:50. The rifle shooters had a real problem with tan, which was not such a big issue for the Umpires. Looking at the frequency of choice for the individual colours the majority of both groups liked blue (See table 6). Using the pairings teal/blue and yellow/tan, to make sure all expected values were greater than 5 the colour distributions were not significantly different. Although they came close for the worst colours $p = 0.062$ ($p = 0.167$ for best).

Rifle				
Observed	Teal	Yell	Blue	Tan
Best	9	7	6	0
Worst	0	9	1	12
Netball				
Observed	Teal	Yell	Blue	Tan
Best	6	12	14	8
Worst	5	25	5	9

Table 6: Comparison of the frequencies of individual colour choice between rifle and netball.

Discussion

The results support the hypothesis that using fixed tints of about 65% LTF colour preference is not random and therefore specific to the individual. This was particularly true for teal, tan, yellow and blue. Without the confusion of a second variable (saturation) it is possible to refer these findings back to the physical properties of light and tint absorption.

The range of response varied from very strong feelings (Immediate removal of the head from behind lorgnette or saying this makes me feel sick) to complete indifference. Very strong feelings against one tint (typically yellow) were often balanced by a strong liking for another tint (typically blue) in the same subject.

Yellow is at the peak sensitivity of the visual system so it is likely that this colour for someone who is already light sensitive would cause the strongest reaction. It follows that a blue filter, which maximally absorbs yellow light, will be comfortable for the same subject. It could be reasonable to say that liking blue and a strong dislike of yellow is an indication of clinically significant light sensitivity.

This finding might be taken into account when supplying corrective spectacles and that the response would be graded as mild, medium or strong to give a measure of the degree of light sensitivity and a guide to tint saturation.

It is important to be able to interpret individual colour choice in terms of the physical properties of light and filters as well as understanding the clues to the aetiology of the light sensitivity or reduced contrast sensitivity, which the preferred colour and its antithesis give.

The meaning of colour choice

Choice of blue

The findings suggest that both groups have light sensitive tendencies but this is more marked in the Netball Umpires. Strong light sensitivity typified by disliking yellow and liking blue has been linked to binocular dysfunction and pattern glare. When the subject is fighting to maintain binocular single vision bright light is an added distraction, which can tip the visual system from binocular overload to complete breakdown - the straw that breaks the camel's back. Light sensitivity is an expression of the subjects' need to avoid this distraction as well as demonstrating how important it is to maintain binocular single vision.

Choice of yellow

Liking yellow must have a different aetiology. It might be assumed that these subjects are not so light sensitive, but have a physiological need for the contrasting effect of yellow filters. Yellow filters increase contrast by removing the background luminescence caused by ultra violet (UV) and blue light. Normal subjects would be expected to be indifferent to the effect of a yellow filter.

Blue light and associated UV is strongly scattered by intra and extra ocular opacities like floaters, vitreous haze, early lens changes and corneal scarring, which can contribute to a disability glare. The blue and UV absorption properties of a yellow tint would reduce this light scatter. It might be expected that some of the older group of Umpires would benefit from this effect even though eight of the shooters were the older coaches.

It has also been shown that reduced contrast sensitivity due to poor visual development (amblyopia) can be enhanced by removing the veiling background luminescence caused by UV and blue light (using a yellow tint). This can in some way compensate for physiologically reduced contrast sensitivity, typically caused by uncorrected hyperopia or accommodation insufficiency in children.

The variables of hue and saturation

The consideration of the physical properties of high light transmission fixed tints helps to explain the original finding of Meares and Irlen and why there is a range of colour choice in the precision tints of the Colorimeter and Chromagen lenses. It is harder to explain why these mostly heavily tinted lenses, have a positive effect on reading speed despite the inevitable reduction in contrast sensitivity.

Cortical fusion

It may help to understand the effect of binocular dysfunction on cortical fusion. This can be demonstrated by the effect of fixation disparity, which is often a sign of binocular imbalance. When this occurs subjects may report that one of the nonius bars on the Mallett test for example, is faded (partial suppression) or intermittently turns on and off (intermittent suppression). This can be the first sign of developing monocular amblyopia, which is an adaptation to binocular dysfunction.

Single vision is so important to normal vision (recent loss makes it more difficult to judge position in visual space) that the brain will work very hard to prevent double vision even at the expense of depth perception by suppressing the weaker eye. The degree of suppression will vary according to the level of binocular control (or lack of it). It can vary from partial suppression only, in low levels of fixation disparity to complete macular suppression in manifest squint.

It is worth noting that if the brain is able to adapt to binocular problems in this way, then if the physiological visual dysfunction is corrected the amblyopia might be expected to resolve (without occlusion - patching of the better eye). It is likely that the older the subject the longer this process will take. However, there is no evidence to suggest that it is ever too late to address this problem. This would be particularly true in the teens and early twenties if accompanied by the signs and symptoms of reading difficulties, which can have a profound effect in this formative period.

The effect of saturated tints

It has been shown that binocular conflict can cause reading difficulties and this can be resolved by the use of aligning prisms in combination with the correction of refractive error.

Another way would be to occlude the partially suppressing eye to remove the binocular conflict. This could be achieved by using tints (as demonstrated by the depth of suppression test), which are dark enough to cause the weaker eye to switch off. This tint would be precisely defined to switch off the affected eye but not too dark to compromise the sight in the other eye.

The disadvantage of this technique would be that it relies on breaking down binocular vision leaving the subject with darkly tinted glasses that reduce contrast sensitivity and colour discrimination.

The Wilkins effect

The findings of the Colorimeter (due to Wilkins) and Chromagen lenses suggest that thus improved reading speed is not due to the Irlen effect but to the removal of the binocular conflict, which may be the primary cause of the reading difficulty. In other words Meares/Irlen treats the symptoms (light sensitivity or reduced contrast sensitivity) and precisely tinted lenses address the cause (poor binocularity). The "Wilkins effect" may be diagnostic of visual stress (or more simply stress in the visual system) caused by binocular deficiency.

Cortical hyper excitability

Visual stress and the need for precisely tinted lenses has been explained by light being received by a hyper excitable area of the visual cortex, which is relieved by diverting the visual pathway away from it using a precisely coloured and saturated filter. This would support the theory that this area of cortex, demonstrated by scans in individuals with dyslexia, is a congenital abnormality not amenable to treatment.

Alternatively, if this area of the brain is over excited by the effort of trying to combine two disparate and degraded images, it follows that correcting the fixation disparity with spectacles to relieve the binocular instability could also resolve the difficulty.

This argument changes the meaning of visual stress and its association with dyslexia. It changes from a condition, which is unrelated to vision and only susceptible to palliative treatment to one, which is directly related to vision and correctable with reading spectacles with the appropriate refractive findings and correcting prism.

Conclusion

Colour preference is specific to the individual and may be a defining characteristic of particular groups of athletes. The frequency of colour choice in the Netball Umpires and the Rifle shooters was not random and this was particularly true for the colours blue, tan (orange), teal (blue green) and yellow. It appears that one explanation for the significance of these colour choices is their relationship to visual disability. Previous research has shown an association between light sensitivity and binocular deficiency. For instance if a subject is struggling to make the eyes work together then the added distraction of bright light threatens a complete breakdown of binocular vision. This has the effect of making the subject extra sensitive to yellow light which is already at the peak sensitivity of the visual system.

On the other hand subjects who have suffered from some deficit in visual development which has caused a loss of contrast sensitivity (amblyopia) do well with a yellow tint which attenuates the veiling background luminescence caused by ultraviolet and blue light, making print easier to see. This effect is particularly obvious when a yellow overlay is placed over black print because the contrast of black against a yellow background is greater than black against a white background. This effect is likely to be the same with yellow tinted spectacles.

Colour preference could be expected to vary according to which were the greater, poor binocularity or poor visual development. It follows that liking particular tints will depend on the degree and cause of visual disability. It is likely that in subjects with no underlying disability colour preference will be weak or non-existent.

The case for testing one variable

The results using tints of fixed hue argue the case for testing one variable at a time. Tests which combine the effect of hue and saturation make the meaning of the results more difficult to interpret, particularly when a fixed high LTF hue leads to a plausible explanation of the effect and aetiology of colour preference.

The results of the Colorimeter and Chroma gen lenses, demonstrate increases in reading speed without a clear explanation of why. The defining of "visual stress" and its association with dyslexia leads to difficult arguments. For instance that people with dyslexia have congenital (unproven) brain abnormalities, which cause areas of cortical hyper excitability. This by definition excludes the possibility that dyslexia is anything to do with vision and therefore only susceptible to palliative treatment (extra time in exams, applied use of information technology).

This leads to the question, why are these precisely tinted lenses albeit different colours, so often highly saturated?

It is possible that allowing two variables, hue and saturation is diverting attention from the true aetiology of reading difficulties. Hue on its own gives an explanation of the importance of colour and its potential association with visual disability but invites the question, does saturation have a different effect to colour.

It has been shown that the depth of amblyopia can be measured by how dark the tint needs to be in front of the good eye to make an amblyopic eye turn on.

This allows the possibility that if two eyes are required to look through tints of increasing saturation there will come a point when the weaker eye, which is already partially suppressing will turn off. If it is true that reading difficulty is often due to binocular conflict then inevitably if one eye is turned off the binocular vision problem will be resolved. This removes the barrier to reading caused by binocular instability. The subject would be expected to read faster as long as the better eye can cope with the loss of contrast sensitivity and colour constancy. High contrast black on white print would facilitate this.

This principle of increased reading speed in symptomatic binocular deficiency corrected with aligning prisms is well established. Why then shouldn't it be true in diagnosed dyslexics who have the same sorts of binocular presenting signs?

The answer to this question may lie in the interpretation of the effect of heavily saturated tints. That dyslexia is not due to an innate hyper-excitability in the visual cortex but to two disparate images causing that particular part of the brain to overwork as it tries to interpret the degraded sensory input from two unstable, disparate eyes.

Differential chromatic occlusion

The findings of the Colorimeter (due to Wilkins) and Chromagen lenses may be the first demonstration of what might be called "Differential Chromatic Occlusion". This would suggest that improved reading speed with precisely tinted lenses is not due to the Meares/Irlen effect but to the removal of the binocular conflict, which is the primary cause of the reading difficulty. Meares/Irlen treats the symptoms (light sensitivity or reduced contrast sensitivity) and saturated lenses address the cause (poor binocularity).

The "Wilkins effect" may be diagnostic of, simply put stress in the visual system caused by binocular deficiency. This opens the door to the correction of dyslexia with normal spectacles at distance and/or near with aligning prisms based on measured fixation disparity; taking into account eye dominance, light sensitivity and evidence of a subsequent increase in the rate of individual character recognition (CRST).

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Conflict of Interest

The Eye Bright Test (EBT) has a British patent and is available for sale though SVUK Ltd., the author is managing director of SVUK Ltd. The proceeds from any sales go to support the work of the Association of School and Sportvision practitioners (ASvP). Since the formation

of SVUK Ltd in 1999 the directors have not taken any dividends and all profits have been re-invested in the company to further the work of Association Members. The author's own practice Optical3 is the Guarantor of SVUK Ltd.

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