Visual stress: evidence, mechanism, co-morbidities, treatment  
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Questions
- Why are coloured overlays so commonly used in schools and yet so controversial?
- Which patients with migraine find coloured lenses useful?
- What other neurological conditions benefit from coloured filters?
- What are the mechanisms of visual stress?

One possible explanation for the effects of coloured overlays
- Inconsistent
- Idiosyncratic
- Perplexing

School lighting
In 2009 >80% of lighting in British classrooms was still
- fluorescent
- controlled by magnetic circuitry (Winterbottom & Wilkins, 2009).

Flicker
Gas discharge in the lamp occurs twice with each cycle of the AC electricity supply (100Hz).
Lamp varies in brightness and colour (technically chromaticity)

Persistence
The variation depends on the phosphor coating, which continues emission after activation by the gas discharge.
- Lamp with halophosphate coating varies from bright white to brown
- Triphosphor lamps vary between bright white and dim green (Wilkins & Clark, 1990).
Thorn Polylux 4000

Variation of light at a frequency of 100-200 per second cannot be seen, but it gives a signal in the electroretinogram. The cells respond to the rapid variation (Berman, Greenhouse, Bailey, Clear, & Raasch, 1991).

Eye-strain and headaches

The variation in brightness/chromaticity from fluorescent lamps is known to cause eye-strain and headaches.

- does not affect everybody
- serious effect on a few
- overall average incidence of headaches and eye-strain is halved when the variation is reduced using electronic circuitry (Wilkins, Nimmo-Smith, Slater, & Bedocs, 1989).

Double masked study

Vision

The variation in brightness/colour from fluorescent lamps also affects

- control of eye movements across text (Wilkins, 1986)
- visual performance (Veitch & McCall, 1995).

Adaptation

People adapt to flicker in the long term. Early televisions used a cathode ray tube that was scanned from top to bottom repeatedly 50 times per second. Flicker was worse when TV upside down. The difference in perception of flicker in the two directions of scan depended on the number of hours television watched.

- we are continuously adapting to our visual “diet” (Thomson & Saunders, 1997).
Coloured overlays

• substantial minority of school children
• different colour for each individual, individually selected.
• read more quickly with the chosen overlay
• increase in speed predicts subsequent voluntary long-term usage.
• eye-strain and headaches common (Wilkins, 2003).

Reduction in variation

Coloured filter can reduce the variation in colour (chromaticity) from fluorescent lighting.

Some colours may be more effective for certain lamps:

• When the variation is from white to green, a green filter will reduce the variation in chromaticity.
• When the variation is from white to brown, a yellow filter will reduce the variation in chromaticity and luminance (Wilkins & Wilkinson, 1991).

Use of overlays

The effectiveness of a particular colour will depend on the adaptation to the variation.

Adaptation to the colour of the overlay may also occur.

Experience has shown that some children will use their overlays for a limited time until they report the overlay is no longer effective. When this occurs a change in colour can sometimes restore the beneficial effect.

Lenses

• Many children who find coloured overlays useful benefit from coloured lenses.
• Users of coloured lenses are known to experience long-term effects of adaptation on their perception of colour (Engel, Wilkins, Mand, Helwig, & Allen, 2016).

Confirmation

Study of 799 schoolchildren in SW India,
Classrooms are lit with daylight,
Overlays had no effect on reading speed whatever (Srinivasan, Krishnan, Wilkins, & Allen, 2018).
34 children who had specific learning difficulties read under both daylight and fluorescent lighting with magnetic circuitry.
Overlay increased reading speed under the fluorescent lighting but not under daylight (Krithica Srinivasan, personal communication).
Rapid variation in colour

- May explain the headaches, eye-strain and fatigue
- But why the effect on reading speed?

Reading

Eye movements made during reading can be large and fast. When fast the variation in brightness and colour from lighting produces a spatial pattern on the retina during the eye movement (“phantom array”) (Roberts & Wilkins, 2013).

This pattern may be confused with that from other aspects of the text itself.

Reading speed

Eyes are re-aligned after each large rapid eye movement

Re-alignment takes longer when the vertical strokes of letters form a regular pattern, as in the word *mini* (Janta, Jaschinski, & Wilkins, 2010).

The effects of the spatial pattern of text on eye alignment occur without any awareness.

Re-alignment

If the phantom array may interfere with the adequate alignment of the eyes during reading:
- When the phantom array is reduced with a coloured filter, reading speed should increase.
- Greater effect in children whose binocular coordination is compromised, many of whom have poor reading skills (Palomo-Álvarez & Puell, 2010).

Note that adaptation means that effects of magnetically ballasted lighting may outlast exposure.

Time-line

The widespread introduction of fluorescent lighting in schools took place over about two decades from the mid 1950s (Pott, 1952). The first reports of coloured overlays helping reading were those of Meares (1980). So the use of coloured overlays in schools may be attributable in part to the widespread use of magnetically ballasted fluorescent lighting, adaptation to which helps explain the large individual differences in choice of coloured overlays and the changes in preference.

Controversy

Some classrooms have fluorescent lighting with electronic ballast that removes the 100Hz variation. No benefit from coloured filters would be expected.
Seasonal effects

Overlays are more commonly chosen by children during the winter months.

Caution re LEDs

A change in school lighting practice is overdue. Fluorescent lamps controlled by electronic ballast are healthier and less expensive to run, paying for themselves in about two years. Nowadays LED lighting is generally preferred, but some flickers and some does not (Lehman & Wilkins, 2014). Any change to LED lighting should therefore be managed with attention to the recommendations of IEEE1789 (Lehman, Wilkins, Berman, Poplawski, & Johnson Miller, 2011; Lehman & Wilkins, 2014).

Not the whole picture

The effects of fluorescent lighting are closely tied in with the other player in this story –

Cortical hyperexcitability → visual discomfort

Convergent evidence from
• Computational modelling
• Neuroimaging
• Clinical conditions such as migraine

Computational modelling

• Images that are uncomfortable reduce sparseness of firing, thereby increasing firing rate and overall metabolism
• Reducing intracortical inhibition also reduces sparseness, explaining individual differences in observers as due to inhibitory failure – cortical hyperexcitability
Urban scenes

The model correlated 0.60 with the ratings of discomfort from images used in an initial study and 0.53 with those in a replication.

Near infrared spectroscopy

\[ \text{HHb} + \text{O}_2 = \text{HbO}_2 \]

700 900 wavelength (nm)

reflectance

Oxygenation of brain

Change in oxygenation

Migraine

Many of the children who benefit from coloured overlays suffer headaches and have migraine in the family (Maclachlan, Yale, & Wilkins, 1993).
Cortical excitability in migraine

- Large BOLD response in fMRI
- Low thresholds for phosphenes with TMS
- AEDs used in treatment

Precision tints in 11 patients with migraine

Precision tints and control tints - different for each patient

Non-stressful pattern

Stressful pattern
Large reduction in activation
- only with precision tint

Huang, Zong, Wilkins, Jenkins, Bozoki & Cao (2011)

Colorimetry in migraine

Aldrich, Hibbard & Wilkins (submitted)

Replication

Hyperexcitability and vision

• What effect does cortical hyperexcitability have on visual function?

• Clearly vision is impaired by the aura but what about vision between headaches?

Contrast discrimination
Cortical hyperexcitability and vision

Contrast discrimination

• Participants who experienced a consistently lateralised visual aura had lower discrimination thresholds (i.e. they saw better) in the affected field.
• This was normalised (i.e. vision was worse) with a coloured filter
• This was not the case for controls

Aldrich, Hibbard & Wilkins (submitted)

Normalisation?

Visual search

Coloured filters in neurological conditions

Although migraine may be the most prevalent neurological condition, there are many others in which coloured filters can help:

– Autism spectrum disorder
– Tourettes
– Concussion
– Stroke
– Photosensitive epilepsy

Aldrich, Hibbard & Wilkins (submitted)
Autism spectrum disorder

Amanda Ludlow

Coloured overlays increase reading speed in children with ASD

They improve visual performance more generally

Coloured lenses can have therapeutic effects

Coloured overlays improve performance in the Mind in the Eye task

Lydia Whitaker

Tinting a computer screen a colour comfortable for reading improves the 2AFC discrimination of intensity of facial expression of emotion

Effects of Coloured Lighting on Behaviour of Children with and without Autism Spectrum Disorder

6/12 read >15% more quickly with a coloured overlay. None of the controls did so.

Stroke

17 stroke patients and 17 controls. With spectral filters Rate of Reading increased by 8% with decrease in errors. No benefit from grey filters. No effects in controls.

Visual search response time improved with spectral filters, but not accuracy.

Concussion

Anecdotal reports
Visual stress in neurological disorders

- Migraine (photophobia)
- Autism (sensory overload)
- Tourettes (reading speed)
- Stroke (visual processing problems)

All have a co-morbidity with epilepsy

Photosensitive epilepsy

- Carterette and Symmes (1952)
- Rao and Prichard (1955)
- Brausch and Ferguson (1965)

Photosensitive epilepsy

- 18/22 (82%) found statistically significant improvements in reading continuous or discontinuous text with coloured filters. Of the four studies that did not find such an improvement, two found a significant reduction in symptoms and a third found a significant improvement with one reading test (WRAT) but not another (Neale).

Visual stress more generally

Precision - a bivariate normal model

Coloured overlays and precision-tinted lenses: poor repeatability in a sample of adults and children diagnosed with visual stress

The Repeatability of Colorimetry is Precisely as Expected

1 SD = 0.02

OPO

Technical Note

Coloured overlays and precision-tinted lenses: poor repeatability in a sample of adults and children diagnosed with visual stress

Visual stress more generally

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A Delphi study to develop practical diagnostic guidelines for visual stress (pattern-related visual stress)

Bruce J. M. Evans, Peter M. Allan, Arnold J. Winkel
Visual stress

- Mechanisms involve cortical excitability and exacerbation by environmental flicker
- Visual stress is common in disorders that are associated with a lowered seizure threshold
- Precision is required for optimal therapy with coloured lenses