Dyslexia and Vision

A review of current evidence and clinical interventions

by Yap Tiong Peng

Nearly 10% of children face difficulties in reading, spelling and writing, even if they are highly intelligent and articulate.[1,2] Their learning process may be hampered by weaknesses including speed of processing, short-term memory, organisation, sequencing, spoken language and motor skills; and they may also have difficulties with their auditory and/or visual perception.[3] Hence, the cause of dyslexia is multifactorial.

Vision is a core component of the process of reading and learning.[4] Certain vision problems are particularly prevalent and can contribute to a child's reading difficulties. Any child facing difficulties in reading, or who reads competently but reluctantly, or who reads less accurately than would be expected from their other abilities, ought to consult a specialist in vision.

This article will focus on the aspects of vision and visual perception only.

Reading involves a very wide range of cognitive skills, and visual-spatial difficulties are related to higher level visual function that is beyond the standard test of 20/20 vision. Nearly 50% of dyslexic children have some complaints about their vision, and this includes words 'moving', 'shimmering', 'blurring', 'doubling' or simply a general level of visual discomfort ('asthenopia').

Sometimes, they may also report seeing distorted patterns and colours that are not actually there. The symptoms can worsen whilst viewing a page of black text on a white background. The symptoms are often mild and some children fail to describe them, or may suppose that they are normal. There are also children who may complain about tired eyes, acute headaches and migraines. These

Overview of Learning Difficulties

'Dyslexia' refers to a cluster of symptoms, which result in people having difficulties with specific language skills, particularly reading and spelling, and also with other language skills such as writing. Difficulties include spelling, poor handwriting and difficulties putting thoughts on paper. 'Dyscalculia' is a term to describe the lack of numerical skills, and 'dyspraxia' is a term to describe the difficulties in coordination due to developmental issues. 'Dysgraphia' refers to difficulties in writing. There are also conditions that may be associated with learning difficulties, and these include Attention Deficit Disorder (ADD), which is often associated with hyperactivity (ADHD), and their main features are inattention and impulsivity.

Yap Tiong Peng is a senior consultant optometrist at IGARD Group. Trained in Manchester, he is adept in assessing the eye and vision of children with learning difficulties and behavioural issues, as well as the provision of therapeutic interventions for Myopia, Amblyopia, Strabismus and functional deficits in vision (e.g. eye focusing, low vision, visual stress and visual tracking issues) for both children and adults.

He was formerly a research fellow at Alexandra Hospital, and a part-time lecturer at the University of Manchester and Singapore Polytechnic. He taught the courses 'Binocular Vision' ('Orthoptics') and 'Advanced Visual Neurophysiology'. His 2012 joint lecture on 'Vision and Learning' with Professor Bruce Evans (City University, London) was featured on national television; he has also jointly lectured with Australia's authority on 'Colour Vision', Professor Stephen Dain (University of New South Wales, Australia), on the topics 'Intuitive Colorimetry' and 'Visual Stress'.

Throughout his career, Tiong Peng is often consulted for his expert opinion on 'Computer Vision Syndrome' and 'Visual Ergonomics'. He is a graduate of the UMIST (University of Manchester) and Imperial College (University of London). His current research work in Singapore investigates the 'brainwaves' (Electroencephalogram) of children suffering from Amblyopia ('lazy' eyes) in collaboration with an international team from London, Sydney and Melbourne.

symptoms can interfere with reading and learning.

Most often, the symptoms are not related to an eye disease[4], but the problem may be in the functional aspects of their vision or visual perception. These problems are measurable through optometric evaluations of visual efficiency, and they are not due to a psychological reason.

Teachers, medical doctors, allied health professionals, and caregivers all play a part in picking up these subtle tell-tale signs of potential vision problems in children. Mild symptoms arising from the conditions may slow down reading and may also discourage children from prolonged reading. Even good readers and those with 'mild' learning difficulties can also unknowingly suffer from vision problems. In the run-up to school exams, they may complain of headaches, eyestrain or discomfort when coping with a large amount of reading.

Symptoms of Visual Perceptual Problems

- **Letters appearing to move – this can occur in many forms including the words moving up and down, side to side, words merging, words breaking up and words moving at the beginning and end of the lines**
- **Letters appearing to blur, especially with closely-spaced small print**
- **Letters appearing double**
- **Letters changing in size**
- **Letters changing in contrast**
- **Letters or word reversals**
- **Colours or shapes appearing on the page**
- **Text appearing to flicker**
- **The page appearing too bright**
- **Discomfort under fluorescent lights**
- **Headaches, nausea or dizziness**
- **Eyes becoming tired or sore**

In addition to the symptoms, doctors, teachers and parents may observe behaviours which may raise the possibility of vision problems.[4]

- **Wearing spectacle lenses with tints or sunglasses when reading**
- **Rubbing eyes**
- **Excessive blinking**
- **Tracking the text with a finger due to difficulties in keeping their place**
- **Closing or covering one eye whilst reading**
- **Moving unusually close or far away from the text**
- **Poor concentration which might be indicated by yawning, frequently looking away from the page and fidgeting**
- **Poor reading fluency; reading slows down as the person continues to read**

Standard Eye Examination

A routine eye examination with an optometrist or ophthalmologist can pick up early signs and symptoms of eye problems and vision issues, ranging from refractive errors, strabismus (poor eye alignment), amblyopia ('lazy' eyes) to eye diseases.

The standard test chart 'visual acuity' is not generally impaired in dyslexia, but problems can occur in any children who have refractive errors, such as myopia, hyperopia and astigmatism.[5] For example, hyperopia is commonly found in children with reading difficulties[6] and some studies have suggested that hyperopic children have impaired literacy standards[7] and poorer visual perceptual skills than myopes or emmetropes.[8]

However, it has been shown that there is generally no correlation between refractive errors and reading difficulties.[9] Both optometrists and ophthalmologists are able to prescribe spectacles to alleviate the child's blurred vision, but spectacles alone do not resolve reading difficulties.

Some symptoms cannot be completely remediated with ordinary spectacle lenses and this may be due to poor alignment of the eyes (strabismus), 'lazy' eyes (amblyopia), binocular vision anomalies (e.g. poor convergence and focusing of the eyes) and visual perceptual issues (e.g. Meares-Irlen Syndrome or Visual Stress). These conditions can interfere with normal everyday vision. Although they do not directly result in reading difficulties, they can adversely affect many functional aspects of vision, visual perception and the child's fine eye-hand coordination skills (e.g. handwriting and certain sports).[10,12] Interventions offered by specialist optometrists include ophthalmic prisms (in spectacles), occlusion therapy ('eye patching' to encourage the use of the amblyopic eye), orthoptic vision therapy ('eye exercises' to encourage the two eyes to work together as a team) and precision coloured lenses (to alleviate visual stress).[10,13] In addition, some children can benefit in seeing an ophthalmologist (eye surgeon) to surgically correct their eye misalignment and this can have a positive impact on the child's confidence and self-esteem.

Functional Aspects of Vision

The most common visual problems in dyslexia are the reduced ability to focus close up and a poor or unstable coordination of the two eyes. Any child with reading difficulties should have a full assessment of the functional aspects of vision, involving an assessment of binocular vision (orthoptics) and visual perception.[4] These are not typically conducted in a routine Standard Eye Examination, because it involves a long battery of clinical optometric tests to evaluate their binocularity, ocular accommodation and visual tracking (oculomotor) skills. The patient should also be screened for visual stress (e.g. Meares-Irlen Syndrome). Owing to the large amount of tests (and depending on the complexity of each case), the patient may feel tired, and, it may be necessary for some tests to be conducted on a separate visit.

Binocularity

Binocularity, or binocular vision, refers to the use of the two eyes together as a team. A temporary misalignment between the two eyes can contribute in some cases to visual discomfort[14] and a decline in visual performance[15], but it does not often result in severe double vision or blurred vision.[10]

A failure of accurate binocular vision can manifest itself in many forms, and it can be a result of 'convergence insufficiency'[16], 'binocular instability'[17] and 'unstable or decompensated heterophoria'.[15] Treatment with orthoptic 'eye exercises' used in vision therapy allow the child to gain control of their binocular vision by allowing the two eyes to point accurately towards the same direction.[10]

How the Eyes Maintain Focus

Ocular accommodation refers to how the eye's ciliary muscles adjust and readjust the focusing system of the eye whilst maintaining clear vision. Problems in accommodation that can lead to visual discomfort[16,18] can be clinically measured by assessing its amplitude (maximal ability to focus), lag (accuracy of focusing) and facility (rate of change of accommodation).

Dyslexic children were found to have lower median amplitude of accommodation than the age-matched control group,[17,19] and they are more likely to suffer from accommodative insufficiency compared to good readers.[20] Orthoptic vision therapy and spectacles may be prescribed by the specialist optometrist should there be an issue in ocular accommodation and/or binocular vision.

Visual Tracking Skills

Visual tracking skills can be clinically assessed to provide a snapshot of how the eyes move whilst reading. When you read, the eyes make a series of rapid jerks across the page called saccades. Following each saccadic eye movement, the eyes have to be realigned to reduce the vergence error, and the process of realignment may take longer in individuals having poor binocular coordination [21]. There is evidence that binocular instability contributes to the reading difficulties[21,22,23] and spelling errors[22,23] that some children make. This can be remediated through orthoptic vision therapy.[10]

Studies have found magnocellular deficits in the visual processing system in some dyslexia. The visual processing system consists of two main parallel pathways (magnocellular and parvocellular), and there are numerous interconnections between them. There is also a third pathway, the koniocellular pathway. A review based on a large body of research indicated that up to two thirds of people with dyslexia have a deficit in their magnocellular system.[24]

Children may make reading errors possibly because they are insufficiently aware of the precise position of letters in a word. The magnocellular deficit appears to be linked to binocular instability[9] and a deficit of visual-spatial attention.[25] It remains unknown whether the magnocellular deficit directly causes these visual confusions, whether the magnocellular deficit causes binocular instability which in turn causes confusions, or whether both confusions and binocular instability are the result of some other causal link.

A deficit of visual-spatial attention may produce a perceptual interaction of target and background elements and has been associated with impaired visual search and reading difficulties.[26] There is some evidence that visual-spatial attention deficits can be improved with vision training and it can help with reading.[27]

Professor John Stein from Oxford University explained that yellow filters are able to 'boost the magnocellular system' by reducing inhibition from the short-wavelength cones[28,2], but this still does not fully explain why some children with dyslexia prefer other colours whilst others do not find coloured filters beneficial at all. It is now understood that the colour preference can be very precise for each individual,[29,30] and they should only use coloured filters if they are tested positive for another condition known as Meares Irlen Syndrome.[31]

Meares-Irlen Syndrome

Meares-Irlen Syndrome (or sometimes Irlen Syndrome) is a photosensitive condition that affects the visual cortex and hinders reading.[32] It is scientifically known as 'Visual Stress' or 'Pattern Glare', and historically referred to as 'Scotopic Sensitivity Syndrome'. Its prevalence varies depending on the diagnostic criteria used,[4] but significant degrees of visual stress affect about 12% of unselected samples of the population[33,34] and about 30% of children with dyslexia.[35]

Research by the British Medical Research Council (MRC) showed that lenses can be carefully tinted to a precise colour to help alleviate the symptoms that derive from an underlying hyper-excitability of neurons in the human brain[31] and it is possibly a result of impaired gain control mechanisms. Besides the use of a precision colour filter, the effects of visual stress can also be alleviated by modifying the design and layout of printed text.[11] The symptoms described by patients are not specific to the condition and they can be very similar to other problems of the eye and vision. Hence, current international guidelines (e.g. British College of Optometrists[36]) recommend the diagnosis of visual stress only after excluding all possible eye and visual conditions, and the use of an Intuitive Colorimeter to accurately measure the optimum coloured filter.

Although coloured lenses have been known to relieve 'eyestrain' for nearly 200 years (British Optical Association Museum, British College of Optometrists, UK), the first scientific report that colour could assist in reading can only be traced back to a report in 1964 by Dr MacDonald Critchley.[37] In 1980, a New Zealander school teacher, Ms Olive Meares, published a paper describing the visual perceptual difficulties in her students[38] and how they were reduced with the use of coloured overlays (coloured plastic sheets). Three years later, Californian psychologist Dr Helen Irlen reported how the coloured filters reduce visual distortions[39,40], and she patented and commercialised the sales of 'Irlen' branded lenses through the Irlen Institute. Criticisms arose in the United States and worldwide due to the lack of scientific evidence and research on Meares-Irlen Syndrome, but since the 1990s, an extensive volume of research was made possible with the invention of the Intuitive Colorimeter by Professor Arnold Wilkins who worked at the MRC Applied Psychology Unit in Cambridge, UK.

The research evidence and standardised testing methodology meant that certified optometrists worldwide could now diagnose Meares-Irlen Syndrome and prescribe coloured lenses to treat each patient effectively, and did not have to rely on proprietary trade secrets. The Intuitive Colorimeter is used by many specialist optometrists, institutions and hospitals throughout the world. In the U.K., precision coloured filters are already funded by the government under the Student Disability Allowance for students in higher education, and Special Educational Needs Coordinators throughout the U.K. provide coloured overlays in the classroom for children who struggle to read.[41]

Treatment Efficacy using Precision Coloured Filters

In patients with visual stress (Meares-Irlen Syndrome), an appropriately chosen chromaticity will not only improve perceptual clarity and reduce perceptual distortions, but also can reduce visual fatigue and increase the speed of reading and of visual search.[32] The optimal chromaticity for each individual is very precise, but a less precise colour can also offer some degree of help. A study of unselected children in mainstream education found that when offered a choice of overlays, 20% routinely used an overlay of their chosen colour for reading. They did so without prompting for months on end, claiming improved clarity and reduced perceptual distortion.[42]

The efficacy of precision coloured filters in improving reading speed is validated through an open trial[43] and a subsequent double-masked randomised control trial[44] in the UK that was funded by the Medical Research Council. The research involved the use of the Intuitive Colorimeter which allowed a gamut of >6000 chromaticities through the adjustment of 'hue' (i.e. the colour), 'saturation' (i.e. strength of colour), and 'luminance' (i.e. brightness). The test allows each variation to be made continuously rather than discretely, and the perceptual effects of colour can be studied while the patient's eyes are colour-adapted and all test surfaces are uniform. The spectral properties of the light entering the eyes closely resemble those when the coloured lenses are worn under conventional fluorescent lighting, even though additive colour mixture is used in the colorimeter and subtractive mixture is used for the lenses. The similarity of spectral power distribution means that individuals who have a colour deficiency can use the instrument.[4] This level of precision ensured the patient's optimal visual comfort. By contrast, other commercially available systems such as the ChromoGen™ offers 12 different colours whilst there are no available figures for the system under Irlen™ brand.

In Australia, a randomised placebo-controlled trial was conducted using Irlen™ system.[45,46] Using conventional measures of reading ability, the study found similar results. The study also compared the individual filters to a pair of blue lenses. The blue lenses were found to be less effective than the individually prescribed pair. A study in the United States used ChromoGen™ contact lenses that were initially fitted monocularly and then binocularly.[47] Using clear contact lenses (with only a handling tint) as a control, they showed that tinted contact lenses improved reading speed on the Rate of Reading test to a greater extent than the control. Although the study claimed to be a double-masked placebo-controlled trial, it is not certain whether the trial was masked because patients may well have been able to appreciate the difference between a clear lens and one that was tinted.[4]

Many studies have been conducted with overlays in schools using the Wilkins Rate of Reading test.[48] There are some differences between this test compared and conventional reading tests – the patient is asked to read a paragraph consisting of randomly ordered common words. Each line has the same high frequency words in a different order. Children who are poor at reading can succeed at the task because the words are simple. Children often make errors of transposition of words or omission of a line, but they are usually unaware of their errors because the text is meaningless, so a sense of failure is avoided. The words from the Wilkins Rate of Reading test cannot be guessed from context, and so visual errors are easy to measure.[4]

Five percent of children in mainstream schools read at least 25% more quickly with an overlay of their chosen colour. Placebos had little effect on the reading speed, and the further the chromaticity from the optimal one, the slower the reading speed. However, when the difference in colour exceeded a certain value (delta E* ~ 80) the reading speed showed no further decrease and remained similar to the reading speed under white light.[31] The improvement in perceptual efficiency using precision coloured filters has also been demonstrated using visual search tests including the Developmental Eye Movement test, and the circles search test as well as in conventional reading performance and in the speed of sentence comprehension.[49]

When precision coloured lenses are worn in the form of spectacles, the entire visual field is coloured and the eyes adapt to the colour. The conditions of adaptation are different in the case of an overlay, which provides one surface colour among many, when illuminated with white light. The difference in the conditions of adaptation may explain why the optimal overlay cannot be used to predict the colour of the optimal lens.[50] The chromaticity can change in the young, but adults usually continue with the same colour for many years, sometimes decades. In two open trials, 80% of patients were still wearing their filter when followed up after one year.[43]

Scientific Evidence for Cortical Hyperexcitability and Other Conditions Related to Visual Stress

Current research suggests a neurological basis for visual stress (Meares-Irlen Syndrome) and coloured filters are also useful for people suffering from photosensitive migraines and photosensitive epilepsy. Uncomfortable visual stimuli can provoke seizures in patients with photosensitive epilepsy. Using the electroencephalograph (EEG), Wilkins (1995) showed that photosensitive patients were often sensitive not only to flickering light, but also to geometric visual patterns with very specific characteristics: high contrast and in a striped configuration. Reading material (which forms stripes from horizontal lines and from vertical letter strokes) has the potential to elicit visual stress.

Using functional magnetic resonance imaging (fMRI), Professor Jie Huang and his colleagues[29] from Michigan State University measured the blood oxygenation level dependent (BOLD) response in the visual cortex when volunteers viewed gratings with various spatial frequencies. In normal volunteers, patterns with mid-range spatial frequencies which induce pattern glare produced a slightly larger BOLD response than those with higher and lower spatial frequencies. The response at mid-range spatial frequencies was abnormally high in migraineurs, consistent with their greater susceptibility to pattern glare and perceptual distortions. The elevated response is consistent with other evidence for a hyperneuronal response in migraine: (1) the threshold for phosphenes in response to transcranial magnetic stimulation (TMS) of the occipital cortex is lower in migraineurs than in controls, and (2) the visual evoked potential has greater amplitude[57] and shows reduced habituation. It is hypothesised that the cortical hyperexcitability involves a subset of orientation columns of complex cells in the visual cortex.[4, 11, 32]

Precision coloured filters may rearrange cortical activity in such a way as to avoid strong excitation in the hyperexcitable orientation columns of the cortex.[4,32] The avoidance of strong excitation in hyperexcitable columns may prevent the spread of excitation, and with it the inappropriate firing of visual neurons that gives rise to illusions and distortions. The hyperexcitability may exist in conditions that include not only migraine and photosensitive epilepsy, but also autism (which has a high comorbidity with epilepsy)[49,50] and multiple sclerosis (which has a comorbidity not only with epilepsy but also with migraine).[53-56]

Developmental Psychologist Dr Amanda Ludlow and her colleagues[49,52] showed that 80% of children with autistic spectrum disorder (ASD) improve their reading speed with overlays by more than 5%, compared to 20% of controls matched for age and intellectual level. They also reported the case of a boy whose sensory sensitivity improved dramatically with the use of a pair of blue tints. In a separate study, twenty-five of 26 patients with multiple sclerosis improved their reading speed with their chosen overlay by more than 5%.[58] Grey overlays, included as a control, had no effect on reading speed. After a period of coloured overlay use, there was an improvement in reading speed without the overlay. MG

Acknowledgement
This review article is based on the articles by Professor Arnold Wilkins, Professor Bruce Evans and Dr Peter Allen.

References

1 Habib M. The neurological basis of developmental dyslexia; an overview and working hypothesis. Brain 2000; 123:2373-2399.
2 Stein J and Kapoula Z. Visual Aspects of Dyslexia. Oxford University Press 2012.
3 British Dyslexia Association. Definition of Dyslexia.
4 Allen P, Evans BJW and Wilkins AJ. Vision and Reading Difficulties. Published on behalf of the Association of Optometrists, Ten Alps Creative 2009, London, U.K.
5 Suchoff IB. Research on the relationship between reading and vision – what does it mean? J Learn Disabil 1981; 14:573-576.
6 Ygge J, Lennerstrand G, Axelsson I and Rydberg A. Visual functions in a Swedish population of dyslexic and normally reading children. Acta Ophthalmol 1993; 71:1-9.
7 Roch-Levecq AC, Brody BL, Thomas RG and Brown SI. Ametropia, preschoolers' cognitive abilities, and effects of spectacle correction. Arch Ophthalmol 2008; 126:252-258.
8 Rosner J and Gruber J. Differences in the perceptual skills development of young myopes and hyperopes. Am J Optom Physiol Opt 1985; 62:501-504.
9 Evans BJW. Do visual problems cause dyslexia? Guest Editorial. Ophthal Physiol Ot 1999; 19(4):277-278.
10 Evans BJW. Pickwell's Binocular Vision Anomalies. 5th ed. Oxford, Elsevier, 2007.
11 Wilkins A. Origins of Visual Stress. In: Visual Aspects of Dyslexia, Ed. Stein J and Kapoula Z., Oxford University Press 2012; 4: 63-77. (Access online: http://www.essex.ac.uk/psychology/overlays/2012-206.pdf)
12 Suttle CM, Melmoth DR, Finlay AL, Sloper JJ and Grant S. Eye-hand coordination skills in children with and without amblyopia. Inv Ophthalmol Vis Sci 2011;52(3):1851-64.
13 Suttle CM. Active treatments for amblyopia: a review of the methods and evidence base. Clin Exp Optom 2010; 93(5):287-299.
14 Karania R and Evans BJW. The Mallet Fixation Disparity Test: influence of test instructions and relationship with symptoms. Ophthal Physiol Opt 2006; 26:507-522.
15 O'Leary CI and Evans BJW. Double-masked randomized placebo-controlled trial of prismatic corrections on rate of reading and relationship with symptoms. Ophthal Physiol Opt 2006; 26(6):555-565.
16 Chase C, Tosha C, Borsting E and Ridder WH. Visual discomfort and objective measures of static accommodation. Optom Vis Sci 2009; 86:883-889.
17 Evans BJW, Drasdo N and Richards IL. Investigation of accommodative and binocular function in dyslexia. Ophthal Physiol Opt 1994; 14(1):5-19.
18 Drew SA, Borsting E, Stark LR, Chase C. Chromatic aberration, accommodation, and color preferences in asthenopia. Optom Vis Sci 2012; 89:E1059-E1067.
19 Borsting E, Rouse M, Deland P, Hovett S, Kimura D, Park M and Stephens B. Association of symptoms and convergence and accommodative insufficiency in school-age children. Optometry 2003; 74: 25-34.
20 Tosha C, Borsting E, Ridder WH, Chase C. Accommodation response and visual discomfort. Ophthal Physiol Opt 2009; 29:625-633.
21 Bucci MP, Bremond-Gignac D and Kapoula Z. Poor binocular coordination of saccades in dyslexic children. Graefes Arch Clin Exp Ophthalmol 2008; 246(3):417-428.
22 Cornelissen P, Bradley L, Fowler S and Stein J. Covering one eye affects how some children read. Dev Med Child Neurol 1992; 34:296-304.
23 Cornelissen P, Bradley L, Fowler S and Stein J. What childen see affects how they spell. Dev Med Child Neurol 1994:36:716-727.
24 Evans BJW. Dyslexia and Vision. Chichester: Wiley: 2001.
25 Omtzigt D, Hendriks AW and Kolk HHJ. Evidence for magnocellular involvement in the identification of flanked letters. Neuropsychologia 2002; 40(12):1881-1890.
26 Casco C, Tressoldi PE, Dellantonio A. Visual selective attention and reading efficiency are related in children. Cortex 1998:34:531-546.
27 Lorusso ML, Facoetti A, Toraldo A and Molteni M. Tachistoscopic treatment of dyslexia changes the distribution of visual-spatial attention. Brain Cogn 2005: 57(2):135-142.
28 Ray NJ, Fowler S, Stein JF. Yellow filters can improve magnocellular function: motion sensitivity, convergence, accommodation and reading. Ann N Y Acad Sci 2005; 1039: 283-293.
29 Huang J, Zong X, Wilkins A, Jenkins B, Bozoki A, Cao Y. fMRI evidence that precision ophthalmic tints reduce cortical hyperactivation in migraine. J. Cephalalgia 2010.
30 Wilkins A, Sihra N and Smith IN. Technical Note: How precise do precision tints have to be and how many are necessary? Ophthal Physiol Opt 2005, 25: 269-276.
31 Wilkins A, Sihra N and Myers A. Increasing reading speed by using colours: Issues concerning reliability and specificity, and their theoretical and practical implications. Perception 2005, 34: 109-120.
32 Wilkins AJ. Visual Stress. Oxford University Press 1995.
33 Singleton C and Trotter S. Visual stress in adults with and without dyslexia. J Res Reading 2005; 28:365-378.
34 Jeanes R, Busby A, Martin J, Lewis E, Stevenson N, Pointon D and Wilkins A. Prolonged use of coloured overlays for classroom reading. Bri J Psychol 1997; 88:531-548.
35 Kriss I and Evans BJW. The relationship between dyslexia and Meares-Irlen Syndrome. J Res Reading 2005; 28:305-354.
36 Examining patients with specific learning difficulties or visual discomfort, In: Guidance and Professional Standards, The College of Optometrists, U.K.
37 Critchley M. Developmental dyslexia. Whitefriars Press 1964, London.
38 Meares O. Figure/background, brightness/contrast and reading disabilities. Visible Language 1980; 14:13-29.
39 Irlen H. Successful treatment of learning difficulties. The Annual Convention of the American Psychological Association 1983; Anaheim, California.
40 Irlen H. Reading By The Colors: Overcoming Dyslexia And Other Reading Disabilities Through The Irlen Method. Avery Publishing Group 1991, New York.
41 Fitzmaurice C. International Institute of Colorimetry; Private Communication 2012.
42 Wilkins AJ, Lewis E, Smith F and Rowland E. Coloured overlays and their benefits for reading. J Res Reading. 2001; 181:10-23.
43 Maclachlan A, Yale S and Wilkins AJ. Open trials of precision ophthalmic tinting: 1-year follow-up of 55 patients. Ophthal Physiol Opt 1993; 13:175-178.
44 Wilkins AJ, Evans BJW, Brown JA, Busby AE, Wingfield AE, Jeanes RJ, et al. Double-masked placebo-controlled trial of precision spectral filters in children who use coloured overlays. Ophthal Physiol Opt 1994; 144:365-370.
45 Robinson GL and Foreman PJ. Scotopic Sensitivity / Irlen Syndrome and the use of coloured filters: A long-term placebo controlled and masked study of reading achievement and perception of ability. Percept Mot Skills 1999a; 79:467-483.
46 Robinson GL and Foreman PJ. Scotopic Sensitivity / Irlen Syndrome and the use of coloured filters: A long-term placebo-controlled study of reading strategies using analysis of miscue. Percept Mot Skills 1999b; 88:35-52.
47 Harris D and MacRow-Hill SJ. Application of ChromaGen lenses in dyslexia: a double-masked placebo controlled trial. J Am Optom Assoc 1999; 70(10):629-640.
48 Wilkins AJ, Jeanes RJ, Pumfrey PD and Laskier M. Rate of Reading Tests: its reliability, and its validity in the assessment of the effects of coloured overlays. Ophthal Physiol Opt 1996; 16:491-497.
49 Ludlow A, Wilkins A, Heaton P. The effects of coloured overlays on reading ability in children with autism. J Autism Dev Disord 2006; 36:507-516.
50 Northway N. Predicting the continued use of overlays in school children – a comparison of the Developmental Eye Movement test and the Rate of Reading test. Ophthal Physiol Opt 2003; 23(5):457-462.
51 Lightstone A, Lightstone T and Wilkins AJ. Both coloured overlays and coloured lenses can improve reading fluency, but their optimal chromaticities differ. Ophthal Physiol Opt 1999; 19(4):279-285.
52 Ludlow AK, Wilkins AJ, Heaton P. Colored overlays enhance visual perceptual performance in children with Autism Spectrum Disorders. Res Autism Spectr Disord 2008; 2:498-515.
53 Moreau T, Sochurkova D, Lemesie M, et al. Epilepsy in patients with multiple sclerosis: radiological clinical correlations. Epilepsia 1998; 39:893-896.
54 Gee J, Chang J, Dublin A, et al. The association of brainstem lesions with migraine-like headache: an imaging study of multiple sclerosis. Headache 2005; 45:670-677.
55 Caramia M, Palmieri M, Desiato M, et al. Brain excitability changes in the relapsing and remitting phases of multiple sclerosis: a study with transcranial magnetic stimulation. Clin Neurophysiol 2004; 115:956-965.
56 Reddy H, Narayanan S, Woolrich M, et al. Functional brain reorganisation for hand movement in patients with multiple sclerosis: defining distinct effects of injury and disability. Brain 2002; 125:2646-2657.
57 Sand T, Zhitniy N, White L and Stovner L. Visual evoked potential latency, amplitude and habituation in migraine: a longitudinal study. Clin Neurophysiol 2008; 119(5): 1020-1027.
58 Newman Wright et al (2007). Reference is: Newman Wright A, Wilkins A and Zoukos Y. Spectral filters can improve reading and visual search in patients with multiple sclerosis. J Neurol 2007; 254(12):1729-1735.