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The uses of colour in optometric practice to ameliorate symptoms of visual stress

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The idea of using colour to help people who struggle to read is not new. There are wonderful examples of coloured reading glasses from the end of the 18th century in the British Optical Association museum at the College of Optometrists in Craven Street, London. Nowadays, colour can be introduced by the use of coloured paper, by covering the text with coloured plastic sheets (coloured overlays), by changing the background colour of a computer screen (sometimes using proprietary software), by means of coloured reading lamps, as well as by coloured lenses (Figure 1).

Figure 1. Early examples of coloured spectacles used to help people read. (Courtesy of the British Optical Association Museum.)

The first scientific report of the use of colour to assist reading was that by MacDonald Critchley in 1964. He reported the case of a dyslexic child who was able to read words on a coloured card but unable to read them on a white card. In the 1980s interest in the area began to develop following the work of Olive Meares, a school teacher from New Zealand. Meares (1980) described how pupils who were susceptible to visual perceptual difficulties could have these problems reduced by using coloured paper or by covering the page with sheets of transparent coloured plastic.

In 1983 Helen Irlen, a psychologist from California, presented a paper to the American Psychological Association describing how coloured filters reduced visual distortions experienced by her students. Irlen subsequently published a book, *Reading by the Colours*, in which she reported that 31 out of 37 individuals with visual perceptual problems were helped with a coloured overlay (Irlen 1991). When choosing from a selection of coloured sheets each person found that some colours reduced the perceptual distortions whereas other colours increased them; for each individual there was one optimal colour. Irlen went on to set up the Irlen Institutes where CR39 spectacle lenses were tinted to a colour that was selected after testing with a large range of colours. Unfortunately, due to the lack of published peer-reviewed scientific evidence, these commercial activities aroused scepticism from many established eye care practitioners and that scepticism is still evident today (Allen et al. 2010a).

This paper will attempt to provide a balanced view of the current evidence concerning the use of coloured spectacle lenses. The condition in which symptoms are alleviated by coloured filters has had many names, most recently Meares–Irlen syndrome, pattern-related visual stress and Meares–Irlen syndrome/visual stress. For simplicity, in this paper it will be called visual stress.

There are several mechanisms that have been advanced to explain visual stress. This review concentrates on three mechanisms: (1) magnocellular deficit; (2) binocular instability; and (3) cortical hyperexcitability. These mechanisms are not mutually exclusive, and may all contribute to an individual's symptoms. Accommodative mechanisms may also be involved (Allen et al. 2010b; Chase et al. 2009; Tosha et al. 2009) but it is currently difficult to see how these could account for the need for a precise colour.

Underlying hypothesis: mechanisms of visual stress

Magnocellular theory

The magnocellular theory hypothesises that visual stress is due to a deficit in the magnocellular visual system, which is sensitive to high temporal frequency (Livingstone et al. 1991). There is evidence that a proportion of dyslexic people have a deficit of the magnocellular visual system but there is little evidence that the deficit is specific to dyslexia. Moreover, a great many different tests have been used to identify the deficit, and there is little association between them (Goodbourn et al. 2011).

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Children with signs of a magnocellular deficit are more likely to make reading errors that are suggestive of visual confusion than are other children (Cornelissen et al. 1998a), and they are less likely to be aware of the precise position of letters in a word (Cornelissen et al. 1998b). Stein (2001) argues that boosting magnocellular performance using yellow filters can improve reading performance.

Binocular instability

Binocular instability is a condition characterised by low fusional reserves and an unstable heterophoria. During normal eye movements, small vergence errors occur which mean that, even in an orthophoric patient, adequate fusional reserves are required to maintain comfortable fusion. Bucci et al. (2008) found evidence of poor binocular coordination during saccades in children with dyslexia, which might be a contributor to reading difficulties. Most dyslexic participants had abnormal fusional reserves and also abnormal binocular coordination during and after saccades. There is evidence that binocular instability may contribute to the reading and spelling errors that some children make (Cornelissen et al. 1992, 1994). Moreover, binocular instability is sometimes associated with symptoms similar to those of visual stress (Evans et al. 1996a). It is currently possible to hypothesise many alternative causal links between binocular instability, magnocellular deficits and perceptual distortions (Evans et al. 1996b).

Cortical hyperexcitability

In nature, repetitive patterns (like those in Figure 2a) are rare, but in the modern, largely man-made, environment they are quite common and cause some people problems.

Figure 2a. An example of stripes in the modern environment.

Text forms a striped pattern (Figure 2b). When susceptible people look at these patterns they can see visual perceptual distortions (eg movement and blur) and experience discomfort, including headaches (Wilkins et al. 1984). The patterns that cause most problems are those that most strongly stimulate the visual system (medium spatial frequencies at high contrasts) and, on the basis of neuroimaging studies, the mechanism is likely to be an 'overloading' of the visual cortex (Huang et al. 2003, 2011).

Figure 2b. A representation of text as it may appear to a patient with visual stress. The distortions are dynamic. Adapted from *What I see* by Ffai Gritten.

Individuals who see most distortions in periodic patterns with mid-range spatial frequency are generally those who experience frequent headaches (Marcus & Soso 1989; Wilkins et al. 1984). If the headaches are on one side of the head, the illusions predominate in one lateral visual field (Wilkins et al. 1984), suggesting a neurological mechanism. Individuals with migraine are particularly susceptible to the illusions, and can find the patterns very uncomfortable to look at; viewing the patterns may even induce a migraine attack (Marcus & Soso 1989). Patients with migraine are not the only individuals at risk from such patterns. Many patients with photosensitive epilepsy who are liable to seizures from flickering light are also liable to seizures from the patterns (see below). The patterns responsible for visual illusions have characteristics similar to those that induce seizures. Sometimes symptoms can be reduced in these patients by the use of coloured lenses. Within V2 of the macaque cortex, neurons detecting differently coloured gratings are distributed across the cortical surface in an arrangement that is reminiscent of the CIE Uniform Chromaticity Scale diagram (Xiao et al. 2003). It has been argued that, by altering the spectral composition of the retinal image with coloured lenses, cortical activity can be rearranged so as to avoid strong local excitation in hyperexcitable orientation columns of the cortex (Wilkins 2003). The avoidance of strong excitation in hyperexcitable columns prevents the spread of excitation and with it the inappropriate firing of visual neurons that gives rise to illusions and distortions.

The pattern glare test can be used in practice to help identify patients who are susceptible to pattern glare and visual stress (Figure 3).

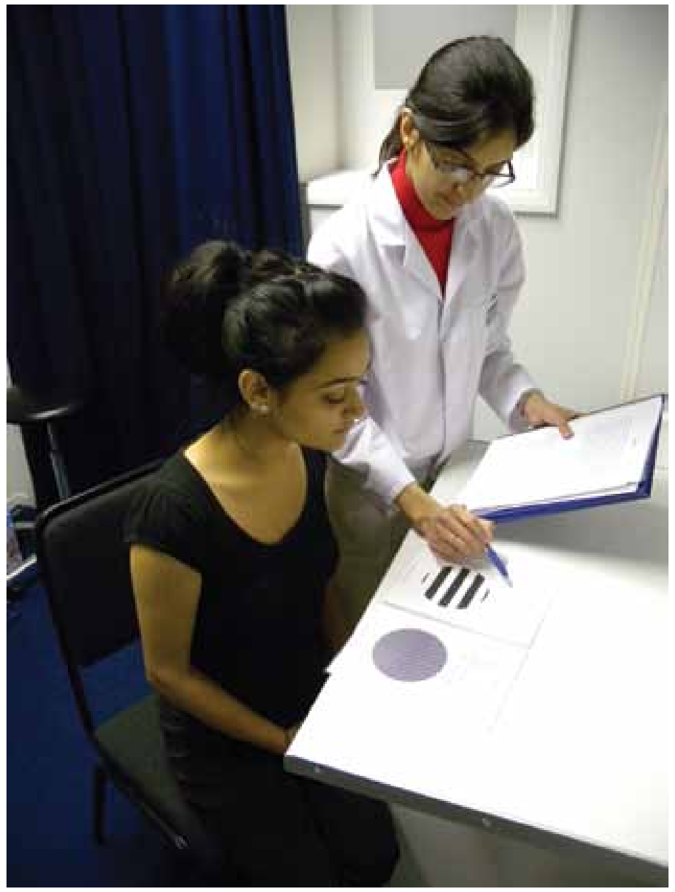

Figure 3. Explaining the pattern glare test to a patient.

It should be noted that the symptoms of visual stress are similar to those of binocular instability (Evans 2007) and accommodative anomalies (Allen et al. 2010b) and these conditions should be excluded before a diagnosis of visual stress is made (College of Optometrists Guideline 2011). Visual stress is comorbid with several conditions and four for which there is preliminary evidence are specific learning difficulties, migraine, autism and epilepsy. In view of the mechanism outlined above it seems likely that the factor these conditions have in common is a hyperexcitability of the visual cortex and this is discussed below.

Specific learning difficulties

There is a variety of evidence to support the use of coloured lenses for people with a specific learning difficulty, but the issue remains controversial.

Open trial

In an early open trial patients selected a chromaticity that reduced perceptual distortion of text viewed in an Intuitive Colorimeter. The Intuitive Colorimeter (invented by Arnold Wilkins) permits the separate manipulation of the intuitive dimensions of colour: hue, saturation and brightness. Wilkins also developed a range of coloured lenses that can be made up to match the colour that a person finds optimal in the colorimeter. In this open trial the coloured lenses that were dispensed following testing with the colorimeter were still being used 1 year later and were reported as beneficial by over 80% of participants (Maclachlan et al. 1993). The trial was indicative but not conclusive because of the role that placebo effects can play in studies of this kind, but the proportion of patients benefiting agrees with subsequent larger-scale clinical trials (Robinson & Foreman 1999a, b; Wilkins et al. 1994).

Double-masked trial

When viewing text in the colorimeter (Figure 4), patients adapt to the coloured light, so the lenses appear more strongly coloured than expected; the colour appearance of the lenses that are most beneficial cannot therefore easily be recognised. The separation of the colour appearance of the light from the colour appearance of the lenses enabled a double-masked study to be conducted, whereby patients were offered two pairs of spectacles, only one of which provided the chosen chromaticity; patients and clinicians were not aware which pair was which (Wilkins et al. 1994).

The children who took part in the study selected their optimal colour in the colorimeter. A suboptimal placebo control setting was ascertained by gradually changing the hue until the child reported the distortions starting to reappear. The average separation of control and active lenses was small (the CIE Uniform Chromaticity Scale chromaticities were separated by 0.065 on average). Spectacle lenses were made to match each setting, and one pair, active or control, selected at random by an independent collaborator, was glazed into frames and sent to the child. The children and their parents were asked to keep diaries in which they noted any symptoms of eye strain or headache. At the conclusion of the study the diaries revealed statistically significantly fewer symptoms in children who had been prescribed the active tint. An additional important finding from this study was that the tint had to be precise in order to have the more beneficial effect – the active and placebo tints were similar in colour.

Figure 4. The Intuitive Colorimeter mark 3.

Robinson and Foreman (Australian) study

Robinson and Foreman used Irlen lenses to conduct a randomised placebo-controlled trial (Robinson & Foreman 1999a, b). The investigators, using conventional measures of reading ability, found that coloured filters helped people with visual perceptual difficulties but only if the coloured lenses were individually and precisely prescribed. Participants were able to see their lenses at the time of selection so the trial may not have been strictly double-masked, although one of the control pair of lenses was said to be very similar to the optimal colour. The lack of photometric data means that the effectiveness of the masking in this study remains open to question.

There have been many additional studies of coloured filters for people with reading difficulties (Allen et al. 2010a; Evans 2001; Wilkins 2005), but the present brief review concentrates on the studies that were randomised controlled trials and which prescribed the optimal colour for each individual with precision. A large multicentre double-blind randomised controlled trial is now indicated to assess the efficacy of coloured lenses to help people with specific learning difficulties. Research has consistently found a heightened sensitivity to high-contrast patterns in people with specific learning difficulties who benefit from coloured filters, supporting the mechanism outlined above (Allen et al. 2008; Hollis & Allen 2006).

Migraine

Migraine is a condition of recurring headaches linked with other symptoms, such as sensitivity to light and sound, with nausea, and sometimes aura. In the UK about 18% of women and 8% of men suffer migraine, and as a result an estimated 25 million days per year are lost from work or school (Shapiro & Goadsby 2007; Steiner et al. 2003; World Health Organization 2001). Headaches are frequently encountered in optometric practice, with migraine accounting for as many as 54% (Harle & Evans 2004). Migraine is associated with cortical hyperexcitability which manifests as a sensitivity to patterns (Harle & Evans 2004).

Migraine can have many triggers, including diet, hormonal factors, stress, irregular sleep periods and visual stimuli. Wilkins et al. (2002) investigated the effectiveness of precision tinted lenses (PTLs) in the prevention of visually precipitated migraine. They showed that symptoms were significantly reduced when PTLs were worn compared to suboptimal control lenses. In an associated publication Evans et al. (2002) showed that the reduction in pattern glare symptoms was significantly greater in the PTL group. As the sample sizes in the above studies were small, the results should be treated as suggestive rather than conclusive.

A mechanism whereby tinted spectacle lenses may help prevent migraine has recently been established. In two brain-imaging studies using different techniques (Coutts et al. unpublished observations; Huang et al. 2011), the cortical response to uncomfortable visual patterns has been shown to be different in people with migraine. Both independent studies (one using functional magnetic resonance imaging and the other near-infrared spectroscopy) have shown that in adults with migraine the use of PTLs, individually designed to reduce visual discomfort, has the effect of normalising the otherwise abnormal oxygenation of the blood in prestriate visual areas of the cortex. The normalisation occurred only when the tint had a specific colour that had been individually chosen to reduce visual discomfort. The tint was individually selected using the Intuitive Colorimeter and the selected colour differed from one individual to another. In both studies lenses tinted to a colour that was only slightly different were less effective, and similar in effect to grey lenses (Figure 5).

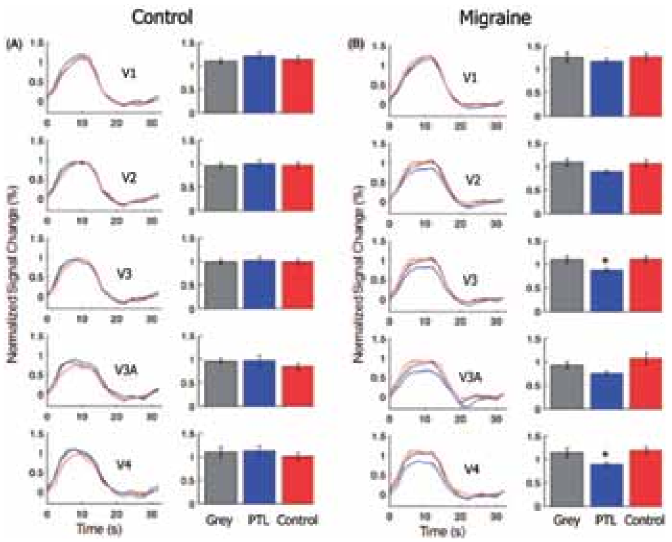

Figure 5. Activation in visual areas V1, V2, V3, V3A and V4 from a stressful striped pattern for control subjects (A) and migraine patients (B). Left columns in (A) and (B), cortical area activation curves; right columns in (A) and (B), comparison of the peak heights of the cortical area activation curves in the left columns. For the control subjects, cortical area activation showed no difference in any visual area among the three lenses. For the migraine patients, however, the precision tinted lenses produced significant reductions to cortical activation in V3 and V4. The precision tinted lenses also reduced the cortical activation in V2 and V3A, though the differences were not statistically significant. The activation has been expressed relative to that from control patterns. (Adapted from Huang et al. 2011).

In summary, recent evidence has converged to provide a scientific rationale for the ophthalmic prevention of some migraines. A small-scale trial has demonstrated that the treatment shows promise but, again, a large randomised controlled trial is needed to establish definitively if PTLs are effective in preventing migraine and if so, in what proportion of migraine sufferers. It should be stressed that PTLs are likely to help only those patients whose migraines are triggered by visual stimuli, such as patterns, fluorescent lights and text. Migraine can be associated with other visual problems (Harle & Evans 2004, 2006), so an eye examination is indicated in all cases with a visual trigger.

Autism (autistic spectrum condition (ASC))

To date there has been limited research concerning optometric assessment in individuals with ASC due in part to the difficulties with testing, arising from limited communication skills and behavioural problems (Shulman 1994). However a variety of optometric problems are common among people with ASC. For example, strabismus has been shown to be prevalent in autism. Scharre & Creedon (1992) investigated 34 children with autism, aged between 2 and 11 years, measuring binocular visual acuity, refractive error, binocular vision and oculomotor status. None of the participants had spectacles, which was striking, given that 44% had a refractive error greater than 1.00D in one meridian and/or anisometropia greater than 1.00D. Studies of visual acuity of individuals with autism have found inconsistent results (Simmons et al. 2009).

Visual performance in ASC has been shown to improve with coloured filters. Ludlow et al. (2006) examined the effects of coloured overlays in children with ASC and showed that, when using the overlays, 15/19 children aged 7–15 read >5% more quickly and 9/19 read >20% more quickly. The overlays were chosen individually to increase the 'clarity' of text. The increase was substantially greater in ASC than in controls matched for age and verbal intelligence. Ludlow et al. (2008) have also shown that in a matching-to-sample task and a visual search task, children with ASC performed more quickly and more accurately with a coloured overlay chosen individually.

To date one study has been carried out to investigate the effect of PTLs in autism, a case study of JG (Ludlow & Wilkins 2009). JG showed acute hyperactivity and nausea under bright lights, and in rooms with brightly coloured walls and suffered from severe migraines. Six months after wearing glasses of a prescribed colour, he participated in Christmas festivities for the first time. Previously he had shut himself off, complaining of too much noise, light, smells and people. With the glasses he has shown a greater awareness of both his and other people's personal space, is more coordinated and has shown improvements in social function. A degree of caution must be exercised when considering a single case study, particularly as a range of other factors may have influenced the change in the child's behaviour. Nonetheless, this anecdotal evidence suggests a possible benefit from colour that warrants further investigation.

Epilepsy

The use of coloured lenses to treat photosensitive epilepsy has a long and inconsistent history (see review by Harding & Jeavons 1994). Photosensitive patients are at risk of seizures from flickering light and also occasionally from steadily illuminated patterns (Wilkins 2010). Flicker that is binocular is a far greater risk than that presented to one eye. The flicker that results from changes in colour can be worse than that from changes in brightness (Parra et al. 2007). The discomfort from changes in colour is proportional to the colour change involved, that between red and blue posing the greatest risk of a seizure. These findings have resulted in many attempts to treat the condition with glasses. Cross-polarised spectacles are sometimes effective (Jain et al. 2001), as are blue glasses (Capovilla et al. 1999; Takahashi & Tsukahara 1992), but mainly in isolated cases. Blue cross-polarised glasses have been trialled (Kepecs et al. 2004) but again with inconsistent effect. PTLs are also sometimes effective (Wilkins et al. 1999) but again, not universally. There is therefore no general recommendation, although occasionally blue spectacles and those selected individually can be surprisingly effective.

Conclusions

The use of coloured lenses in optometric practice is becoming more common. There are optometric anomalies associated with reading difficulty, and probably the most common of these is visual stress. There is an increasing body of evidence to support the treatment of visual stress with coloured filters but further randomised controlled trials would be valuable. For establishing cause-and-effect relationships, no study design is more highly regarded than the randomised controlled trial. Participants with the target condition are randomly allocated to two groups: one receiving the real treatment and the other receiving a control treatment (placebo). The participants and the experimenters should be masked so that they do not know whether an individual is receiving the real or the control treatment. If people with the condition show improvement with the treatment colour to a significantly greater degree than with the control colour, then this is strong evidence that the treatment is of benefit over and above that of a placebo.

More work is also needed to elucidate the precise mechanism of visual stress and to clarify the most efficient approach to diagnosis. Evidence is building quickly, with the majority of studies being supportive of the cortical hyperexcitability theory.

Caring for people with the conditions highlighted above is a challenging but fascinating area and there is growing awareness amongst teachers, parents and patients of the need for specialist eye care for people with these problems. Not all optometrists will be likely to have specialist knowledge in this field but it is hoped that the information in this paper will be useful as background reading for optometrists in general practice.

Summary

Evidence has accumulated regarding the efficacy of coloured lenses in reducing symptoms in individuals susceptible to visual perceptual problems (visual stress) and yet there is still scepticism from some quarters. This article discusses the mechanisms which have been advanced to explain visual stress, including magnocellular deficits, binocular instability and cortical hyperexcitability. Each mechanism is discussed in some detail with references to the supporting scientific literature. The authors then discuss the use of coloured lenses in specific learning difficulties, giving examples of randomised controlled trials and highlighting where further research is required. The role of coloured lenses in migraine, autism and epilepsy is also covered.

Declaration of interest

Peter Allen has no proprietary interest in any of the products mentioned in this article. The Intuitive Overlays, Wilkins Rate of Reading Test, Intuitive Colorimeter and Precision Tinted Lenses were invented by Arnold Wilkins who receives an award to inventors from MRC, based on a proportion of the royalty for these products. The Pattern Glare Test was developed by Arnold Wilkins and Bruce Evans, who receive royalties based on the sales of this product.

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Multiple choice questions

This paper is reference C-18448. Two points are available for UK optometrists. Please use the inserted answer sheet. There is only one correct answer for each question.

1. In which year did Helen Irlen present a paper on the use of coloured filters to reduce visual distortions?

(a) 1964
(b) 1980
(c) 1983
(d) 2010

2. Which of the following mechanisms advanced to explain visual stress is most difficult to reconcile with the need for a precise colour?

(a) Accommodative instability
(b) Binocular instability
(c) Magnocellular deficits
(d) Cortical hyperexcitability

3. Regarding the magnocellular theory, which of the following statements is incorrect?

(a) The magnocellular system is sensitive to high temporal frequency
(b) A deficit of the magnocellular system is specific to dyslexia
(c) A proportion of dyslexic people have a deficit of the magnocellular system
(d) Children with magnocellular deficits experience more visual confusion than other children

4. Regarding binocular instability, which of the following statements is incorrect?

(a) It is characterised by low fusional reserves and unstable heterophoria
(b) It has been demonstrated in dyslexic children during saccades
(c) It can contribute to reading and spelling errors that children make
(d) During normal eye movements no fusional reserves are required to maintain fusion

5. Which of the following combinations of spatial frequency and contrast is most likely to overload the visual cortex?

(a) High spatial frequency, high contrast
(b) Medium spatial frequency, low contrast
(c) Medium spatial frequency, high contrast
(d) High spatial frequency, medium contrast

6. Regarding cortical hyperexcitability, which of the following statements is incorrect?

(a) Migraine sufferers can find periodic patterns uncomfortable to look at
(b) Photosensitive epileptics can have seizures provoked by periodic patterns
(c) Coloured lenses have not been shown to reduce symptoms in symptomatic epileptic patients
(d) The pattern glare test can be used to identify patients susceptible to visual stress

7. Approximately what percentage of participants felt that their coloured lenses were beneficial in a study by Maclachan et al. in 1993?

(a) 60%
(b) 70%
(c) 80%
(d) 90%

8. In the study by Wilkins et al. in 1994, what was the average separation between chromaticities for the control and active lenses?

(a) 0.055
(b) 0.065
(c) 0.075
(d) 0.085

9. Regarding the use of precision tinted lenses (PTLs) in migraine, which of the following statements is incorrect?

(a) PTLs can normalise abnormal oxygenation of the blood in parts of the visual cortex
(b) PTLs have been shown to help all migraine sufferers irrespective of the trigger
(c) The tint must have a specific colour
(d) The colour required will differ from one individual to another

10. Approximately what percentage of children with an autistic spectrum condition improved their reading rate by more than 20% when using coloured overlays?

(a) 20%
(b) 30%
(c) 40%
(d) 50%

11. Of the 44% of autistic children found to have a significant refractive error, what percentage had been prescribed spectacles?

(a) 0%
(b) 5%
(c) 10%
(d) 15%

12. Which colour change poses the greatest risk of provoking a seizure in photo-sensitive epileptics?

(a) Red to blue
(b) Red to green
(c) Green to blue
(d) Blue to green

CPD Exercise

After reading this article can you identify areas in which your knowledge of the use of colour in optometric practice has been enhanced?

How do you feel you can use this knowledge to offer better patient advice?

Are there any areas you still feel you need to study and how might you do this?

Which areas outlined in this article would you benefit from reading in more depth, and why?