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Susceptibility to pattern glare and the effect of spectral filters on rate of reading and visual search in stroke patients

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Aston University

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The present thesis investigates pattern glare susceptibility following stroke and the immediate and prolonged impact of prescribing optimal spectral filters on reading speed, accuracy and visual search performance.

Principal observations:

A case report has shown that visual stress can occur following stroke. The use of spectral filters and precision tinted lenses proved to be a successful intervention in this case, although the parameters required modification following a further stroke episode.

Stroke subjects demonstrate elevated levels of pattern glare compared to normative data values and a control group.

Initial use of an optimal spectral filter in a stroke cohort increased reading speed by ~6% and almost halved error scores, findings not replicated in a control group. With the removal of migraine subjects reading speed increased by ~8% with an optimal filter and error scores almost halved.

Prolonged use of an optimal spectral filter for stroke subjects, increased reading speed by >9% and error scores more than halved. When the same subjects switched to prolonged use of a grey filter, reading speed reduced by ~4% and error scores increased marginally. When a second group of stroke subjects used a grey filter first, reading speed decreased by ~3% but increased by ~3% with prolonged use of an optimal filter, with error scores almost halving; these findings persisted with migraine subjects excluded.

Initial use of an optimal spectral filter improved visual search response time but not error scores in a stroke cohort with migraine subjects excluded. Neither prolonged use of an optimal nor grey filter improved response time or reduced error scores in a stroke group; these findings persisted with the exclusion of migraine subjects.

For Melanie, Emily and Imogen

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List of Abbreviations

AC/ A	Accommodative Convergence/ Accommodation
CIE	International Commission on Illumination
CPD	Cycles Per Degree
CT	Computed Tomography
EEG	Electroencephalography
FAST	Face Arm Speech Time
fMRI	functional Magnetic Resonance Imaging
HFA	Humphrey Field Analyser
MISViS	Meares Irlen Syndrome/ Visual stress
MRI	Magnetic Resonance Imaging
MS	Milliseconds
NHS	National Health Service
NICE	National Institute for Health and Clinical Excellence
PASW	Predictive Analytics SoftWare
PGS	Pattern Glare Score
SD	Standard Deviation
S	Seconds
SF	Spatial Frequency
TOAST	Trial of Org 10172 in Acute Stroke Treatment
UK	United Kingdom
UKPDS	United Kingdom Prospective Diabetes Study
USA	United States of America

1.0 Stroke, pattern glare and visual search

1.1 General Introduction

Ocular discomfort can occur when viewing certain types of images, most notably striped patterns (Wilkins, 1995), an effect termed patterned glare (Wilkins and Nimmo Smith, 1984) or pattern glare (Evans and Drasdo, 1991). For susceptible individuals, this adverse visual perceptual response can result in visual stress causing symptoms of eyestrain, headaches and glare, along with illusions of colours, shape and motion (Wilkins and Nimmo Smith, 1984). Visual stress coexists with a range of neurological conditions, although to date the evidence for visual stress following stroke is scant. Impairment to visual search ability can occur following stroke (Keller and Lefin-Rank, 2010; Hildebrandt *et al*., 2005) and visual search tasks have been used to identify subjects with visual stress (Singleton and Henderson, 2007), with certain cohorts showing improvements in task performance with the introduction of spectral filters (Newman Wright *et al*., 2007). The sections that follow in this introduction provide a brief overview of the key elements of stroke and a review of pattern glare and visual stress management, as well as visual search, establishing a rationale for the subsequent experimental chapters.

1.2 Stroke

1.2.1 Introduction

The definition of stroke, given by the World Health Organisation is a clinical syndrome of rapidly developing clinical signs of focal (at times global) disturbance of cerebral function, lasting more than 24 hours or leading to death with no apparent cause other than that of vascular origin (NICE Clinical Guideline 68, 2008) The definition is designed to reflect the fact that tissue damage can be reversible and allows separation from the related syndrome

of transient ischaemic attack where stroke symptoms resolve completely within 24 hours (Donnan *et al.*, 2008). A stroke, previously referred to as a cerebrovascular accident, is a medical emergency, which can cause permanent neurological damage and death. A stroke can result from thrombosis or occlusion causing ischaemia, or from haemorrhage (Sims and Muyderman, 2010).

Stroke is the second most common cause of death after ischaemic heart disease and is a major cause of disability worldwide (Donnan *et al.*, 2008). Stroke is responsible for 9% of deaths around the world and could soon be the most common cause of death (Murray and Lopez, 1997). In the UK, stroke is one of the largest health burdens, responsible for 53,000 deaths in 2007, with more than 175,000 consultant appointments within the NHS hospital system (Bhatnagar *et al.*, 2010). One of the most significant risk factors is advancing age, with an exponential increase from the age of 30 years (Ellekjaer *et al.*, 1997).

1.2.2 Classification

Stroke may be classified in to two major types, ischaemic or haemorrhagic (National Institute of Neurological Disorders and Stroke, 2012), with the overwhelming majority (87%) being caused by ischaemia (Donnan *et al.*, 2008). Classification of the stroke is important, as the management of the patient is dependent upon aetiology.

In ischaemic stroke, blood supply is prevented from reaching the brain adequately due to obstruction from arterial or venous thrombosis, emboli or a general decrease in blood supply resulting from systemic hypoperfusion (Shuaib and Hachinski, 1991). Around a third of ischaemic strokes occur without an obvious underlying cause and are termed cryptogenic (Guercini *et al.*, 2008). Ischaemic stroke may be classified by system, such as the Oxford Community Stroke Project Classification that relies on the initial presenting symptoms with the event being classified as total anterior circulation infarct, partial anterior circulation infarct,

lacunar infarct, or posterior circulation infarct; this enables the clinician to predict the extent, location, aetiology and prognosis for any given patient (Bamford *et al.*, 1991). The Trial of Org 10172 in Acute Stroke Treatment (TOAST) classification (Adams *et al.*, 1993) is based upon presenting symptoms as well as the outcome from further investigation, with the stroke categorised by thrombosis or embolism from atherosclerosis, embolism from cardiac origin, occlusion of a small blood vessel, other determined cause, or undetermined cause.

Haemorrhagic stroke is most commonly caused by hypertensive small-vessel disease resulting from the rupture of aneurysms. Subarachnoid haemorrhage accounts for around 5% of all strokes and is mostly caused by the rupture of aneurysms within the subarachnoid space. Rupture of intracranial veins can also result in haemorrhagic stroke and are generally less severe events (Donnan *et al.*, 2008).

1.2.3 Recognition

At least one presenting symptom of sudden onset face weakness, inability to raise both arms, or abnormal speech is highly predictive of stroke, whereas when all three of these symptoms are absent, the likelihood of stroke is significantly decreased (Goldstein and Simel, 2005); these predictors have led to the FAST system (face, arm, speech, time) devised by the Department of Health, UK (NICE Clinical Guideline 68, 2008), promoted to improve stroke recognition by relatives, medics and patients themselves.

1.2.4 Aetiology

In thrombotic stroke, a persistent clot forms in a vessel (National Institutes of Health, 2012). Typically, the blockage is gradual, leading to a slow onset of stroke. Large vessels may be affected, including the common and internal carotids, the vertebral and the Circle of Willis. Thrombi may arise due to atherosclerosis, vasoconstriction, artery dissection, along with

inflammatory conditions, such as vasculitis and giant cell arteritis. Smaller arteries such as the middle cerebral artery, branches arising from Circle of Willis, distal vertebral and basilar artery may also develop thrombi due to a build up of hyaline, secondary to blood pressure and advancing age (NHS Choices; Marsh and Keyrouz, 2010). Cerebral venous sinus thrombosis can result in stroke due to a local rise in venous pressure that exceeds arterial pressure, resulting in haemhorrhage (Stam, 2005).

Embolic stroke occurs when a clot formed elsewhere in the body, frequently a thrombus, has broken off and travels to the event site. Emboli may also be particles of cholesterol, commonly arising from the heart, as well as air, cancer cells or bacterial clumps. In embolic stroke, symptoms are sudden onset but may be transient if the emboli dissipates or relocates (Marsh and Keyrouz, 2010).

Stroke can result from systemic hypoperfusion that reduces blood flow to the brain due to cardiac arrhythmias and cardiac arrest, or reduced output due to pulmonary emboli, or myocardial infarction (Shuaib and Hachinski, 1991).

Intracerebral haemorrhage occurs most commonly due to vascular hypertension and typically affects smaller arteries. Intracerebral haemorrhage has a higher mortality rate than other types of stroke with 44% of patients dying within a month (Donnan *et al.*, 2008).

1.2.5 Diagnosis

Stroke diagnosis is determined by presenting clinical signs along with the use of imaging techniques including computerised tomography (CT scan), magnetic resonance imaging (MRI scan) and Doppler ultrasound. MRI scans have greater diagnostic ability than CT scans, especially for ischaemic events (Hill, 2005). Specifically, CT scans have sensitivity of 16% for identifying ischaemic stroke compared with 83% for MRI scans (Chalela *et al.*,

2007). For haemorrhagic stroke, CT scans and MRI scans have similar sensitivity at 89% and 81%, respectively, although MRI scans are more accurate than CT scans at detecting chronic haemorrhages (Kidwell *et al.*, 2004).

1.2.6 Prevention

Management of modifiable risk factors for stroke is the primary prevention strategy that includes the control of hypertension, reduction of cholesterol levels and management of comorbidity, e.g. diabetes (Medical Research Council Working Party, 1985). Hypertension accounts for over a third of strokes (Whisnant, 1996) with studies conclusively showing reduced risk for haemorrhagic and ischaemic stroke by lowering blood pressure (Prospective Studies Collaboration, 1995). The use of statin therapy to reduce cholesterol levels is rewarded with a 15% reduction in stroke risk (O'Regan C *et al.*, 2008). Diabetics have a relative risk factor for stroke of 2 to 3 times. With comorbidities such as hypertension and elevated cholesterol levels, controlling these risk factors is of principal importance for diabetics. Nevertheless, whilst tight control of blood-glucose levels seems to improve the outcome for microvascular disease, such as retinopathy, it does not appear to reduce macrovascular complications such as stroke (UKPDS, 1998).

Educating patients about the adverse effects of smoking (Kelly *et al.*, 2008), excessive alcohol consumption (Reynolds *et al.*, 2003; Gorelick, 1987) and ensuring adequate physical activity (Marsh and Keyrouz, 2010) are also central to the primary prevention strategy. A diet of Mediterranean style is thought to reduce the risk of stroke by more than 50% (Fisher *et al.*, 2006).

Anticoagulant drugs such as aspirin and warfarin have been used commonly to reduce stroke risk for over half a century, particularly for secondary prevention following an initial stroke or transient ischaemic attack (Johnson *et al.*, 1999).

1.2.7 Treatment

Acute stroke patients are given the best survival chance by being admitted to a stroke unit as soon as possible. Rapid assessment of aetiology is key to administering the appropriate treatment (Donnan *et al.*, 2008).

For ischaemic stroke, the objective is to remove the obstruction as quickly as possible to limit cell death, either by pharmacological means, thrombolysis, or mechanical removal, thrombectomy (Saver, 2006; Smith *et al.*, 2008). For haemorrhagic stroke, careful neurological investigation is required to determine if surgery is necessary to treat the site of the bleed. Maintenance of optimal blood pressure, blood glucose and oxygen levels are paramount for haemorrhagic stroke victims during the recovery phase.

1.3 Visual dysfunction following stroke

1.3.1 Introduction

The incidence of visual dysfunction following stroke is reported to be between 30% and 85%, with symptoms ranging from subtle depth perception changes to complete cortical blindness (Kapoor and Ciuffreda, 2002). The visual changes associated with stroke may be sensory in origin, affecting visual acuity, the visual field and perceptual impairment, or motor origin, affecting binocular vision.

1.3.2 Sensory impairment

Visual acuity may be impaired following stroke, the extent to which will be dependent upon the site of the lesion. For unilateral post-chiasmal lesions acuity is normally unaffected, whereas bilateral post-chiasmal lesions, affecting the foveal nerve fibres, will typically impair

acuity in both eyes to the same degree. Lateral chiasmal lesions frequently impair acuity in the ipsilateral eye, whereas midchiasmal lesions will commonly impair acuity in both eyes, although usually asymmetrically and proportional to the extent of the accompanying visual field defect (Frisen, 1980).

The most common type of visual field defect following stroke is complete homonymous hemianopia occurring in approximately 8% of strokes and usually results from a middle cerebral or posterior cerebral artery stroke affecting either the optic radiation or visual cortex of the occipital lobe. An inferior quadrantanopia occurs when the stroke affects the parietal lobe optic radiation, whilst superior quadrantanopia results from insult to the optic radiation inferiorly in the temporal lobe (Gilhotra *et al.*, 2002). Homonymous visual field defects arise from damage to the occipital lobe in 54% of cases, 33% originate in the optic radiations, with around 6% in the optic tract. Multiple sites are affected in 5% of cases, with just 1% originating in the lateral geniculate body (Zhang *et al.*, 2006). The extent to which the visual defect spontaneously improves is variable, although around 50% of patients show some improvement, usually within the first three to six months (Kedar *et al.*, 2006). Rehabilitation of visual field loss currently falls into categories of compensation, substitution and restitution. Compensatory strategies involve visual search training that promotes an individuals ability to make extra saccades towards the hemianopic field. However, the majority of patients do find this difficult and the process can in fact be counterproductive (Zihl, 1999). Substitution therapy involves the use of optical devices such as prisms, mirrors and telescopes to displace images from the hemianopic field to the functional side (Peli, 2000). The acceptance of this intervention is variable although some patients successfully expand their field to useful extent (Bowers *et al.*, 2008). Visual field restitution is a controversial area involving flicker stimulation of the hemianopic field (Schofield and Leff, 2009). The rationale for this treatment is that cortical stimulation allows reorganization of surviving neurons to improve visual function. A recent review, however, has found that there is insufficient evidence to conclude

that any of the aforementioned strategies offer genuine benefit for stroke rehabilitation (Pollock *et al.*, 2011).

Visual neglect describes sensory impairment most commonly resulting from damage to the right cerebral hemisphere, causing visual neglect of the left-hand side of space, with reports of varying incidence of between 13 and 85% (Sinanovic *et al.*, 2010). Patients with a right parietal lobe lesion with visual neglect would behave as if the left side of sensory space is absent. Extreme examples include patients who ignore food on the left side of their plate or only shaving one side of their face; these patients may frequently collide with objects or structures such as door frames on the neglected side but should not be confused with similar problems resulting from hemianopic visual field defects in others (Unsworth, 2007).

Visual perceptual deficits can result from traumatic brain injury, including stroke, and patients may complain of light-sensitivity, strain, fatigue and reading difficulties (Tosta and Johnson, 2009). Other reports have recognised a susceptibility to photophobia following traumatic brain injury; these individuals have shown improvements in reading ability with the use of photochromic filters (Jackowski *et al.*, 1996). Further evidence recognises that many brain injury patients, including those with stroke, have difficulty with reading, such as skipping lines of text, and problems moving to the next row of print, albeit with the suggestion that these complications arise from motor rather than sensory origin (Han *et al.*, 2004). It has been shown that even following minor head injuries, particularly those involving concussion, subjects demonstrate a lowered tolerance to brightness and sound (Bohnen *et al.*, 1991); this is supported by earlier evidence of photophobia and sound sensitivity in patients with closed head injury (Waddell and Gronwall, 1984). Measures of critical flicker frequency have also been found to be elevated in those with mild traumatic brain injury, with accompanying symptoms of light and motion sensitivity. It has been proposed that neurological disinhibition (see Section 1.4.3), as a result of the brain injury, may be causal of the subjective hypersensitivity to light and motion in these individuals (Chang *et al.*, 2007), a theory that

supports earlier work, which demonstrated hyperexcitability in the visual cortex, in patients with homonymous hemianopia, following stroke (Braun *et al.*, 2001); this study, using Magnetoencephalography (MEG), showed reduced activity within the scotoma region as compared to stimulation of the intact hemifield, as well as increased activity at the border region of the scotoma. Some patients may even report hallucinations following stroke, so called Charles Bonnet syndrome, which can arise as a result of vision loss from a variety of causes (Khan *et al.*, 2008); this condition may be under-reported due to patients concerns about the reaction of others to their symptoms (Eperjesi and Akbarali, 2004).

1.3.3 Ocular motor impairment

The ocular motor system broadly consists of versional, vergence and accommodative components. Damage to the ocular motor system following stroke is common and can result in diplopia, blurring, difficulty following targets, reading problems and asthenopia. Saccadic deficits in stroke patients are reported as being greater than 50%. About one-third of stroke victims present with strabismus at near; a similar proportion have convergence insufficiency (Ciuffreda *et al.*, 2007). Accommodative deficits are less common in this cohort than those with traumatic brain injury occurring in around 12% of stroke patients (Ciuffreda *et al.*, 2007).

1.4 Pattern glare and visual stress

1.4.1 Introduction

Ocular discomfort often manifests when viewing certain image types, such as repetitive striped patterns (Wilkins, 1995). The intensity of these effects will vary according to individual susceptibility and the precise nature of the pattern, most notably, its spatial frequency and contrast level (Wilkins *et al.*, 1984). For some, this discomfort occurs in every day life and these individuals are said to have visual stress arising from pattern glare susceptibility. The

symptoms that arise from pattern glare are often referred to by their historically derived terms, Meares–Irlen syndrome and scotopic sensitivity syndrome (Evans, 1997) and more recently referred to by the acronym MISViS, which denotes the title Meares–Irlen syndrome/ visual stress (Evans and Stevenson, 2008). The characteristics of the visual stimulus, which cause, or at least contribute in generating visual stress, is sensory in origin (Huang *et al.*, 2011) and therefore distinguishable from factors of motor origin, such as ocular motor balance, binocular vergence, and accommodation (Yekta *et al.*, 1989). The visual perceptual distortions that are generated by susceptibility to pattern glare is maximal when the spatial frequency of the stimulus is around three cycles per degree, with a pattern of even width and spacing, high contrast and viewed binocularly (Wilkins, 1995; Wilkins *et al.*, 1984). Many of the attributes necessary to generate pattern glare in the susceptible individual are present within standard text documents formed by the individual rows of words separated by the successive spacing between rows (Wilkins and Nimmo-Smith, 1984; Wilkins and Nimmo-Smith, 1987). The spatial frequency of this alternating high contrast pattern, formed by text, has been shown to fall within the range known to generate pattern glare symptoms (Wilkins *et al.*, 2004); this is coupled with striped patterns formed by letter strokes in individual words, as well as the vertical strokes of letters that also have a spatial frequency falling within a range sufficient to generate pattern glare symptoms in susceptible individuals.

1.4.2 Background

The symptoms arising from pattern glare susceptibility can frequently be reduced with the use of spectral filters, optimally selected for the individual (Wilkins *et al.,* 1994; Jeanes *et al.*, 1997; Robinson and Foreman, 1999; Evans and Joseph, 2002), with these effects being more than placebo and not due to contrast reduction (Jeanes *et al.*, 1997). Normative data reports show that 22% of school children read significantly faster with a spectral filter (Wilkins *et al*, 2001), and 38% within a university student sample (Evans and Joseph, 2002). Dyslexic

children seem to derive greater benefit from spectral filters than non-dyslexic children, and the prevalence of visual stress may be higher in this cohort (Kriss and Evans, 2005). The use of spectral filters has evolved from historical scientific reports dating back to 1964 by MacDonald Critchley of a dyslexic child who seemed only able to read text on coloured card (cited by Allen *et al*., 2009) and a further report in 1980 from a teacher, Olive Meares, who described reduction of visual perceptual distortions using tinted plastic sheets (Meares, 1980). The use of spectral filters gained momentum, promoted by the American Psychologist, Helen Irlen (Irlen, 2005). She demonstrated that individuals could reduce visual perceptual distortions with the use of optimally selected spectral filters and this led to the development of Irlen Centers which have since been established in various parts of the world (Irlen, 2005). Irlen developed a range of different ophthalmic tints by dip-dying lenses, to replicate the benefits of coloured overlays. The work of Irlen was met with scepticism amongst ophthalmic practitioners, which still exists today (Ritchie *et al.*, 2011) as her commercial activities preceded the robust scientific trials that were to follow. Credence for these seemingly controversial interventions, however, began to build with the development of the Intuitive Colorimeter by Professor Arnold Wilkins. The Intuitive Colorimeter, described later in detail (see Chapter 2), allows the user to manipulate hue, saturation and brightness, independently, to produce a precise colour that minimises visual perceptual distortions for the individual (Wilkins *et al*., 1992). The optimum colour selected during the assessment process can then be replicated as a precise ophthalmic tint. During the examination process, the subject becomes adapted to the colour of the light and is unaware of its precise characteristics; this process of adaptation allowed a double-masked trial to be undertaken, which proved that a precise ophthalmic tint was more beneficial in reducing eyestrain and headache than a suboptimal control tint (Wilkins *et al.*, 1994).

1.4.3 Rationale for using spectral filters

Despite the use of spectral filters evolving from anecdotal observations dating back almost 50 years, a sound scientific basis for their use continues to be developed (Wilkins *et al.*, 1994; Evans *et al.*, 2002; Wilkins *et al.*, 2002; Xiao *et al.*, 2003; Huang *et al.*, 2011). Nevertheless, the origin of pattern glare and visual stress remains equivocal, although it is thought that these effects arise due to cortical hyperexcitability (Wilkins *et al.*, 1984; Huang *et al.*, 2011; Wilkins and Neary, 1991; Harle and Evans, 2004; Harle *et al.*, 2006). However, several alternative theories for the mechanism of symptom reduction with spectral filters have been proposed including accommodative and magnocellular theories.

It has been suggested that the use of spectral filters alters the level of chromatic aberration, with subsequent impact upon accommodation. Children with dyslexia have been shown to have slightly reduced amplitudes of accommodation although not at levels likely to impair reading ability (Evans *et al.*, 1994) with others reporting a high prevalence of accommodative and binocular vision anomalies in prospective Irlen lens wearers (Scheiman *et al.*, 1990). Others have shown subtle binocular and accommodative dysfunction in a Meares-Irlen cohort, namely, reduced stereoacuity, vergence and accommodative amplitude (Evans *et a*l., 1995). Nevertheless, subjects without binocular and accommodative anomalies still show benefit from using spectral filters and it has been proposed that these deficits are correlates, rather than causative, of Meares-Irlen syndrome (Evans *et al.*, 1996; Simmers *et al.*, 2001). It has also been argued that subjects with reduced amplitudes of accommodation would be expected to select lenses with transmission characteristics biased towards short wavelengths, something not borne out in the literature, suggesting that an accommodative mechanism for their benefit is unlikely (Evans *et al.*, 1996). Others have shown no significant difference in the mean level of accommodation when comparing subjects with and without Irlen lenses, although an increase in accommodative variability was noted when subjects were wearing their filtered lenses (Ciuffreda *et al.*, 1997) and data showing increased

microfluctuations in accommodation for subjects with visual stress whilst not wearing a tinted lens (Simmers *et al.*, 2001). A recently published paper has shown that subjects with high levels of visual discomfort are more likely to select coloured lenses that reduce accommodative demand (Drew *et al.*, 2012). A further, recent, double-masked study considered the effects of coloured overlays on the accommodative response of individuals, comparing individuals with pattern-related visual stress *versus* those without (Allen *et al.*, 2010). The study found that although accommodative lag was greater in the group with visual stress, and was reduced by the use of an optimised filter, this was not related to its colour. They proposed that the changes known to occur in spherical aberration and in higher order aberrations during accommodation are modified with the use of a spectral filter, which may subsequently alter accommodative control. In other words, the changes occurring in accommodation arise from visual stress, rather than the other way around.

It has been proposed that the symptoms arising from visual stress are related to a deficit of the magnocellular pathway (Kruk *et al.*, 2008; Stein, 2001). The visual system comprises two parallel pathways: the parvocellular pathway, predominant in central vision, responsible for the discrimination of fine detail, is responsive to high contrast but insensitive to movement and flicker; the magnocellular pathway which is most sensitive in the peripheral field and, therefore, responsive to movement and flicker, with sensitivity to low-contrast, coarse detail. These classifications, however, are over-simplistic with considerable overlap between parallel systems (Merigen and Maunsell, 1993), complicated further by the existence of the koniocellular pathway, a third system that has received comparatively little coverage in the literature (Allen et al, 2009). Nevertheless, there is considerable research to show the presence of a magnocellular deficit in dyslexia. A review of the evidence by Evans in 2001 highlighted that up to two-thirds of those with dyslexia could have a magnocellular deficit (Talcott *et al.*, 1998; Felmingham and Jakobson, 1995), although this has been disputed by others (Hutzler *et al.*, 2006; Johannes *et al.*, 1996) Regardless of this, visual stress has been shown to be a correlate of dyslexia and distinctly separate from it (Kruk *et al.*, 2008). A

hypothesis was developed that yellow filters may be of benefit in dyslexia by enhancing the magnocellular system (Ray *et al.*, 2005). Yellow filters may be expected to improve image quality by reducing chromatic aberration and reducing light scatter (Fowler *et al*., 1991), although the accompanying reduction in retinal luminance may be counterproductive (Eperjesi and Agelis, 2011). However, the basis for using yellow filters does not explain the precise nature of tints that are required to reduce symptoms in those with visual stress, including those with dyslexia. Furthermore, magnocellular function has been shown to be normal in subjects with visual stress (Evans *et al.*, 1995; Evans *et al*., 1994, Simmers *et al.*, 2001; Conlon *et al.*, 2009; White *et al.*, 2006).

The contemporary argument is that cortical hyperexcitability (disinhibition), may underlie the existence of visual stress; a hypothesis growing in credibility with a developing evidence base (Huang *et al.*, 2011; Wilkins *et al.*, 1999; Xiao *et al.*, 2003; Wilkins, 2003). The hypothesis arises from the knowledge that pyramidal neurons share inhibitory interneurons and the strong sensory stimulation of these may result in local reduction of inhibitory neurotransmitter. The result of this may lead to a distribution of excitation allowing neurons to fire in an inappropriate manner. It is felt that this misfiring is responsible for the generation of perceptual distortions and illusions in susceptible individuals. It has been shown that there is large variation in the spectral sensitivity of cortical neurons (Xiao *et al.*, 2003), and the use of spectral filters, therefore, may serve to redistribute this excitation resulting in a drop of activity in hyperexcitable areas and an accompanying reduction in the associated perceptual disturbances for the individual. Further evidence comes from a study observing changes to blood oxygenation in the visual cortex using fMRI (Huang *et al.*, 2003). The results from this work showed an increase in oxygenation in response to striped stimuli with an aversive spatial frequency. More recently, a further study utilising fMRI has shown that precision ophthalmic tints reduce cortical hyperexcitability in migraine sufferers whereas sub-optimal tints do not (Huang *et al.*, 2011). Other studies of interest have shown that the arrangement of V2 in the macaque cortex has neurons responsible for detecting differently coloured

gratings, are configured in a manner that is reminiscent of the CIE chromaticity diagram (Xiao *et al.*, 2003), supporting the argument that the use of a precise colour would allow for redistribution of cortical activity in hyperexcitable regions. Furthermore, visual stress has been shown to be associated with a range of neurological conditions including photosensitive epilepsy (Wilkins *et al.*, 1999), migraine (Wilkins *et al.*, 2002; Evans *et al.*, 2002; Harle and Evans, 2004; Harle, 2006), dyslexia (Kriss and Evans, 2005; Singleton and Trotter, 2005; Jeanes *et al.*, 1997; Evans and Joseph, 2002), autism (Ludlow *et al.*, 2006; Ludlow *et al.*, 2008) as well as multiple sclerosis (Newman Wright *et al.*, 2007), suggesting a common neurological link.

1.4.4 Optometric correlates of visual stress

Subjects identified with visual stress have been shown to have normal measures of visual acuity, refractive error, AC/ A ratio and flicker perception (Evans *et al.*, 1995). It has been shown, however, that reduced vergence, amplitude of accommodation and stereo-acuity are correlated with visual stress, along with elevated levels of pattern glare, as compared with a group matched for age, reading ability and intelligence (Evans *et al.*, 1995).

1.4.5 Comorbidity of visual stress and neurological disorders

Numerous neurological conditions have shown benefit from using spectral filters to manage the symptoms arising from pattern glare (Wilkins and Evans, 2010).

1.4.5.1 Specific Learning Difficulty

Visual stress is a known correlate of specific learning difficulties (Evans *et al.*, 1999) with rigorous trials showing that these subjects obtain significant reduction in eyestrain and headaches (Wilkins *et al.*, 1994) as well as improvements in reading speed when using

optimal spectral filters (Bouldoukian et al., 2002), a finding that is not replicated with placebo measures.

1.4.5.2 Epilepsy

Around 4% of patients with epilepsy will experience seizures when viewing adverse visual stimuli, most notably with flickering lights and striped patterns of specific spatial frequency (Wilkins *et al.*, 1984). The seizures can originate from excitation in the visual cortex of one, or both cerebral hemispheres (Wilkins, 1995). Often these patients are photophobic, with seizures occurring only in response to stressful visual stimuli, such as light flickering between trees, or the tread pattern on escalators. In these patients, the electrical activity, measured using electroencephalography (EEG), can be abnormal between seizures as well as during them. An open trial in 1999 examined the use of coloured spectacle lenses to treat photosensitive epilepsy (Wilkins *et al.*, 1999). In this study, subjects were assessed for potentially suitable precision ophthalmic tints using the Intuitive Colorimeter. Following this procedure, 74% of participants elected to have precision tinted spectacles prescribed for them. A follow up at an average of 2.4 years later showed that 57% felt a benefit from the tinted spectacles and continued to use them on a regular basis. For six of the subjects, the reduction in symptoms of dizziness under fluorescent lighting and aura from using computer screens, were pronounced. In three cases, a reduction in the number of seizures could be linked to the use of the precision tinted lenses.

1.4.5.3 Migraine

Certain types of visual stimuli are known to be triggers for migraine. There appears to be striking link between this neurovascular condition and pattern glare (Wilkins *et al.*, 2002; Evans *et al.*, 2002; Harle and Evans, 2004; Harle *et al.*, 2006). Those susceptible to noting illusions in response to viewing striped patterns have been shown to have a relationship to headache frequency, and that this headache type is more likely to be a migraine type than a tension type (Wilkins *et al.*, 1984). Others have shown that subjects have an increase in

reported illusions on days when they have headaches, with a particular aversion to striped patterns, especially when the headaches are migraines (Nulty *et al.*, 1987). Often, sufferers of migraine avoid bright light during attacks, with many using sunglasses even between episodes (Drummond, 1986). Glare is responsible for the light sensitivity in migraine sufferers and this heightened sensitivity to light is consistent with heightened sensitivity to other visual stimuli such as striped patterns (Drummond, 1997). Data from imaging studies have demonstrated hyperexcitability of the visual cortex in migraine sufferers (Aurora *et al.*, 1999), with others showing, using fMRI, that migraine sufferers with aura have an induced hyperneuronal response in the visual cortex when viewing square-wave gratings designed to elicit pattern glare (Huang *et al.*, 2003). A double-masked randomised trial has shown that using a precision tint is beneficial in reducing the frequency of headaches, compared with a suboptimal control tint (Wilkins *et al.*, 2002). Compelling evidence has demonstrated normalisation of cortical activity measured by fMRI occurring when migraine subjects wear precision ophthalmic tints whilst viewing visually stressful stimuli (Huang *et al.*, 2011).

1.4.5.4 Autism

Sensory abnormalities have been widely reported in individuals with autistic spectrum disorder, including those of visual origin, which are principally recognised as being a hypersensitivity to lights and colours (Olney, 2000). Visual distortions can also exist in these individuals creating problems reading printed text and difficulty maintaining appropriate spacing between letters and words. It has been proposed that autistic individuals presenting with these symptoms are likely to be suffering from visual stress (Ludlow *et al.*, 2012). Spectral filters have been shown to offer significant benefit for these individuals, with 79% of autistic children demonstrating an increase in reading speed of at least 5%, compared with only 16% in an age and intelligence matched control population (Ludlow *et al.*, 2006; Ludlow *et al.*, 2008). Interestingly, a recent finding has shown that autistic children can improve perception of emotional expression using spectral filters (Ludlow *et al.*, 2012)

1.4.5.5 Multiple Sclerosis

Substantial benefits in reading ability, for a group of multiple sclerosis patients, have been demonstrated with the intervention of optimal spectral filters (Newman Wright *et al.*, 2007). The study established that twenty-five out of twenty-six of the participants reported a reduction in their visual stress symptoms when using an individually selected coloured filter. Half of the subjects were able to read at least 20% faster with their overlay with substantially reduced errors made on a visual search task in over 50% of cases; these findings were not replicated with a grey filter.

1.4.6 Spectral filters

There are several different versions of spectral filters that are commercially available, each with slightly different characteristics. It is important that these are optimally selected for the individual (Jeanes *et al.*, 1997; Wilkins and Lewis, 1999). The Intuitive Overlays (iOO Sales Ltd., London) are the most commonly used filters for research studies and consist of nine differently coloured filters and a grey filter, combinations of which offer the individual 30 shades of colour (Wilkins, 2003). Unlike the filters supplied by Irlen Centers, the Intuitive Overlays have been designed with an even distribution of chromaticities to offer similar saturation and evenly spaced hue angle (Wilkins, 1994). Cerium filters (Cerium Visual Technologies, Kent) are comparable to the Intuitive Overlays, albeit with 12 overlays of similar colour, offering 32 shades in total. Other sources of spectral filter systems have been developed by National Reading Styles Institute, which comprises 24 colours, including two types of grey, that are designed to be used singularly, as well as Crossbow Overlays, a selection of 10 colours that can be used in combination to provide 30 shades.

1.5 Visual Search

1.5.1 Introduction

Visual search tasks typically involve identifying objects visible within the current field of view (Wolfe, 1998). Stroke subjects are known to demonstrate impaired visual search function (Keller and Lefin-Rank, 2010; Hildebrandt *et al*., 2005) and current rehabilitation techniques involves training patients to make extra saccades towards areas of defective visual field, with limited success (Bowers *et al*., 2008; Pollock *et al*., 2011). Visual search tasks have been utilised to identify individuals with visual stress (Singleton and Henderson, 2007), although subsequent task improvement with spectral filters does not necessarily follow (Allen *et al*., 2008). Nevertheless, spectral filters have been shown to improve visual search performance in patients with multiple sclerosis (Newman Wright *et al*., 2007), as well as children with below-average reading ability (Tyrell *et al*., 1995).

1.5.2 Visual search task design

A standard visual search task requires the subject to find a target amongst numerous distractors with outcome measures of response time and accuracy typically being considered. In visual search tasks where each item is processed in turn, serial neural processing is required. An example of this may be to find a target letter, e.g. V, within an array of distractor letters, e.g. L. In contrast, for tasks requiring parallel processing, the subject can more easily identify the target within the distractors. For example, to identify a red target amongst green distractors, the number of distractors has little bearing on the subject's ability to detect the target with all items processed simultaneously (Wolfe, 1998). The proposal of a neat categorisation of parallel and serial visual search task given prominence over 30 years ago (Treisman and Gelade, 1980) has been disputed more recently (Thornton and Gilden, 2007) with distinction between these two categories being

less straightforward. The strict definition of serial search is that each item is processed individually, but it has been shown that more than one item may be processed during a single attentional fixation (Muller *et al.*, 1994) thereby complicating the definition. Furthermore, the amount of time the subject spends at a target/distractor location, so called dwell time, has been used to define the task as parallel or serial. A dwell time of ~ 5 ms/item has been routinely suggested as a parallel search task giving the assumption that times outside of these limits are serial processing tasks. However, parallel tasks such as the judgement of spatial relations may well require dwell time of > 40-50 ms (Logan, 1994). The acceptance of task errors further complicates the distinction, with missed targets during serial search tasks naturally reducing subject dwell time (Chun and Wolfe, 1996). In addition, target and distractor attributes may be modified to increase dwell time. For example, the classic 'parallel' search task described earlier, where the subject is required to identify red targets amongst green distractors, could be defined as serial task based on dwell time if the subject were required to detect green targets amongst yellowish green distractors (Nagy and Sanchez, 1990). Regardless of definition, it seems that only visual search tasks of a certain difficulty are able to distinguish between those with low and high levels of visual stress (Conlon and Humphreys, 2001) and this has perhaps greatest significance from a clinical standpoint.

1.6 Summary

The preceding sections have described stroke as a common condition with deficits to visual function, including perceptual anomalies and visual search impairment, frequently arising as a result of the disease. Despite successful management of adverse visual perceptual symptoms in a range of neurological conditions with optimal spectral filters, little is known about the impact of these interventions within a stroke cohort. The experimental chapters that follow will consider the hypothesis that stroke subjects may have susceptibility to pattern

glare and if this is accepted, spectral filters may help to rehabilitate reading ability and visual search performance in this subject group.

2.0 Laboratory Design

2.1 Introduction

The following sections describe the assessments utilised in the subsequent experimental chapters. A flow chart detailing the intended programme of research is provided in Appendix 4.

2.2 Pattern Glare Test

The Pattern Glare Test (see Figure 2.1) is designed to elicit visual perceptual distortions in susceptible subjects and is now considered to be an established, efficient way to identify individuals with visual stress (Evans and Stevenson, 2008). It is a simple test, consisting of three high-contrast gratings, each subtending 13.63 degrees at the eye when viewed at 40 cm. Each pattern has a duty cycle of 50% with their grating orientation set horizontally to mimic text. The first pattern has a low spatial frequency (low-SF) of 0.3 cycles per degree (cpd) when viewed at 40cm, designed to trigger relatively few distortions and unlikely to have an association with headaches and eyestrain (Wilkins and Nimmo Smith, 1984); this first pattern, therefore, serves as a useful control for suggestive individuals. The second pattern is designed to elicit maximum distortions, with a mid-spatial frequency (mid-SF) of 2.3 cpd at 40cm. Those who respond adversely to this mid-SF pattern are likely to experience symptoms of visual stress in their everyday environment. The third high-contrast grating serves as another control with a higher spatial frequency (high-SF) of 9.4 cpd at 40cm. It would be expected that this high-SF pattern would generate fewer symptoms than the second mid-SF pattern. Further detail on the range of spatial frequencies at varying working distances for the Pattern Glare Test are given in Table 2.1. The patterns are viewed in succession and the symptoms generated are summed to give a Pattern Glare Score for each of the gratings. Pattern glare would be suggested if the patient responds with a high score on

the mid-SF grating and/ or a score with the mid-SF pattern which is greater than the score with the high-SF grating, the so-called ‘mid-high difference’ variable; this relative, rather than absolute, mid-high difference measure allows for normalisation of the subject by accounting for suggestive individuals. Normative values for the Pattern Glare Test have been established (Evans and Stevenson, 2008), taking into account that only a high test score should be regarded as clinically significant (Wilkins and Evans, 2010). The normal range for the mid-SF pattern has been shown as a Pattern Glare Score of less than 4, and an upper limit of the normal range for the mid-high difference variable as being 1. In other words, those with a Pattern Glare Score of >3 on the mid-SF grating, or a score of >1 on the mid-high difference variable demonstrate an abnormal degree of pattern glare. The literature also shows that individuals with relatively low levels of visual discomfort are more likely to report distortions with the high-SF than the mid-SF grating, this being attributable to a greater influence of optical factors when viewing this finer grating rather than symptoms of neurological origin, with these subjects also more likely to report fewer distortions overall (Conlon *et al.*, 2001). It has been shown that Pattern Glare Scores are similar in males and females (Evans and Stevenson, 2008). When considering age, younger participants are found to report more distortions on the mid-SF and the high-SF gratings than older subjects (Evans and Stevenson, 2008). Overall, with advancing age, there is a greater decrease with the high-SF grating than the mid-SF grating which, in turn, results in a small overall increase in the ‘mid-high difference’ variable, although not at levels of statistical significance (Evans and Stevenson, 2008). Migraine sufferers score similarly to a control population when viewing each grating in turn, however they score significantly higher when considering the mid-high difference variable (Evans and Stevenson, 2008).

Figure 2.1 The Pattern Glare Test (shown smaller than actual test) available from i.O.O. Sales Ltd., London. Reproduced with permission from Professor Arnold Wilkins and Professor Bruce Evans.

Table 2.1 Spatial Frequencies for the Pattern Glare Test (Wilkins and Evans, 2010). Reproduced with permission from Professor Arnold Wilkins and Professor Bruce Evans.

To undertake the Pattern Glare Test, subjects are instructed (Wilkins and Evans, 2010) to view Pattern 1 (low-SF) at their usual reading distance, concentrating on the central square in the pattern for five seconds. They are asked to report if any of the following effects are

noticed: (1) colours, (2) bending of lines, (3) blurring of lines, (4) shimmering or flickering, (5) fading, (6) shadowy shapes (7) any other effects (to be specified). Subjects are also asked to specify if any of these effects are predominantly on the left side, right side, or both sides of the pattern. The process is then repeated for Pattern 2 (mid-SF) and finally for Pattern 3 (high-SF). The symptoms are summed to give an individual Pattern Glare Score for each of the three patterns. The scores for the high-SF grating are subtracted from the mid-SF grating to determine the mid-high difference variable.

2.3 Wilkins Rate of Reading Test

The potential benefit an individual can obtain from using spectral filters may not be obvious until a subject becomes fatigued, taking around ten minutes when reading conventional text (Tyrell *et al*., 1995). The utility of spectral filters can be assessed rapidly and reliably, however, using the Wilkins Rate of Reading Test (Wilkins *et al.*, 1996). The test (see Figure 2.2) is designed to be visually stressful (Wilkins, 1995) and is used to compare an individual's reading performance under one set of conditions and then compared under another, usually following the introduction of a spectral filter which has been optimally selected. The test consists of a paragraph of text comprised of 15 simple words in a random order. These words are 2, 3 and 4-letter words used frequently in English language and are usually familiar to those with a reading age of ~ 7 years. Each of the 10 lines within the paragraph has the same 15 words but in a random order. The test is produced in a Times, 9 point font, designed to accelerate fatigue, thereby demonstrating quickly if a subject is likely to benefit from a spectral filter. Importantly, the test allows the subject to succeed even if they are not especially competent at reading. The randomisation of the words allows an individual to make errors they are often unaware of, therefore, avoiding a sense of failure or despondency. Further, successive words within the sentence cannot be guessed by the preceding word; each word has to be individually read allowing a measure of visual and visuo-perceptual performance without syntactic or semantic constraints. Undertaking the test

requires the subject to read aloud the text as quickly as possible, over the course of 1 minute, with the examiner noting how many words are read within this time, along with a record of any errors made, thus producing two outcome measures. The test is usually performed once with a spectral filter, then without, without again and finally once again with the filter, a so-called ABBA design. Averaging these scores allows the effects of practice and fatigue to largely balance out. Different versions of the test with parallel design are provided to allow for repeated testing. An improvement in reading speed of around 5% with an optimal spectral filter is sensitive and specific at determining those likely to continue using it for a prolonged period (Jeanes *et al.*, 1997).

Figure 2.2 The Wilkins Rate of Reading Test available from i.O.O. Sales Ltd., London. Reproduced with permission from Professor Arnold Wilkins.

2.4 Procedure for determining an optimal spectral filter

An optimal filter can be determined for the individual by a process of successive elimination (Wilkins, 2003). For the present study, spectral filters termed Intuitive Overlays were supplied by i.O.O. Sales Ltd. The Test Pack consists of a Test Page, (see Figure 2.3) designed to cause fatigue and elicit visual perceptual distortions, nine differently coloured filters, and a grey filter.

Figure 2.3 Intuitive Overlays Test Page available from i.O.O. Sales Ltd., London. Reproduced with permission from Professor Arnold Wilkins and Professor Bruce Evans.

The grey filter is often omitted from the assessment as it rarely reduces symptoms (Wilkins, 2003). The filters are arranged in a strict sequence to avoid presenting similar or complimentary colours in succession. Rose is presented first, followed by lime-green, blue, pink, yellow, aqua, purple, orange and mint-green. The first filter is placed over the left-hand side of the Test Page, with the gloss side face down and the subject is asked to decide which side of the page is clearest and most comfortable, the side with the filter or the side without. If the side without the filter is clearest, the next one in the sequence replaces it. If the side with the filter is preferred, the subject is asked to decide if it is better matte side or gloss side uppermost; this preference is then maintained for the remainder of the assessment. Further, this filter is left in place and the next one in the sequence is placed alongside it so that two

different filters butted next to each other now cover the Test Page. The subject is again asked which side is clearest and most comfortable leaving the preferred filter in place each time until all of the filters in the pile are exhausted. If the white page is preferred to all of the filters then the test is concluded. Otherwise the best single filter will have been determined by successive elimination. Some subjects prefer stronger saturation and this can be determined by adding a second filter. The best single filter can be combined with three other filters in succession, with those of neighbouring hue. For example, blue can be combined with a second blue filter, or aqua, or purple. To determine if stronger colours are preferred, the best single filter is placed landscape so that it covers both sides of the Test Page, and the additional filters are added on top over just one side of the Test Page. If a stronger saturation is preferred, the best of the three combinations determines the final optimal filter.

2.5 Circles Search Test

The Circles Search Test (Newman Wright *et al.*, 2007) is a visual search task designed to require serial processing (Allen *et al.*, 2008). The test consists of 10 rows of shapes, each containing 1 circle and 9 ellipses, laser printed on an A4 sheet (see Figure 2.4). On each row, one circle is randomly placed amongst 9 ellipses of varying orientation. The ellipses have a major axis of 12 mm and a minor axis of 10 mm, chosen at random to orientate from the vertical at 0°, 45°, 90° and 135°. The spatial frequency content of the task has peaks at 0.45 CPD and 1.37 CPD, when viewed at 40cm (unpublished data, Wilkins, 2012). Four versions of the test are used with the circles and ellipses placed in different sequences for each version; this allows for repeat testing under different conditions, for example, with and without a spectral filter. Each shape has a number in the centre and the subject is required to identify the target (circle) on each row, as quickly as possible, amongst the distractors (ellipses) by calling out the number in its centre. The examiner records the response time for the task and the error score. Subjects are asked to complete the task, firstly with an optimal

spectral filter, then without a filter, without again, and finally with, using a different version of the test each time.

Figure 2.4 The Circles Search Test. Reproduced with permission from Professor Arnold Wilkins.

2.6 Intuitive Colorimeter Mark 2

The Intuitive Colorimeter (see Figure 2.5) is a device that enables a precise ophthalmic tint to be specified based upon its ability to reduce visual perceptual distortions for an individual (Wilkins, 2002). The device illuminates a Test Plate of text designed to elicit perceptual distortions. The light is produced by fluorescent tubes and passes through a cylindrical filter into a matt white inner box. The filter (see Figure 2.6) has seven different sectors of coloured filters each of which is equidistant from its neighbour and evenly positioned around colour space as dictated to by the International Commission on Illumination (CIE) 1976 uniform chromaticity scale diagram (see Figure 2.7).

The light is reflected and scattered by the inner surfaces of the box allowing it to mix. As the examiner rotates the cylindrical filter, the hue is continuously varied. As the cylinder is moved backwards and forwards, the saturation is varied. The colour of the light can be manipulated using these separate controls for hue, saturation and brightness to determine the setting that provides the best visual comfort for the subject. The optimal coloured light can be matched using combinations of tinted trial ophthalmic lenses to produce a tint specification. The validity of the Intuitive Colorimeter in producing an optimal tint specification for the individual has been established by multiple open and double-masked clinical studies (Machalan *et al*, 1994; Wilkins *et al*, 1994; Wilkins, 1995; Lightstone *et al*, 1999; Wilkins *et al*, 2002; Evans *et al*, 2002).

Figure 2.5 The Intuitive Colorimeter Mark 2 available from Cerium Visual Technologies, Kent. Reproduced with permission from Professor Arnold Wilkins.

Figure 2.6 Cylindrical filter from the Intuitive Colorimeter. Reproduced with permission from Professor Arnold Wilkins.

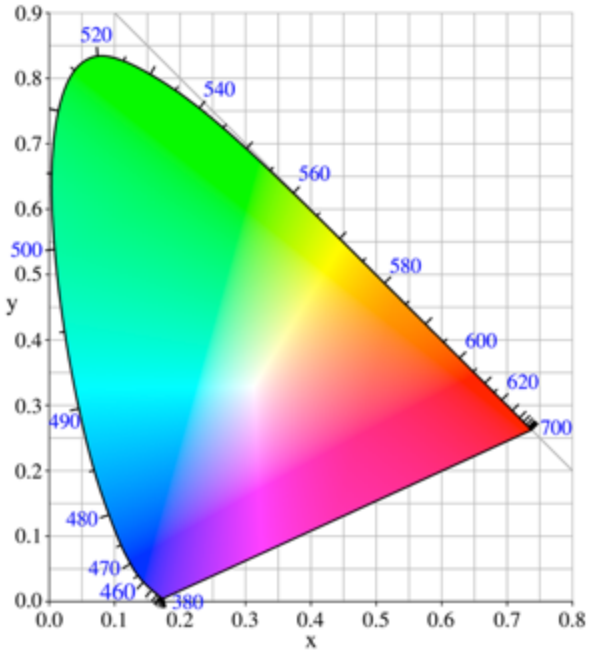

Figure 2.7 CIE chromaticity diagram. Public domain image obtained from Wikimedia Commons.

Figure 2.8 Intuitive Colorimeter Mark 2 Control Panel. Reproduced with permission from Professor Arnold Wilkins.

The instructions for assessment are given in a detailed manual (Wilkins, 2002). The patient sits in front of the main window of the table-top device and views the illuminated Test Plate, whilst the examiner sits on the right side (see Figure 2.8) to operate the controls for hue, saturation and brightness. The subject is asked to describe any perceptual distortions on the Test Plate under white light (i.e. hue and saturation at zero), such as apparent movement, blurring or coloured haloes around the letters. The hue angle is set to zero and the saturation is slowly increased from zero to a setting of approximately 25 before being decreased again to zero. The subject is asked which seemed more comfortable, the coloured light or the white light, with the response recorded on the Fan Chart of the Colorimeter Record Form (see Figure 2.9) annotated with +1 for a small improvement with the colour, +2 for considerable improvement, 0 for no appreciable difference, -1 for slightly worse and -2 for much worse.

Figure 2.9 Colorimeter Record Form. Reproduced with permission from Professor Arnold Wilkins.

The hue angle is now increased to 30 degrees and the process repeated by increasing the saturation to 25 then reducing it to zero and recording the subject's response on the Fan Chart. The process is continued in steps of 30 degrees until the Fan Chart is complete. During this initial assessment the subject may experience significant discomfort with certain hue angles and care should be taken to avoid these settings throughout the remainder of the process. With the Fan Chart complete, the hue angle should be set to the position that offered the subject greatest comfort. The saturation can then be adjusted from zero to the maximum setting of 50 to establish the level that gives the best perception of the Test Plate. The subject is instructed to find the least saturated setting that is comfortable to avoid a specification that results in a tint being too dark. The process can be repeated for other hue angles on the Fan Chart that were identified as improving comfort. The 'good' settings can be compared to each other to establish the overall optimal specification; this can be achieved by successive elimination, asking the subject to choose between Setting 1 and Setting 2, closing their eyes in between presentations. To refine the process, the hue angle can be presented 20 degrees above and below the optimal setting, or even 10 degrees for subjects with good discrimination ability.

The effect of luminance levels can be examined by pulling out the 50% attenuator slide. Ideally, this reduction in brightness will not improve comfort for the subject, thereby avoiding a specification for an overly saturated lens to be produced. The values for the hue and saturation are inputted into a spreadsheet program provided by the manufacturer that gives a specification for the trial lenses required to match the setting. Using a stack of trial lenses, it is possible to match any Colorimeter setting; this can be achieved using two neighbouring dyes in the circle of colours (see Figure 2.10). Each colour has five pairs of lenses except for rose and purple, which have six. The strength of dye doubles between lenses, for example, Trial Lens B is double the strength of Trial Lens A, and half that of Trial Lens C allowing small incremental changes to be achieved.

Figure 2.10 Circle of colours. Reproduced with permission from Professor Arnold Wilkins.

The program will also specify the attenuator setting required to replicate the luminance that will be obtained when made as spectacles for wear under general office lighting. If the program indicates that the 50% attenuator is required to match the tinted lens specification, yet the subject did not prefer the attenuator during the assessment, it should be pointed out that stronger colours require darker lenses. It is worthwhile decreasing the saturation value to a point where the 50% attenuator is no longer indicated by the program to establish if the subject can tolerate a lighter colour. The Test Plate can be replaced by the Wilkins Rate of Reading Test to measure the effect of the optimal tint on reading speed as described in Section 2.3.

The subject can be asked to view the Test Plate under bright white light on setting C through two stacks of trial lenses placed in the binocular lens holder to assess its benefit. The tint can also be tried under different lighting conditions, such as natural daylight and tungsten lighting. It is possible to adjust the tint settings biased for the patient's typical environment by referring to information provided by the spreadsheet program.

3.0 Visual stress symptoms secondary to stroke alleviated with spectral filters and precision tinted ophthalmic lenses: a case report

3.1 Introduction

Visual stress is a condition, discussed in Chapter 1, characterised by symptoms of eyestrain, glare, headaches and visual perceptual distortions when reading text. Spectral filters and precision tinted ophthalmic lenses are proven to be a valid treatment for visual stress (Jeanes *et al.*, 1997; Evans *et al.*, 2002; Wilkins *et al.*, 1994) and it is important that they are determined specifically for the individual (Wilkins *et al.*, 1994). Spectral filters can be optimally selected using the recognised procedure of successive elimination (Wilkins, 2003), whereas precision tinted lens specification can be determined using the Intuitive Colorimeter (Wilkins *et al.*, 1992) described in detail throughout Chapter 2. The Intuitive Colorimeter enables an ophthalmic tint to be chosen according to a patient's subjective assessment of its effects on perception and visual comfort. The impact of these interventions can be reliably measured using the Wilkins Rate of Reading Test (Wilkins *et al.*, 1996), as described in Chapter 2, with an improvement in reading speed of around 5% being predictive of prolonged use of the filter (Jeanes *et al.,* 1997; Wilkins *et al.*, 1996; Wilkins, 2001).

Hitherto, there is little evidence of visual stress following stroke, despite its known association with other neurological conditions, which include migraine (Harle and Evans, 2004; Wilkins *et al.*, 2002; Nulty *et al.*, 1987), photosensitive epilepsy (Wilkins *et al*, 1999), autism (Ludlow *et al.*, 2006), dyslexia (Kriss and Evans, 2005; Singleton and Trotter, 2005; Jeanes *et al.*, 1997; Evans and Joseph, 2002), and multiple sclerosis (Newman Wright *et al.*, 2007). The case presented herein, describes visual stress symptoms, resulting from stroke, subsequently managed with spectral filters and precision tinted ophthalmic lenses. The case

also highlights that the spectral properties of the tint may need modification if the disease course alters.

3.2 Case report

A 36 year old female presented to the author (a UK registered optometrist) complaining of photophobia and blurring in her left visual field since the previous day, along with severe headache on the right parietal side, which had eased somewhat at the time of the eye examination. The clinical findings are summarised in Table 3.1; the main feature being, a congruous left homonymous superior quadrantanopic visual field defect, detected at suprathreshold level using a Humphrey Visual Field Analyser (HFA-II) (see Figure 3.1). Visual field results on file from previous examinations confirmed the defect as being a new finding. The patient was referred urgently to her General Medical Practitioner for further investigation, whereupon, a provisional diagnosis of migraine was given, prior to onward neurological investigation, confirming stroke as the underlying cause.

Refraction	R: -3.50/ -1.75 x 27; L: -4.00 / -2.00 x 152
Visual acuities	R: 6/5 L: 6/5 Binocularly 6/5
Near vision	R: N5 L: N5 Binocularly N5 (at 35 cm)
Ocular motility	Full and smooth in all directions of gaze
Pupil reactions	Normal (near, direct, consensual)
Convergence	Near point: 9 cm
Cover test	Distance: orthophoria; Near: ~ 4-6 Δ exophoria, fast recovery
Intraocular pressures	R: 13 mmHg; L: 13 mmHg (Perkins at 11.30 am)
Ocular health	All findings within normal limits
Visual fields (HFA-II)	C-40 Suprathreshold screening: left homonymous superior quadrantanopia

Table 3.1. Summary of clinical findings for case report.

Figure 3.1 Visual field plots following stroke episodes. Panels A and B were acquired following the first stroke, whilst Panels C and D were following the second stroke.

The patient returned to the optometrist four months later reporting persistent symptoms since her stroke, in particular, discomfort under certain types of lighting, most notably in supermarkets, and to a lesser extent, blur with reading, and specifically that the page felt too bright to view. Examination at this visit showed her refractive error and visual acuities to be unchanged, with full motility, orthophoria at distance and a small exophoria at near with fast recovery, as determined by cover test. The remainder of the ophthalmic examination was also unremarkable, with a stable visual field defect. With symptoms reminiscent of visual stress, an assessment using coloured overlays and the Wilkins Rate of Reading Test was undertaken. An initial symptom questionnaire, completed in line with the supplier's instructions (i.O.O. Sales Ltd., London), showed that when viewing the test page, the patient complained that the letters were blurred, too close together, and most strikingly, the page felt too bright and uncomfortable to view. A measure of her Rate of Reading showed an increase in reading speed from 119 words per minute, to 167 words per minute, when using an optimal yellow spectral filter (Intuitive Overlay supplied by i.O.O. Sales Ltd., London); a change of 40%. From the patient's perspective, the filter dramatically reduced the page brightness, making it comfortable to view. The yellow filter was issued to the patient to use for a month, prior to reassessment. A repeat of the Wilkins Rate of Reading Test, after one month, showed an increase in her Rate of Reading from 125 words per minute, to 165 words per minute; an improvement of 32%. She reported using the yellow spectral filter regularly, with a dramatic improvement in reading comfort, although she was eager to resolve other symptoms, such as discomfort under supermarket lighting. Assessment using the Intuitive Colorimeter (Mark 2) allowed precision tinted lenses to be supplied, providing a solution for more general use. The tint prescribed was orange-yellow (see Figure 3.2), with a light transmission of 50% (CIE chromaticity coordinates: v` = 0.553, u` = 0.239).

The patient reported that the precision tinted lenses successfully managed her symptoms and were worn on a full-time basis. After an interval of 29 months, however, she experienced a further stroke, whereupon her symptoms returned. Ocular examination on this occasion

was consistent with her initial visit, including a stable visual field defect (see Figure 3.1), as measured at suprathreshold level using a Humphrey Visual Field Analyser – II. A repeat of Intuitive Colorimetry assessment showed a change to tint specification (see Figure 3.2), with a yellow-green tint being optimal, having a light transmission of 38% (CIE chromaticity coordinates: v` = 0.537, u` = 0.180). The patient continues to use this second set of precision tinted ophthalmic lenses to date, on a full time basis.

Figure 3.2 Transmission curves for both sets of precision tinted ophthalmic lenses. Panel A illustrates the profile of the tint following the first stroke, whilst Panel B is for the tint prescribed following the second stroke. Reproduced using software available at http://www.essex.ac.uk/psychology/overlays/lens.htm with permission from Professor Arnold Wilkins.

3.3 Discussion

Photochromic lenses have been shown to be of benefit in enhancing reading rate following traumatic brain injury (Jackowski *et al.*, 1996). Photophobia has also been recognised as a symptom that can arise following minor head injuries (Waddell and Gronwall, 1984; Bohnen *et al.*, 1991). Symptom-based evidence, from patient journals, has shown benefits from using precisely tinted spectacle lenses for patients with traumatic brain injury, including stroke (Tosta and Johnson, 2009), although direct measures of visual stress are more predictive of patients likely to derive benefit from an intervention of this type (Hollis and Allen, 2006).

Cortical hyperexcitability has been demonstrated in stroke patients (Braun *et al.*, 2001), and has been hypothesised as a plausible explanation for the existence of visual stress (Huang *et al.*, 2011). Sensitivity to light and motion have also been reported following mild traumatic brain injury, and it has been proposed that neurological disinhibition may be responsible for these findings (Chang *et al.*, 2007).

The present case report suggests that patients can develop visual stress secondary to stroke, possibly arising due to cortical hyperexcitability. The resultant symptoms can be managed effectively with conventional interventions, such as spectral filters and precision tinted ophthalmic lenses. Typically, adults do not require changes to their tint specification for many years (Machalan *et al.*, 1993); however, this case has demonstrated that further modification may be required for stroke patients, if the disease course changes. The outcome from a recent investigation using fMRI may explain these findings; this study demonstrated that precision tinted ophthalmic lenses reduced cortical hyperexcitability in migraine subjects when exposed to visually stressful stimuli (Huang *et al.*, 2011), findings that could not be replicated when the subjects wore grey or control coloured lenses. The

outcome suggests that optimal tints have a therapeutic benefit, of neurological basis, and need to be determined with precision for each individual. In the present case, it could be hypothesised that the original precision tint ceased to be of therapeutic benefit, following changes to cortical activity, as a consequence of the second stroke event. Although the use of spectral filters have proved to be a valuable intervention in this case, the possibility of a co-existing accommodative deficit being partially responsible for the visual difficulties experienced by this subject, cannot be excluded. Nevertheless, it would expected that those with an accommodative anomaly may opt for a lens that preferentially absorbs longer wavelengths of light, rather than the shorter wavelengths absorbed by the filters selected by the subject in this case. Despite this, it would be useful to consider the presence of co-existing visual defects in a stroke cohort for future work.

3.4 Conclusion

The present case report has shown that visual stress symptoms can occur following stroke. Optometrists are well placed to identify and manage these patients with conventional interventions. Additional work, to evaluate pattern related visual stress and the utility of spectral filters in a broader stroke subject group is indicated.

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4.0 Susceptibility to pattern glare following stroke

4.1 Introduction

Pattern glare, described in detail earlier (see Chapter 1), is a term used to describe an adverse response to viewing specific types of visual stimuli, most notably, striped patterns of certain spatial frequencies and contrast level (Wilkins *et al.*, 1984). The condition can cause symptoms of eyestrain headaches and glare, along with undesirable perceptual effects. Pattern glare has known association with a range of neurological conditions including photosensitive epilepsy (Wilkins *et al.*, 1999), migraine (Harle and Evans, 2004; Wilkins *et al.*, 2002; Nulty *et al.*, 1987), dyslexia (Kriss and Evans, 2005; Singleton and Trotter, 2005; Jeanes *et al.*, 1997; Evans and Joseph, 2002), autism (Ludlow *et al.*, 2006), multiple sclerosis (Newman Wright *et al*, 2007), as well as MISViS (Evans *et al.*, 1995; Evans *et al.*, 2002). To date, there is little evidence detailing the existence of pattern glare in other neurological conditions, such as stroke. A recent case report (see Chapter 3) has demonstrated that visual stress symptoms, arising secondary to stroke, can be successfully managed with the use of spectral filters and precision tinted ophthalmic lenses (Beasley and Davies, 2012). Some evidence has emerged from symptom-based investigation, where patients with traumatic brain injuries, including stroke, have demonstrated visual perceptual symptoms, including light-sensitivity, strain, fatigue and reading difficulties that were subsequently reduced with the intervention of optimally determined tinted spectacle lenses (Tosta and Johnson, 2009). Other reports have recognised a susceptibility to photophobia following traumatic brain injury and these individuals have shown improvements in reading ability with the use of photochromic filters (Jackowski *et al.*, 1996). Further evidence recognises that many brain injury patients, including those with stroke, have difficulty with reading, such as skipping lines of text, and difficulty moving to the next row of print, albeit with the suggestion that these problems arise from motor rather than sensory origin (Han *et al.*, 2004), although the impact of visual field defects or visual neglect on reading impairment

should not be overlooked. It has been shown that even following minor head injuries, particularly those involving concussion, subjects demonstrate a lowered tolerance to brightness and sound Bohnen *et al.*, 1991); this is supported by earlier evidence of photophobia and sound sensitivity in patients with closed head injury (Waddell and Gronwall, 1984). Critical flicker frequency thresholds have also been found to be elevated following mild traumatic brain injury, with accompanying symptoms of light and motion sensitivity. It has been proposed that neurological disinhibition, as a result of the brain injury, may cause the subjective hypersensitivity to light and motion in these individuals (Chang *et al.*, 2007).

4.2 Objective

Considering the paucity of literature to date, it would seem logical to determine if there is an association between pattern glare and stroke. Consequently, the purpose of this study is to measure pattern glare susceptibility in stroke subjects as determined by the Pattern Glare Test (see Chapter 2).

4.3 Methods

Twenty stroke participants were recruited along with an equivalent number of healthy age and gender-matched control subjects (see Appendix 4). Suitable candidates for this project were recruited by displaying notices at the research venue; the optometric practice of the author, requesting volunteers to participate in all of the experiments detailed in Chapters 4-8. Several participants were also recruited following contact with the local Stroke Association group. All candidates had been discharged from the care of the hospital department involved in the treatment of their stroke. The stroke participants consisted of 11 females and 9 males with an age range of 38-85 years (mean 66.4 SD 13.43 years). The control participants had an age range of 36-84 years (mean 57.9 SD 13.91 years) consisting of 11 females and 9 males. These subjects were selected for age-matching the groups (unpaired t-test: t = 1.813,

df = 38, P = 0.078). The time since the stroke (or most recent stroke) had a range of 0.83-12 years (mean 4.66 SD 3.31 years). Prior to commencing the research, ethical approval was obtained from Aston University's Audiology/ Optometry Research Ethics Committee (see Appendix 1) with the study designed to follow the tenets of the Declaration of Helsinki. Each subject was given detailed information regarding the nature of the study, both verbally and in written form (see Appendix 2); this allowed informed consent to take place prior to their participation. The participants were required to complete a short questionnaire (see Appendix 3) to ensure that they met the inclusion criteria. This was also necessary to pre-determine if any of the subjects had conditions that could potentially predispose them to pattern glare, e.g. migraine. Crucially, subjects were asked to confirm if they had suffered from any epileptic seizures, as this was the principal exclusion criterion for the study, although during recruitment no subjects. Subjects were also asked to confirm if they were dyslexic, autistic, or suffered from multiple sclerosis, or diagnosed by their General Practitioner as having migraine. The subjects confirmed that they all attended for an eye examination at their specified recall interval. The examiner was not masked from the subjects. All subjects demonstrated that they were able to read N8 sized print at 40 cm with their habitual spectacle correction, prior to undertaking the Pattern Glare Test. From the initial questionnaires, two migraine sufferers were identified within the stroke participants and three migraine sufferers within the control subjects. None of the subjects in either group reported a diagnosis of dyslexia, autism, multiple sclerosis or epilepsy. One stroke participant (Subject 2), had reported using a coloured overlay and latterly, precision tinted lenses, on a regular basis, since having her stroke a few years prior, although these were not used whilst undertaking the Pattern Glare Test.

All subjects were asked to perform the Pattern Glare Test in line with the developer's instructions (Wilkins and Evans, 2010), as described in Chapter 2. In brief, the subjects were asked to view Pattern 1 at 40 cm (low-SF), concentrating on the central square in the pattern for five seconds. They were then asked to report if any of the following effects were noticed:

(1) colours, (2) bending of lines, (3) blurring of lines, (4) shimmering or flickering, (5) fading, (6) shadowy shapes (7) any other effects (to be specified). The subjects were also asked to specify if any of these effects were more noticeable mainly on the left side, right side or both sides of the pattern. The process was then repeated for Pattern 2 (mid-SF) and finally for Pattern 3 (high-SF). The numbers of symptoms reported were then added to give an individual Pattern Glare Score for each of the three patterns. The scores for the high-SF grating were subtracted from the mid-SF grating to determine the mid-high difference variable.

4.4 Statistical Analysis

All data were analysed using the commercially available software (PASW, *v*. 18, IBM, New York, USA). All data were tested for normality and analysed with appropriate tests (Armstrong *et al.*, 2011). A significance level of $\alpha = 0.05$ was used throughout the analysis.

4.5 Results

A summary of the data from the questionnaire and Pattern Glare Test for the stroke and control participants can be seen in Tables 4.1 and 4.2, respectively.

Stroke Subject	Age	Gender	PGS mid-SF	PGS mid-high difference	PGS high-SF
1	83	Female	5	5	0
2	38	Female*	6	2	4
3	64	Female	5	3	2
4	72	Male	1	1	0
5	71	Male	5	3	2
6	52	Male	5	4	1
7	77	Female	3	2	1
8	65	Male	2	2	0
9	62	Male	3	2	1
10	69	Female	0	0	0
11	56	Female**	2	2	0
12	49	Female	3	3	0
13	76	Female	1	1	0
14	43	Male	4	2	2
15	81	Female	1	1	0
16	80	Female	5	4	1
17	74	Female	3	2	1
18	72	Male**	2	2	0
19	59	Male	0	0	0
20	85	Male	2	2	0

Table 4.1 Data from questionnaire and results from Pattern Glare Test for stroke subjects.
* Previous use of precision tint. ** Migraine sufferer.

Statistical analysis of the Pattern Glare Scores (see Table 4.3 and Figure 4.1) showed significantly higher values for the stroke participants *versus* control subjects when viewing the mid-SF pattern (unpaired t-test: $t = 2.457$, $df = 38$, $P = 0.019$); this was also the case when comparing the relative score of the mid-high difference (unpaired t-test: $t = 5.421$, $df = 38$, $P < 0.0001$). When subjects were asked to view the high-SF spatial frequency grating, however, the control subjects yielded a higher Pattern Glare Score than the stroke subjects (Mann-Whitney U test: $P = 0.040$).

Control Subject	Age	Gender	PGS mid-SF	PGS mid-high difference	PGS high-SF
1	45	Female**	1	1	0
2	38	Male	2	0	2
3	63	Male	0	-1	1
4	68	Female	0	0	0
5	70	Female	0	-2	2
6	55	Female	1	-1	2
7	84	Female	2	0	2
8	36	Female**	1	1	0
9	38	Male	2	1	1
10	62	Female**	1	1	0
11	55	Male	0	-1	1
12	60	Male	3	1	2
13	50	Male	3	-2	5
14	68	Female	1	-1	2
15	83	Male	1	1	0
16	61	Male	1	1	0
17	60	Male	4	1	3
18	54	Female	4	0	4
19	40	Female	4	2	2
20	78	Female	2	0	2

Table 4.2 Data from questionnaire and results from Pattern Glare Test for control subjects. ** Migraine sufferer.

Spatial Frequency	Score (mean ± SD)	Score (mean ± SD)
Mid-SF	2.9 ± 1.83	1.65 ± 1.35
Mid-high difference	2.15 ± 1.27	0.10 ± 1.12
High-SF	0.75 ± 1.07	1.55 ± 1.39
	Stroke (n = 20)	Control (n = 20)

Table 4.3 Results from the Pattern Glare Test detailing mean Pattern Glare Scores for stroke and control participants.

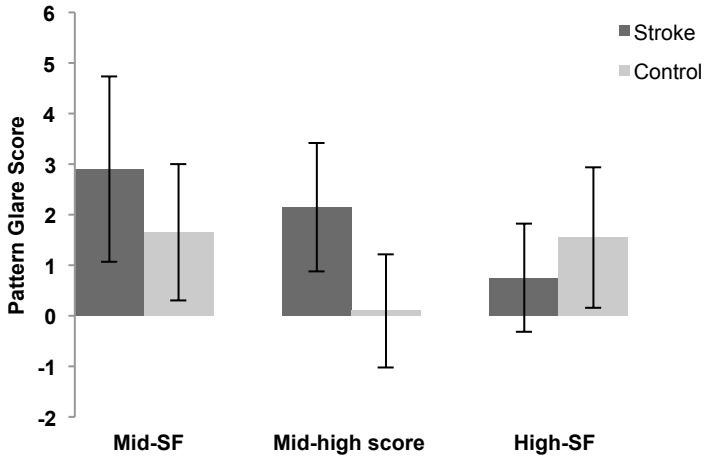

Figure 4.1 Mean Pattern Glare Scores, from the Pattern Glare Test, for stroke and control participants. Elevation of Pattern Glare Scores was found for the stroke subjects when considering the mid-SF grating, and most notably, the mid-high difference variable. Error bars represent ± 1SD.

One of the stroke participants (Subject 2) had reported during the initial questionnaire that she had previously used spectral filters and continued to use precision tinted lenses on an on-going basis. Although these were not worn whilst undertaking the Pattern Glare Test, the prolonged use of filters may have potentially altered performance on a test designed to induce visual stress. It is of interest to highlight, however, that this subject did score highly when viewing the mid-SF pattern (Pattern Glare Score = 6), and moderately so on the relative score of the mid-high difference (Pattern Glare Score = 2). Notwithstanding this, the data were considered again, with this subject omitted from all subsequent analyses. With the removal of this subject, the mean age of the stroke group (mean 67.89 SD 11.97 years) was higher than the control participants (mean 58.40 SD 14.46 years; unpaired t-test: t = 2.227, df = 37, P = 0.032); these data (see Table 4.4 and Figure 4.2), were comparable with earlier measures, demonstrating that the stroke participants score more highly on the mid-SF grating (unpaired t-test: t = 2.197, df = 37, P = 0.034), and the mid-high difference variable (unpaired t-test: t = 5.301, df = 37, P = 0.000), whereas they score lower on the high-SF grating than control subjects (Mann-Whitney U test: P = 0.016).

Spatial Frequency	Score (mean ± SD)	Score (mean ± SD)
Mid-SF	2.74 ± 1.73	1.65 ± 1.35
Mid-high difference	2.16 ± 1.30	0.10 ± 1.12
High-SF	0.58 ± 0.77	1.55 ± 1.39
	Stroke (n = 19)	Control (n = 20)

Table 4.4 Results from the Pattern Glare Test detailing mean Pattern Glare Scores for stroke and control participants, with the exclusion of Subject 2 from the Stroke Group.

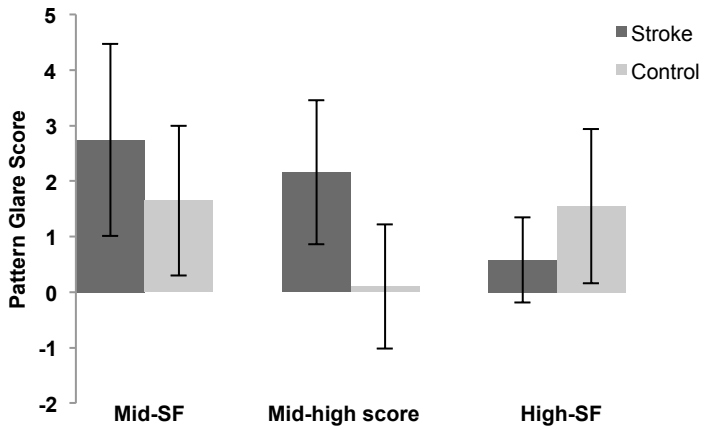

Figure 4.2 Mean Pattern Glare Scores, from the Pattern Glare Test, for stroke and control participants, with the exclusion of Stroke Subject 2. Error bars represent ± 1SD.

The data were also considered for the effect of gender in the stroke group. The males (mean 64.56 SD 12.40 years) in the stroke group were slightly younger than the females (mean 70.90 SD 11.34 years), (unpaired t-test: t = 1.165, df = 17, P = 0.260). The results (See Table 4.5 and Figure 4.3) were not significantly different for the females compared with the males when viewing the mid-SF grating (unpaired t-test: t = -0.163, df = 17, P = 0.872). The females demonstrated a higher mid-high difference variable score than the males but not at levels of significance, (unpaired t-test: t = -0.491, df = 17, P = 0.630). Conversely, the males recorded a higher score when viewing the high-SF pattern (unpaired t-test: t = -0.462, df = 17, P = 0.650).

Spatial Frequency	Score (mean ± SD)	Score (mean ± SD)
Mid-SF	2.66 ± 1.73	2.80 ± 1.81
Mid-high difference	2.00 ± 1.11	2.30 ± 1.49
High-SF	0.66 ± 0.87	0.50 ± 0.71
	Male (n = 9)	Female (n = 10)

Table 4.5 Results from the Pattern Glare Test detailing mean Pattern Glare Scores for gender comparison within the Stroke Group.

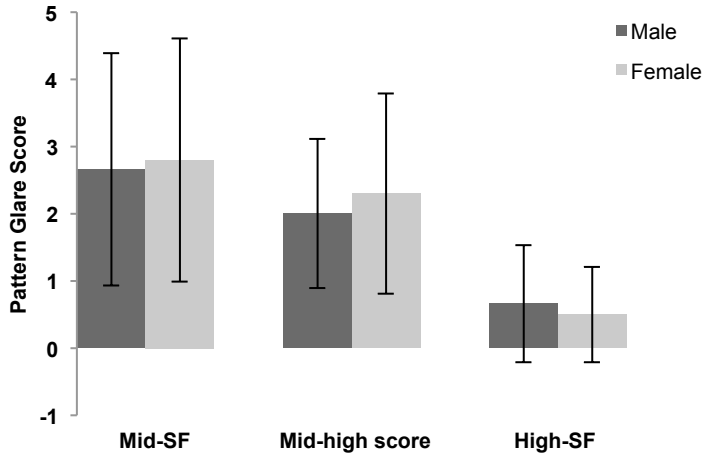

Figure 4.3 Mean Pattern Glare Scores, from the Pattern Glare Test, for male and female stroke participants. Results showed no statistically significant difference between the gender types for any of the measures. Error bars represent ± 1SD.

As pattern glare has a known association with migraine (Harle and Evans, 2004), the data were examined with the respective migraine sufferers in each group removed from the analysis. These groups were found to be age-matched for the stroke group (mean 68.35 SD 12.29 years) and the control group (mean 60.29 SD 14.18 years; unpaired t-test: t = 1.770, df = 32, P = 0.086). The results for this modified data set (see Table 4.6 and Figure 4.4), showed that the stroke subjects exhibited higher Pattern Glare Scores than the control subjects when viewing the mid-SF grating, although not at levels of significance (unpaired t-test: t = 1.888, df = 32, P = 0.068). Results for the relative score of the mid-high difference variable were significantly higher for the stroke subjects (unpaired t-test: t = 5.141, df = 32, P = 0.0000). Consistent with earlier measures, the stroke subjects scored much lower on the

Pattern Glare Test, when viewing the high-SF pattern, compared with the control group (unpaired t-test: t = -3.133, df = 32, P = 0.004).

Spatial Frequency	*Score (mean ± SD)*	*Score (mean ± SD)*
Mid-SF	2.82 ± 1.81	1.76 ± 1.44
Mid-high difference	2.18 ± 1.38	-0.06 ± 1.14
High-SF	0.65 ± 0.79	1.82 ± 1.33
	Stroke (n = 17)	Control (n = 17)

Table 4.6 Results from the Pattern Glare Test detailing mean Pattern Glare Scores for stroke and control participants, with the exclusion of migraine subjects.

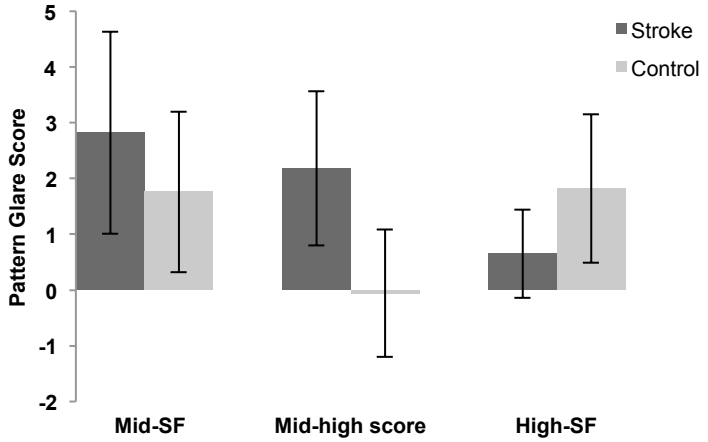

Figure 4.4 Mean Pattern Glare Scores, from the Pattern Glare Test, for stroke and control participants, with the exclusion of migraine subjects. Elevation of Pattern Glare Scores was found for the stroke subjects, when considering the mid-high difference variable. Error bars represent ± 1SD.

4.6 Discussion

The present study has demonstrated that stroke subjects respond with significantly higher Pattern Glare Scores than a control group when undertaking the Pattern Glare Test; this elevation in scores being most notable for the mid-high difference variable, a relative score that allows for normalisation of the subject by taking into account suggestibility. Abnormal pattern glare is considered to be present when a subject delivers a Pattern Glare Score of >3 on the mid-SF grating, or a score of >1 on the mid-high difference variable (Evans and Stevenson, 2008). In fact, 75% of the stroke participants recorded an abnormal degree of pattern glare when considering the mid-high difference measure, compared with just 5%

within the control population. For the stroke participants, the mean score approached the cut-off for abnormality of >3 when viewing the mid-SF grating, but did not exceed it. It was, however, significantly higher than the scores of a control group, at a level of statistical significance. Further suggestion of elevated pattern glare in the stroke group was shown by a decreased measure on the high-SF grating for stroke subjects versus control subjects, at levels of statistical significance. The high-SF measure is usually higher in subjects with a low degree of visual discomfort. These three principal measures were still found to persist even when subjects with potential correlates of pattern glare, namely migraine, were removed from the analyses. It should be noted that the control group were some 10 years younger than the stroke subjects. Established normative values have shown that with advancing age, there is a greater decrease with the high-SF grating than the mid-SF grating which, in turn, results in a small overall increase in the 'mid-high difference' variable, although not at levels of statistical significance (Evans and Stevenson, 2008). In the present study, the groups were, indeed, age-matched when migraine sufferers were removed from the analyses.

Despite a paucity of literature, there is evidence of sensitivity to patterns following traumatic brain injury, including stroke, as determined by analysing self-test responses to a questionnaire designed to recognise sensitivity to glare, light, contrast, bright colours and patterns (Tosta and Johnson, 2009). It has also been shown, however, that this indirect method of determining the existence of pattern related visual stress is not as useful as a direct presentation of a patterned stimulus to the individual concerned (Hollis and Allen, 2006). Whilst an indirect method of analysing pattern glare symptoms serves as a useful indicator, it does not appear to isolate those individuals who are more likely to have their symptoms alleviated by an intervention such as a spectral filter.

Since pattern glare results from cortical hyperexcitability (Huang *et al*, 2011; Wilkins *et al*, 2004), it is perhaps unsurprising that stroke sufferers demonstrate abnormal levels of pattern glare; this is in line with evidence of cortical hyperexcitability following stroke (Braun *et al*,

2001). Lesion-induced cortical hyperexcitability has also been demonstrated following short transient ischaemic attacks (Koerner and Meinck, 2004), suggesting that symptoms of pattern glare could potentially exist in those experiencing milder episodes of so-called 'mini-stroke' in the absence of more obvious functional impairment, and represents an opportunity for further work in this area. It would be valuable for future studies to consider the association of pattern glare, with co-existing visual deficits, such as visual field defects and binocular vision anomalies, in stroke individuals. In addition, it would interesting to explore the location of stroke event in relation to levels of pattern glare.

The present study was limited by a modest sample size, and further work with a larger subject group should be considered, to examine pattern glare trends in a broader stroke cohort. Furthermore, it should be recognised that some of the sample were recruited from an optometric practice, and given that these subjects may have a higher predisposition to visual symptoms associated with their stroke, this could overestimate the levels of visual stress in stroke patients. An opportunity for further work would be to consider the effect of time interval, and number of stroke events, on the outcome measures. In the present study, the majority of the subjects had suffered a stroke several years prior to the data collection.

4.7 Conclusion

It appears that pattern glare is associated with stroke, indicated by an abnormal Pattern Glare Score on the Pattern Glare Test, most notably when considering the mid-high difference variable. This remains the case when those with other co-morbidities of pattern glare, such as migraine, or previously identified visual stress, are removed from the data set. The Pattern Glare Test is commercially available, inexpensive and can be undertaken rapidly as an adjunct to a routine optometric examination. Patients with increased levels of pattern glare can benefit from using spectral filters (Hollis and Allen, 2006; Allen *et al*, 2010; Evans

et al, 1996; Evans and Stevenson, 2008), therefore, the utility of this intervention within a stroke cohort should be considered.

Supporting publication: Beasley IG & Davies LN (2012) Susceptibility to pattern glare following stroke. J Neurol 259:1832-1839

5.0 The immediate effect of spectral filters on reading ability following stroke

5.1 Introduction

Many attributes necessary to elicit visual stress symptoms are present within standard text documents (Wilkins and Nimmo-Smith, 1984; Wilkins and Nimmo-Smith, 1987). The high contrast pattern generated by individual rows of words, separated by the successive spacing between rows, is capable of generating visual stress in susceptible individuals (Wilkins *et al.*, 2004). Viewing stimuli of this type can lead to an adverse response, termed 'patterned glare' (Wilkins and Nimmo-Smith, 1984) or 'pattern glare' (Evans and Drasdo, 1991). The preceding study (see Chapter 4) has demonstrated susceptibility to pattern glare in stroke patients (Beasley and Davies, 2012). Others have reported susceptibility to photophobia following traumatic brain injury, alleviated by using photochromic filters (Jackowski *et al.*, 1996), with even minor head injuries being shown to cause heightened sensitivity to light and sound (Bohnen *et al.*, 1991; Waddell and Gronwall, 1984). There is growing evidence to suggest that cortical hyperexcitability is responsible for the symptoms of visual stress (Wilkins *et al.*, 1984; Huang *et al.*, 2011; Wilkins and Neary, 1991; Harle and Evans, 2004; Harle *et al.*, 2006). Sensitivity to light and motion have been demonstrated following mild traumatic brain injury, and it has been proposed that neurological disinhibition, as a result of the injury, may be responsible for these findings (Chang *et al.*, 2007). Hyperexcitability in the visual cortex has also been shown in patients following stroke (Braun *et al.*, 2001). The symptoms of visual stress can frequently be reduced with a spectral filter, optimally selected for the individual (Jeanes *et al.*, 1997; Evans *et al.*, 2002; Wilkins *et al.*, 1994). Symptom-based evidence has shown benefits from using precisely tinted spectacle lenses for patients with traumatic brain injury, including stroke (Tosta and Johnson, 2009), although direct measures of visual stress are more predictive of patients likely to derive benefit from an intervention of this type (Hollis and Allen, 2006). The potential benefit of spectral filters can be assessed reliably, using the Wilkins Rate of Reading Test (Wilkins *et al.*, 1996).

5.2 Objective

With evidence of elevated levels of pattern glare following stroke (see Chapter 4; Beasley and Davies, 2012) and a recent case reporting successful management of visual stress symptoms, following stroke using spectral filters (see Chapter 3; Beasley and Davies, 2012), it would be appropriate to consider the effect of spectral filters on reading ability in this subject group. Consequently, the objective of the present study is to measure the impact of optimal spectral filters on reading speed and accuracy as determined by the Wilkins Rate of Reading Test, using methods outlined in Chapter 2.

5.3 Methods

After a one-week break (see Appendix 4), the stroke and control subjects recruited for the preceding study (see Chapter 4) undertook the tasks in the present study, concurrently with those tasks described in Chapter 7. The examiner was not masked from the subjects. All subjects were asked to perform the Wilkins Rate of Reading Test, in line with the developer's instructions (see Chapter 2), and using the smallest typeface version supplied. Prior to this, an optimal spectral filter was determined for each individual, by the recognised procedure of successive elimination, as described in Chapter 2. The spectral properties of these filters (Intuitive Overlays supplied by i.O.O Sales Ltd.) were discussed in Chapter 1. The grey filter was omitted from the assessment as it is rarely found to be of benefit (Wilkins, 2003).

5.4 Statistical Analysis

All data were tested for normality and analysed with appropriate tests, using the commercially available software, PASW, *v*. 18, IBM, New York, U.S.A. (Armstrong *et al.*, 2011; Armstrong *et al.*, 2002). A two-factor mixed ANOVA design was used, incorporating one between-subject factor: stroke or control participant, and one within-subject factor: filter

present or absent. Outcome measures were the rate of reading (number of words per minute read correctly) both with and without a filter, along with the corresponding error score. A significance level of $\alpha = 0.05$ was used throughout the analysis.

5.5 Results

A summary of the data from the questionnaire and the Wilkins Rate of Reading Test for the stroke and control participants can be seen in Tables 5.1, 5.2 and 5.3 and Figures 5.1 and 5.2.

Stroke Subject	Age	Gender	Optimum spectral filter	Words per min. Without overlay	Words per min. With overlay	Words per min. Change (%)	Error score Without overlay	Error score With overlay
1	83	Female	Yellow	90.0	105.0	16.7	2.0	2.0
2	38	Female*	Mint green	119.0	169.0	42.0	0.0	0.0
3	64	Female	Pink	157.0	168.5	7.3	3.5	3.0
4	72	Male	Orange	61.0	76.0	24.6	5.5	2.0
5	71	Male	Mint green	114.0	120.0	5.3	2.5	2.0
6	52	Male	Aqua	26.5	28.5	7.6	0.5	0.0
7	77	Female	Yellow	127.0	127.0	0.0	5.5	2.5
8	65	Male	Blue	100.0	103.0	3.0	1.0	0.5
9	62	Male	Yellow	112.5	140.5	24.9	3.5	4.0
10	69	Female	Purple	128.5	127.0	-1.2	1.5	0.5
11	56	Female**	Lime green	111.5	110.0	-1.4	1.0	0.5
12	49	Female	Purple	97.0	103.5	6.7	3.0	0.0
13	76	Female	Mint green	79.0	84.5	7.0	7.5	4.0
14	43	Male	Aqua	101.5	110.0	8.4	4.0	2.0
15	81	Female	Aqua	115.5	133.0	15.2	5.5	2.0
16	80	Female	Purple	93.5	95.5	2.1	1.0	0.0
17	74	Female	Yellow	79.5	85.5	7.6	0.5	1.0
18	72	Male**	Lime green	69.0	72.5	5.1	3.0	1.0
19	59	Male	Purple	161.5	167.0	3.4	2.5	0.0
20	85	Male	Pink	141.0	139.0	-1.4	6.0	2.5

Table 5.1 Data from questionnaire and results from the Wilkins Rate of Reading Test for stroke subjects.
* Previous use of precision tint. ** Migraine sufferer.

Control Subject	Age	Gender	Optimum spectral filter	Words per min. Without overlay	Words per min. With overlay	Words per min. Change (%)	Error score Without overlay	Error score With overlay
1	45	Female**	Lime green	168.0	167.0	-0.6	0.0	0.0
2	38	Male	Blue	177.5	171.5	-3.4	0.5	0.5
3	63	Male	Blue	136.0	131.0	-3.7	1.0	0.5
4	68	Female	Aqua	136.0	135.5	-0.4	0.5	0.5
5	70	Female	Blue	144.0	145.5	1.0	1.5	2.5
6	55	Female	Rose	157.0	143.0	-8.9	0.0	1.0
7	84	Female	Yellow	110.5	107.5	-2.7	6.0	3.0
8	36	Female**	Blue	167.0	167.0	0.0	0.5	0.5
9	38	Male	Blue	196.0	180.0	-8.2	1.5	0.5
10	62	Female**	Rose	156.0	181.0	16.0	1.5	0.5
11	55	Male	Orange	134.0	131.0	-2.2	0.0	0.0
12	60	Male	Lime green	135.0	142.0	5.2	0.5	1.0
13	50	Male	Orange	150.5	165.5	10.0	1.5	1.0
14	68	Female	Blue	152.5	167.0	9.5	0.5	0.0
15	83	Male	Rose	170.0	168.5	-0.9	2.0	1.5
16	61	Male	Orange	190.0	182.0	-4.2	0.5	0.5
17	60	Male	Pink/ Rose	125.5	123.0	-2.0	1.5	1.0
18	54	Female	Yellow	174.5	167.0	-4.3	0.0	1.0
19	40	Female	Mint green	122.5	126.0	2.9	0.0	0.0
20	78	Female	Blue	173.0	171.5	-0.9	0.5	0.5

Table 5.2 Data from questionnaire and results from the Wilkins Rate of Reading Test for control subjects.
** Migraine sufferer.

In the preceding study, detailed in Chapter 4 (Beasley and Davies, 2012), one of the stroke participants (Subject 2), had reported using spectral filters and continued to use precision tinted ophthalmic lenses on an on-going basis. As this subject had previously undertaken the Wilkins Rate of Reading Test, and had prolonged spectral filter use, the data were considered with her results omitted from all analyses. With the removal of this subject, the mean age of the stroke group (mean 67.89 SD 11.97 years) was higher than the control participants (mean 58.40 SD 14.46 years), (unpaired t-test: $t = 2.227$, $df = 37$, $P = 0.032$).

Wilkins Rate of Reading Test	Stroke (n = 19) Mean ± SD	Control (n = 20) Mean ± SD
Words per min. without overlay	104 ± 33	154 ± 23
Words per min. with overlay	110 ± 34	154 ± 22
Error score without overlay	3.0 ± 2.1	1.0 ± 1.3
Error score with overlay	1.6 ± 1.3	0.8 ± 0.8

Table 5.3 Results from the Wilkins Rate of Reading Test for stroke and control subjects.

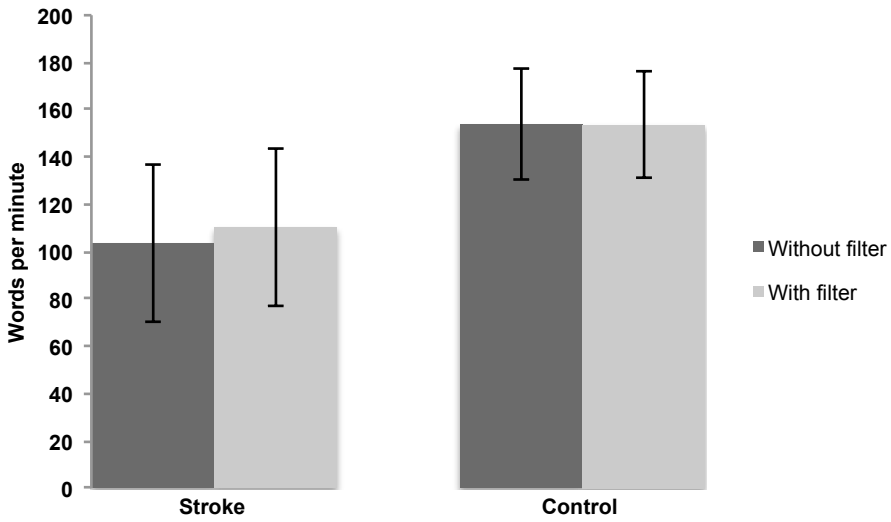

Figure 5.1 Results from the Wilkins Rate of Reading Test for stroke and control subjects. The spectral filter increased the number of words read for the stroke subjects but not the control subjects. Error bars represent ± 1SD.

The analysis for the main effects showed that stroke subjects were unable to read as quickly as the controls ($F_{(1, 37)}$ = 27.079, P = 0.000). The use of filter was found to have a impact on the number of words read per minute ($F_{(1, 37)}$ = 5.715, P = 0.022). An interaction between factors demonstrated an increase in reading speed with the use of a spectral filter for the stroke participants, something not replicated within the control group ($F_{(1, 37)}$ = 6.236, P = 0.017).

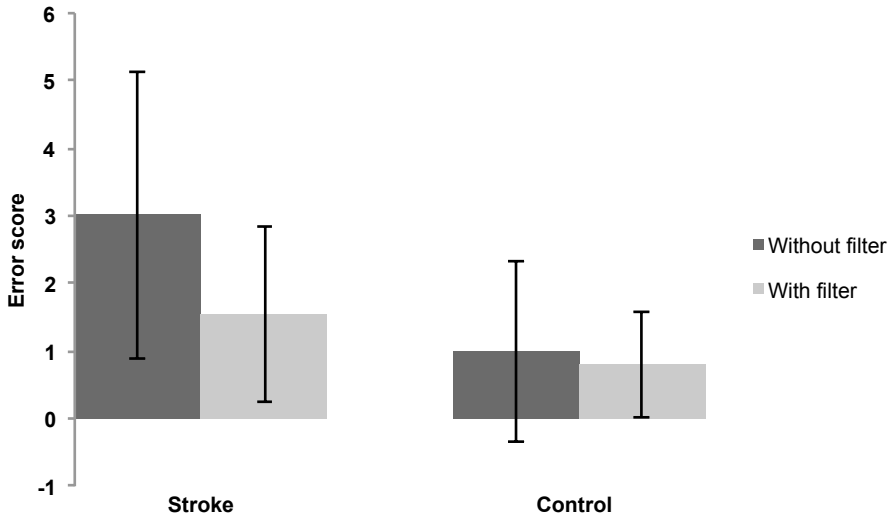

Figure 5.2 Results for error scores from the Wilkins Rate of Reading Test for stroke and control subjects. The use of the spectral filter had a significant impact in reducing errors for the stroke group. Error bars represent ± 1SD.

Analysis showed a difference in error scores between subjects ($F_{(1, 37)} = 10.493$, $P = 0.003$), as well as data with and without a filter ($F_{(1, 37)} = 20.023$, $P = 0.000$). An interaction between factors showed a reduction in error scores when using a spectral filter for stroke subjects only ($F_{(1, 37)} = 11.596$, $P = 0.002$).

Comparison of males and females were also considered for the rate of reading (see Table 5.4 and Figure 5.3) and error scores (see Table 5.4 and Figure 5.4).

Wilkins Rate of Reading Test	Male (n = 9) Mean ± SD	Female (n = 10) Mean ± SD
Words per min. without overlay	99 ± 41	108 ± 25
Words per min. with overlay	106 ± 42	114 ± 26
Error score without overlay	3.2 ± 1.8	2.9 ± 2.5
Error score with overlay	1.6 ± 1.3	1.6 ± 1.4

Table 5.4 Results from the Wilkins Rate of Reading Test showing gender comparison for stroke subjects.

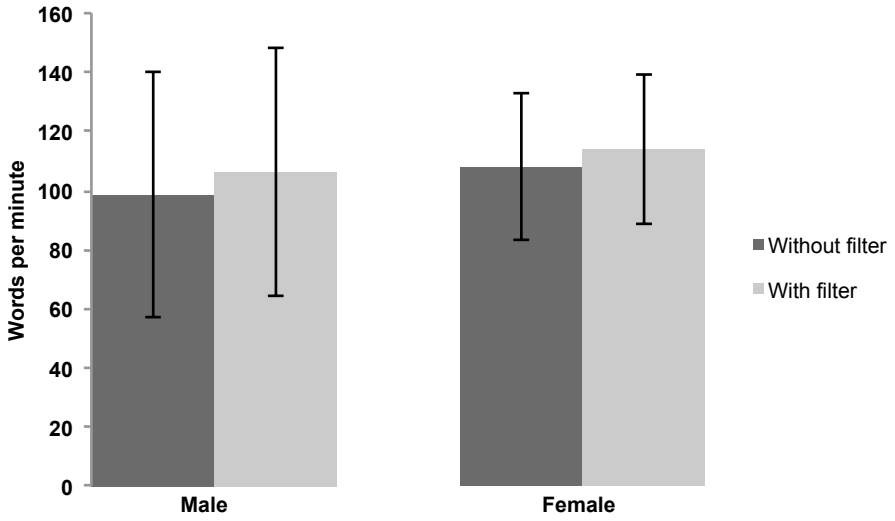

Figure 5.3 Results from the Wilkins Rate of Reading Test showing gender comparison for stroke subjects. Results for males and female stroke subjects were not significantly different with both groups showing benefit from the use of a spectral filter when measuring reading speed. Error bars represent ± 1SD.

Results showed that the filter improved reading speed in both groups ($F_{(1, 17)} = 14.674$, $P = 0.001$), with no difference between the males and females ($F_{(1, 17)} = 0.298$, $P = 0.592$), and no significant interaction between the two factors ($F_{(1, 17)} = 0.202$, $P = 0.659$).

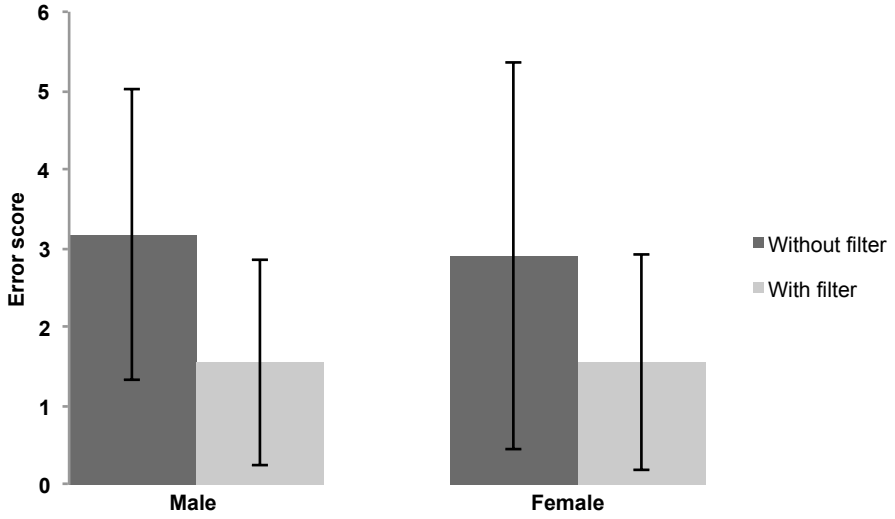

Figure 5.4 Results for error scores from the Wilkins Rate of Reading Test showing gender comparison for stroke subjects. The use of a spectral filter reduced error scores for the males and females. Error bars represent ± 1SD.

The results showed that the filter reduced errors for both males and females, ($F_{(1, 17)}$ = 19.938, P = 0.000), with no difference between gender performance ($F_{(1, 17)}$ = 0.32, P = 0.861) and no interaction between factors ($F_{(1, 17)}$ = 0.155, P = 0.699).

As visual stress has known association with migraine (Harle and Evans, 2004), the data were considered again with the respective migraine sufferers in each group removed from the analyses; these groups were found to be age-matched for the stroke subjects (mean 68.35 SD 12.29 years) and the control group (mean 60.29 SD 14.18 years), (unpaired t-test: t = 1.770, df = 32, P = 0.086).

The results showed (see Table 5.5 and Figure 5.5) a difference between the participants reading speed ($F_{(1, 32)}$ = 18.084, P = 0.000), with the filter having an impact on the number of words correctly read by the subjects ($F_{(1, 32)}$ = 4.640, P = 0.039); this being most noteworthy for the stroke subjects who demonstrated a significant improvement in their rate of reading whilst using an optimum spectral filter, whereas the control group performed better without the filter ($F_{(1, 32)}$ = 10.891, P = 0.002).

Wilkins Rate of Reading Test	Stroke (n = 17) Mean ± SD	Control (n = 17) Mean ± SD
Words per min. without overlay	105 ± 34	152 ± 25
Words per min. with overlay	113 ± 34	150 ± 23
Error score without overlay	3.2 ± 2.2	1.1 ± 1.4
Error score with overlay	1.7 ± 1.3	0.9 ± 0.8

Table 5.5 Results from the Wilkins Rate of Reading Test for stroke and control groups with the exclusion of migraine subjects.

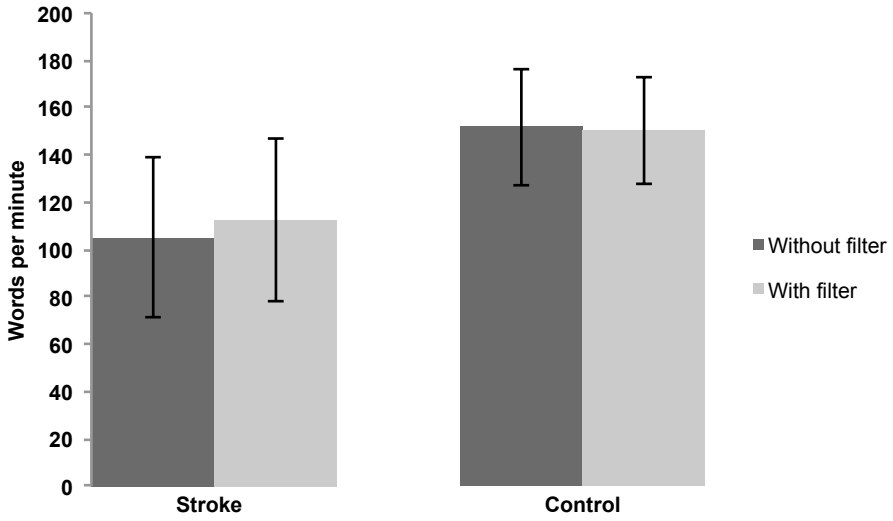

Figure 5.5 Results from the Wilkins Rate of Reading Test for stroke and control groups, with the exclusion of migraine subjects. The spectral filter increased the number of words read for the stroke subjects but not the control subjects. Error bars represent ± 1SD.

Stroke subjects produced more error scores than the control group (see Table 5.5 and Figure 5.6) ($F_{(1, 32)} = 49.264$, $P = 0.006$), with the filter significantly reducing these errors ($F_{(1, 32)} = 15.772$, $P = 0.000$), for the stroke subjects only ($F_{(1, 32)} = 9.830$, $P = 0.004$).

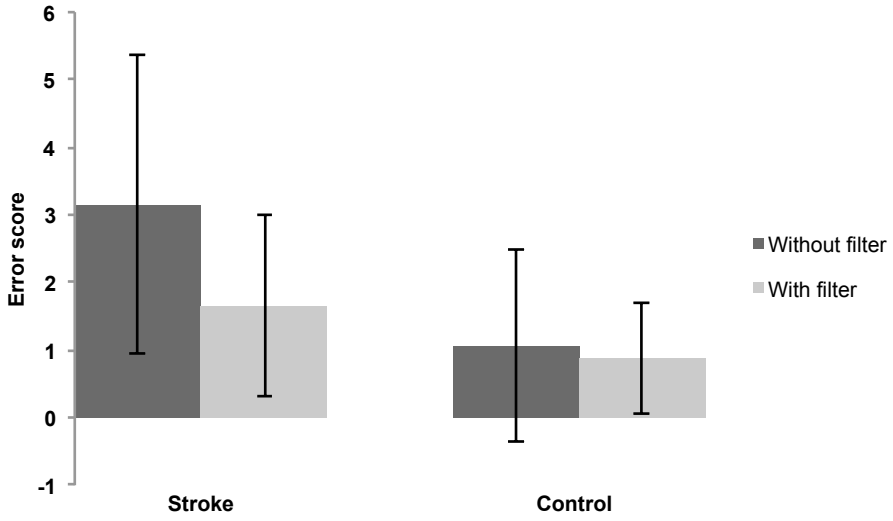

Figure 5.6 Results for error scores from the Wilkins Rate of Reading Test for stroke and control subjects. The use of the spectral filter had a significant impact in reducing errors for the stroke group. Error bars represent ± 1SD.

5.6 Discussion

The present study has shown that the immediate use of an optimal spectral filter can improve reading speed and accuracy for a stroke cohort. For the rate of reading measure, an increase in reading speed of around 5% with the use of a spectral filter has been shown to be predictive of individuals continuing to use this intervention on a regular and prolonged basis (Jeanes *et al.*, 1997), although others have suggested a criterion of >10% as being more appropriate (Kriss and Evans, 2005). Normative data reports show that 22% of school children read >5% faster with a spectral filter (Wilkins *et al.*, 2001), and 38% within a university student sample (Evans and Joseph, 2002). In the present study, the average increase in reading speed was ~6%, with 63% of the stroke participants reading >5% faster with an overlay, compared with 20% of controls. Furthermore, reading errors almost halved with the filter for stroke subjects *versus* ~20% reduction within the control group. When subjects with correlates of visual stress, namely migraine, were removed from the data set, these findings persisted, with stroke subjects demonstrating ~8% increase in reading speed and comparable reduction in error scores with the use of a filter.

Cortical hyperexcitability is the most plausible explanation for the symptoms generated by visual stress (Huang *et al.*, 2011), and can occur secondary to stroke (Braun *et al.*, 2001) as well as following short transient ischaemic attacks (Koerner and Meinck, 2004). Considering the recognised susceptibility to pattern glare, it is perhaps not surprising that spectral filters can reduce visual perceptual deficits in stroke individuals. It would be worthwhile in the future to consider the effects of time interval since the stroke event, as well as any association with co-existing visual deficits in these patients, such as visual field defects, and binocular vision anomalies.

The sample size in the current study was limited, and further work with a larger subject group should be undertaken, to allow the benefits of spectral filters to be considered in a broader

stroke population. It should also be noted that as some of the sample were recruited from an optometric practice, levels of visual stress in stroke patients may be exaggerated, given that these subjects may have a higher predisposition to visual symptoms associated with their stroke. Pattern glare sensitivity to mid spatial frequencies has been shown to decrease with advancing age (Evans and Stevenson, 2008). Although the control group were almost 10 years younger than the stroke subjects, the analyses considered without the migraine subjects, were indeed, age-matched groups.

5.7 Conclusion

The present study has shown for the first time that the immediate use of an optimal spectral filter can improve reading speed and accuracy in stroke patients, as determined by a direct method of assessment. Further work should consider the benefits of prolonged spectral filter use, compared with a placebo measure.

6.0 The effect of prolonged spectral filter use on reading ability following stroke

6.1 Introduction

The experiment in Chapter 5 has demonstrated that optimal spectral filters can improve reading speed and accuracy in a stroke cohort. It would be prudent to test the hypothesis further by considering the effect of prolonged use of spectral filters compared with a placebo measure.

6.2 Objective

The purpose of this experiment is to compare the prolonged effect of optimal spectral filters *versus* a neutral filter on reading speed and accuracy as determined by the Wilkins Rate of Reading Test. A cross over experimental design will be used to examine these effects in a stroke cohort and an age- and gender-matched control group.

6.3 Methods

After a two-week break (see Appendix 4), the stroke and control subjects recruited for the preceding study (see Chapter 5) undertook the tasks in the present study, concurrently with those tasks described in Chapter 8. The cohort had undertaken the Wilkins Rate of Reading Test with and without an optimally selected spectral filter in the preceding study, as described in Chapter 5. The examiner was not masked from the subjects. The cross over design of the present study required each subject to attend for two sessions. Participants were randomly allocated to one of two groups, nominally called Groups 1 and 2 respectively; the subjects were unaware which group they were allocated to. One participant in Stroke Group 1 had reported using a spectral filter and latterly, precision tinted lenses, on a regular basis, since having her stroke a few years prior and her data were excluded from the

analyses. Stroke Group 1 (n = 9) had an age range of 52-83 years (mean 68.33 SD 9.00) and was matched (unpaired t-test: t = 0.147, dF = 17, P = 0.833) to Stroke Group 2 (n = 10), 43-85 years (mean 67.50 SD 14.63). The time interval since their stroke (or most recent stroke) had a range of 0.83-11 years (mean 4.19 SD 3.64 years) for Stroke Group 1 and 1.5-12 years (mean 5.45 SD 2.99 years) for Stroke Group 2; these intervals were not significantly different (unpaired t-test: t = 0.832, dF = 17, P = 0.417). From the initial questionnaires, two migraine sufferers were identified within Stroke Group 2. Control Group 1 (n = 10) had an age-range of 36-84 years (mean 55.90 SD 16.26) and was matched to Control Group 2 (n = 10) (unpaired t-test: t = 0.764, df = 18, 0.454), with an age-range of 40-83 years (mean 60.90 SD 12.78). Three migraine sufferers were identified within Control Group 1.

Subjects were given a one week interval between the previous and the present study at which point Group 1 were issued with their optimal spectral filter, whereas Group 2 were issued with a grey filter with a comparable photopic reflectance; this neutral filter is rarely found to be of benefit and was, therefore, intended as a placebo measure (Wilkins, 2003), the validity of which is discussed in Chapter 9. The subjects were asked to use their allocated filter when reading over a two-week period before returning to undertake the Wilkins Rate of Reading Test for the first time in the present study. For this session, the test was undertaken with their allocated filter, then without, without again, and finally with, using different versions of the text each time. At the end of the first session, subjects returned their allocated filter, prior to a two-week break, at which point the groups were crossed over; Group 1 were issued with a grey filter and Group 2 were issued with their optimal filter to use for a two-week period before returning to repeat the Wilkins Rate of Reading Test in the same manner as the first session, using their newly assigned filters.

At the end of the study, subjects were asked to record if they felt either filter was of benefit and to stipulate their preference if this were the case.

6.4 Statistical Analysis

All data were tested for normality and analysed with appropriate tests, using the commercially available software, PASW, *v*. 18, IBM, New York, U.S.A. (Armstrong *et al.*, 2011; Armstrong *et al.*, 2002). A three-factor mixed ANOVA design was used, incorporating two between-subject factors: (1) stroke or control participant; (2) optimal filter group or grey filter group; and one within-subject factor: filter present or absent (Armstrong *et al.*, 2011; Armstrong *et al.*, 2002). Outcome measures were the Rate of Reading (number of words per minute read correctly) both with and without a filter, along with the corresponding error score. A significance level of $\alpha = 0.05$ was used throughout the analysis.

6.5 Results

6.5.1 Sub-group comparison

In the preceding study (see Chapter 5), Stroke Groups 1 and 2 were both found to read faster with a spectral filter ($F_{(1, 17)} = 15.643$, $P = 0.001$) with no significant difference between subjects ($F_{(1, 17)} = 0.006$, $P = 0.937$). For error scores, both Stroke Group 1 and 2 showed significant benefit from using a spectral filter ($F_{(1, 17)} = 21.230$, $P = 0.000$), with no difference between groups ($F_{(1, 17)} = 0.12$, $P = 0.915$).

The rate of reading results from the preceding study showed no significant difference for Control Groups 1 and 2 ($F_{(1, 18)} = 0.001$, $P = 0.977$), with no benefit from using an optimal filter in either group ($F_{(1, 18)} = 0.005$, $P = 0.946$); this was also the case with error scores for both groups ($F_{(1, 18)} = 1.003$, $P = 0.330$) with neither showing benefit from using a spectral filter ($F_{(1, 18)} = 1.011$, $P = 0.328$).

6.5.2 Session 1

Stroke Group 1 and Control Group 1 were allocated their optimal spectral filter to use for two weeks, prior to undertaking the Wilkins Rate of Reading Test; these groups were found to be age-matched (unpaired t-test: t = 2.028, df = 17, P = 0.06).

Stroke Group 2 and Control Group 2 were allocated a neutral, grey filter to use for two weeks, prior to undertaking the Wilkins Rate of Reading Test; these groups were found to be age-matched (unpaired t-test: t = 1.074, df = 18, P = 0.297).

Detailed data for the Wilkins Rate of Reading Test in Session 1 for Stroke Group 1, Stroke Group 2 and Control Group 1 and Control Group 2 can be seen in Tables 6.1, 6.2, 6.3 and 6.4, respectively.

Stroke Subject	Age	Gender	Filter type	Words per min. Without overlay	Words per min. With overlay	Words per min. Change (%)	Error score Without overlay	Error score With overlay
1	83	Female	Yellow	98.0	131.0	33.7	3.0	3.0
3	64	Female	Pink	167.0	188.0	12.6	2.5	2.0
4	72	Male	Orange	62.0	73.5	18.6	4.0	2.5
5	71	Male	Mint green	117.5	124.0	5.5	2.0	0.5
6	52	Male	Aqua	22.5	26.5	17.8	0.0	0.0
7	77	Female	Yellow	133.0	132.0	-0.8	5.0	2.0
8	65	Male	Blue	107.0	117.0	9.4	1.5	0.0
9	62	Male	Yellow	128.5	138.0	7.4	6.0	1.5
10	69	Female	Purple	139.0	135.0	-2.9	1.5	1.0

Table 6.1 Session 1 results from the Wilkins Rate of Reading Test for Stroke Group 1.

Stroke Subject	Age	Gender	Filter type	Words per min. Without overlay	Words per min. With overlay	Words per min. Change (%)	Error score Without overlay	Error score With overlay
11	56	Female*	Grey	108.5	105.5	-2.8	0.0	0.0
12	49	Female	Grey	110.5	99.5	-10.0	0.5	0.0
13	76	Female	Grey	93.0	93.5	0.5	4.5	5.0
14	43	Male	Grey	103.0	97.5	-5.3	2.0	2.0
15	81	Female	Grey	134.0	135.0	0.8	0.0	0.0
16	80	Female	Grey	114.5	104.5	-8.7	0.0	0.0
17	74	Female	Grey	95.0	94.0	-1.1	1.0	1.5
18	72	Male*	Grey	73.5	73.0	-0.7	4.0	4.5
19	59	Male	Grey	138.5	139.0	0.4	2.0	2.0
20	85	Male	Grey	133.5	130.5	-2.3	1.5	1.0

Table 6.2 Session 1 results from the Wilkins Rate of Reading Test for Stroke Group 2.
* Migraine sufferer.

Control Subject	Age	Gender	Filter type	Words per min. Without overlay	Words per min. With overlay	Words per min. Change (%)	Error score Without overlay	Error score With overlay
1	45	Female*	Lime green	189.0	189.0	0.0	0.5	1.5
2	38	Male	Blue	182.0	178.5	-1.9	0.0	0.0
3	63	Male	Blue	141.5	135.5	-4.2	2.0	3.0
4	68	Female	Aqua	141.0	131.0	-7.1	0.0	0.0
5	70	Female	Blue	133.5	152.5	14.2	0.0	1.5
6	55	Female	Rose	149.5	146.0	-2.3	0.0	0.0
7	84	Female	Yellow	114.5	116.5	1.8	3.5	3.0
8	36	Female*	Blue	188.0	182.0	-3.2	0.0	1.5
9	38	Male	Blue	171.0	168.5	-1.5	0.5	1.0
10	62	Female*	Rose	176.0	182.0	3.4	1.5	1.5

Table 6.3 Session 1 results from the Wilkins Rate of Reading Test for Control Group 1.
* Migraine sufferer.

Control Subject	Age	Gender	Filter type	Words per min. Without overlay	Words per min. With overlay	Words per min. Change (%)	Error score Without overlay	Error score With overlay
11	55	Male	Grey	120.0	122.5	2.1	0.0	0.0
12	60	Male	Grey	133.5	142.5	6.7	0.0	2.0
13	50	Male	Grey	135.5	138.0	1.9	1.5	0.5
14	68	Female	Grey	148.0	161.0	8.8	1.0	2.0
15	83	Male	Grey	176.0	176.0	0.0	1.0	2.0
16	61	Male	Grey	209.5	201.0	-4.1	0.0	0.0
17	60	Male	Grey	136.5	137.0	0.4	1.0	0.0
18	54	Female	Grey	192.5	207.5	7.8	0.0	0.0
19	40	Female	Grey	123.5	121.5	-1.6	1.0	1.0
20	78	Female	Grey	175.5	169.0	-3.7	0.0	0.5

Table 6.4 Session 1 results from the Wilkins Rate of Reading Test for Control Group 2.

A summary of data for Stroke Group 1 and Control Group 1 can be seen in Figures 6.1, 6.2 and Table 6.5.

Wilkins Rate of Reading Test	Stroke Group 1 (n = 9) Mean ± SD	Control Group 1 (n = 10) Mean ± SD
Words per min. without overlay	108 ± 44	159 ± 26
Words per min. with overlay	118 ± 45	158 ± 25
Error score without overlay	2.8 ± 1.9	0.8 ± 1.2
Error score with overlay	1.4 ± 1.1	1.3 ± 1.1

Table 6.5 Session 1 results from the Wilkins Rate of Reading Test, showing comparison of Stroke Group 1 and Control Group 1 using an optimal spectral filter.

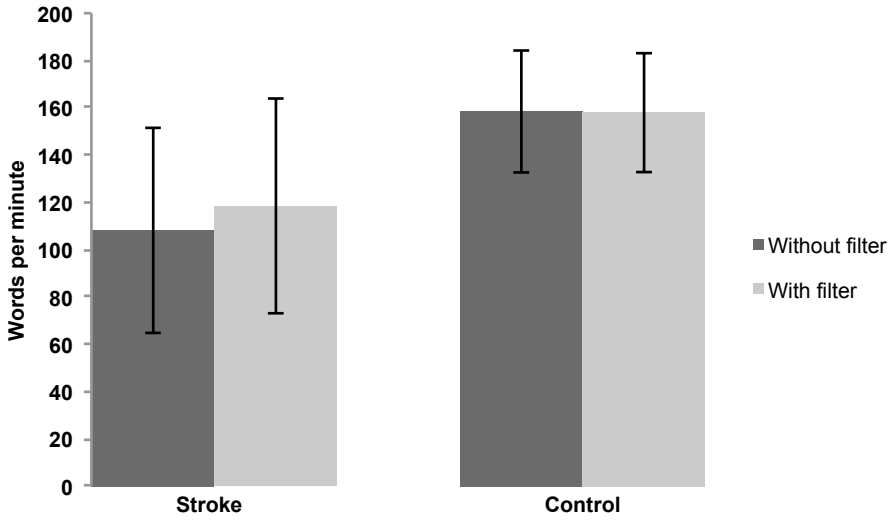

Figure 6.1 Session 1 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1. Stroke subjects showed a significant increase in number of words read per minute when using an optimal spectral filter. Error bars represent ± 1SD.

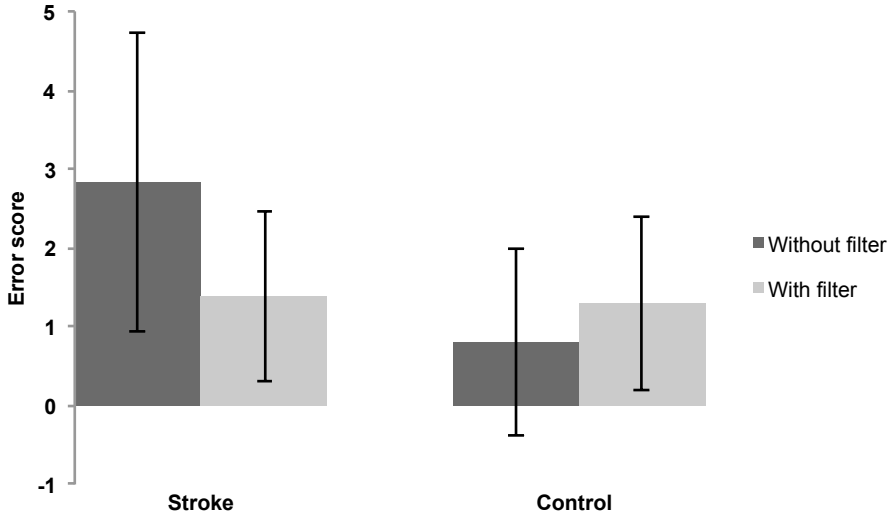

Figure 6.2 Session 1 results for error scores from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1. The use of an optimally determined spectral filter was found to reduce error scores for stroke subjects. Error bars represent ± 1SD.

A summary of data for Stroke Group 2 and Control Group 2 can be seen in Figures 6.3, 6.4 and Table 6.6.

Wilkins Rate of Reading Test	Stroke Group 2 (n = 10) Mean ± SD	Control Group 2 (n = 10) Mean ± SD
Words per min. without overlay	110 ± 21	155 ± 31
Words per min. with overlay	107 ± 21	158 ± 31
Error score without overlay	1.6 ± 1.6	0.6 ± 0.6
Error score with overlay	1.6 ± 1.9	0.8 ± 0.9

Table 6.6 Session 1 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2, using a neutral filter.

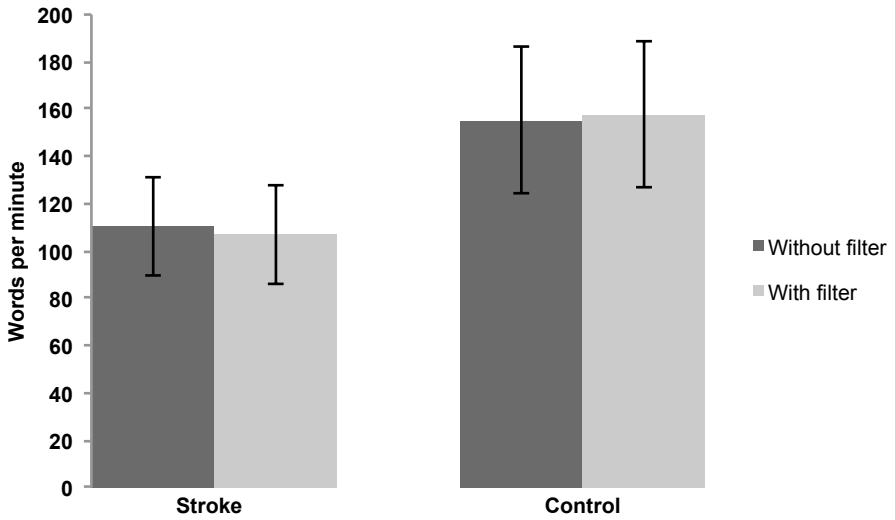

Figure 6.3 Session 1 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2. The use of a neutral grey filter was not beneficial for either group. Error bars represent ± 1SD.

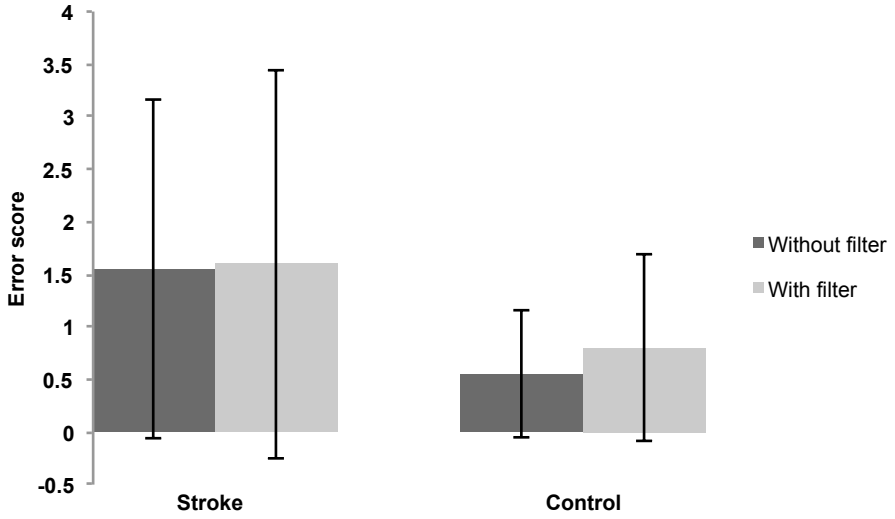

Figure 6.4 Session 1 results for error scores from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2. The use of a neutral grey filter did not reduce error scores for stroke or control subjects. Error bars represent ± 1SD.

The within-subject analysis, for rate of reading, showed no main effect for the presence of the filter ($F_{(1, 35)} = 2.930$, P = 0.096), nor any significant interaction between filter and subject type ($F_{(1, 35)} = 0.826$, P = 0.370), or presence of filter, regardless of its type ($F_{(1, 35)} = 3.843$, P = 0.058). There was, however, a significant interaction between the presence of the filter, the subject type, and the type of filter ($F_{(1, 35)} = 9.654$, P = 0.004), with the stroke subjects demonstrating improvements in reading speed when using their optimally determined filter. The between-subject effects showed a difference between the main effect of subject type, with stroke participants reading more slowly than the controls ($F_{(1, 35)} = 21.756$, P = 0.000), but no difference when considering the filter type ($F_{(1, 35)} = 0.109$, P = 0.743), nor any interaction between these factors ($F_{(1, 35)} = 0.015$, P = 0.902). For error scores, the within-subject analysis showed no main effect for the presence of the filter ($F_{(1, 35)} = 1.138$, P = 0.293). There was a significant interaction between filter presence and the participant type ($F_{(1, 35)} = 12.600$, P = 0.001), as well as the presence of the filter and its type ($F_{(1, 35)} = 4.243$, P = 0.047), and also an interaction between the filter presence, filter type, and participant ($F_{(1, 35)} = 8.338$, P = 0.007), with the use of an optimal spectral filter reducing errors for the stroke subjects. The between-subject factors showed a difference for the main effect of participant type ($F_{(1, 35)} = 5.899$, P = 0.020), but not for the filter-type ($F_{(1, 35)} = 1.273$, P = 0.267), with no interaction observed ($F_{(1, 35)} = 0.040$, P = 0.843).

6.5.3 Session 2

After a two-week break, the subjects had their filter type crossed-over, with Stroke and Control Group 1 given a grey filter to use for two weeks prior to assessment, whereas Stroke and Control Groups 2 were provided with an optimal filter to use over the same time period.

Detailed data for the Wilkins Rate of Reading Test in Session 2 for Stroke Group 1, Stroke Group 2 and Control Group 1 and Control Group 2 can be seen in Tables 6.7, 6.8, 6.9 and 6.10, respectively.

Stroke Subject	Age	Gender	Filter type	Words per min. Without overlay	Words per min. With overlay	Words per min. Change (%)	Error score Without overlay	Error score With overlay
1	83	Female	Grey	98.0	103.0	5.1	3.0	3.0
3	64	Female	Grey	169.0	154.0	-8.9	2.0	2.0
4	72	Male	Grey	56.5	57.5	1.8	3.0	3.0
5	71	Male	Grey	121.0	121.5	0.4	0.0	0.0
6	52	Male	Grey	27.0	26.0	-3.7	0.0	0.5
7	77	Female	Grey	128.0	112.5	-12.1	3.0	3.0
8	65	Male	Grey	115.0	110.0	-4.4	0.0	0.5
9	62	Male	Grey	141.0	131.5	-6.7	0.5	0.0
10	69	Female	Grey	127.0	123.0	-3.2	0.5	1.0

Table 6.7 Session 2 results from the Wilkins Rate of Reading Test for Stroke Group 1.

Stroke Subject	Age	Gender	Filter type	Words per min. Without overlay	Words per min. With overlay	Words per min. Change (%)	Error score Without overlay	Error score With overlay
11	56	Female*	Lime green	126.0	125.0	-0.8	1.0	0.0
12	49	Female	Purple	112.0	109.0	-2.7	0.0	0.0
13	76	Female	Mint green	91.5	95.0	3.8	5.5	3.0
14	43	Male	Aqua	93.5	104.0	11.2	1.0	0.0
15	81	Female	Aqua	133.0	139.0	4.5	0.5	0.0
16	80	Female	Purple	103.5	103.5	0.0	0.0	0.0
17	74	Female	Yellow	90.0	96.5	7.2	0.5	0.5
18	72	Male*	Lime green	71.0	69.0	-2.8	3.5	4.0
19	59	Male	Purple	107.5	110.0	2.3	1.5	0.0
20	85	Male	Pink	130.5	138.0	5.8	1.5	0.5

Table 6.8 Session 2 results from the Wilkins Rate of Reading Test for Stroke Group 2.
* Migraine sufferer.

Control Subject	Age	Gender	Filter type	Words per min. Without overlay	Words per min. With overlay	Words per min. Change (%)	Error score Without overlay	Error score With overlay
1	45	Female*	Grey	180.0	189.0	5.0	0.0	0.5
2	38	Male	Grey	173.5	170.5	-1.7	0.0	0.5
3	63	Male	Grey	146.0	146.5	0.3	0.0	0.0
4	68	Female	Grey	188.0	167.0	-11.2	0.0	0.0
5	70	Female	Grey	161.0	145.5	-9.6	0.0	0.5
6	55	Female	Grey	146.0	150.0	2.7	1.5	0.0
7	84	Female	Grey	122.0	113.5	-7.0	4.5	2.5
8	36	Female*	Grey	186.0	189.5	1.9	0.0	1.5
9	38	Male	Grey	183.5	174.5	-4.9	0.0	0.0
10	62	Female*	Grey	175.5	196.5	12.0	1.5	0.5

Table 6.9 Session 2 results from the Wilkins Rate of Reading Test for Control Group 1.
* Migraine sufferer.

Control Subject	Age	Gender	Filter type	Words per min. Without overlay	Words per min. With overlay	Words per min. Change (%)	Error score Without overlay	Error score With overlay
11	55	Male	Orange	132.0	131.0	-0.8	0.0	0.0
12	60	Male	Lime green	135.5	146.0	7.8	0.5	1.5
13	50	Male	Orange	142.0	148.0	4.2	1.0	2.0
14	68	Female	Blue	154.0	154.5	0.3	1.5	0.5
15	83	Male	Rose	184.0	176.0	-4.4	0.5	1.0
16	61	Male	Orange	202.0	202.5	0.3	0.0	0.0
17	60	Male	Pink/ Rose	144.5	134.5	-6.9	0.5	1.5
18	54	Female	Yellow	200.0	223.0	11.5	0.0	0.0
19	40	Female	Mint green	126.5	127.5	0.8	0.5	0.5
20	78	Female	Blue	179.0	176.5	-1.4	0.0	0.0

Table 6.10 Session 2 results from the Wilkins Rate of Reading Test for Control Group 2.

A summary of data for Stroke Group 1 and Control Group 1 can be seen in Figures 6.5, 6.6 and Table 6.11.

Wilkins Rate of Reading Test	Stroke Group 1 (n = 9) Mean ± SD	Control Group 1 (n = 10) Mean ± SD
Words per min. without overlay	109 ± 43	166 ± 22
Words per min. with overlay	104 ± 39	164 ± 26
Error score without overlay	1.3 ± 1.4	0.8 ± 1.5
Error score with overlay	1.4 ± 1.3	0.6 ± 0.8

Table 6.11 Session 2 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1 using a neutral filter.

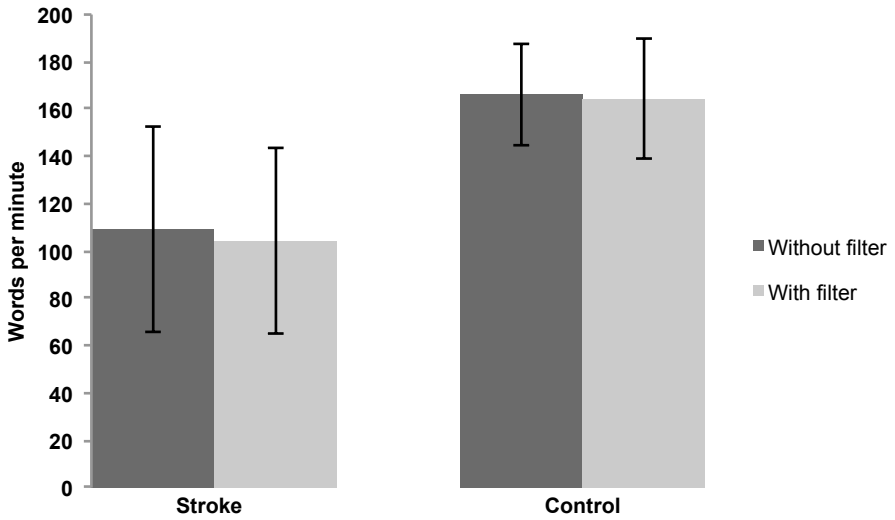

Figure 6.5 Session 2 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1. The use of a neutral grey filter was not beneficial for either group. Error bars represent ± 1SD.

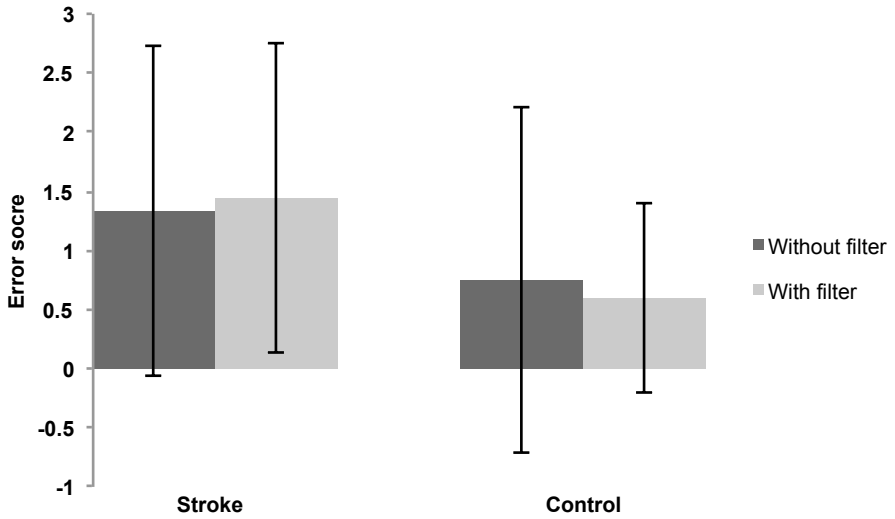

Figure 6.6 Session 2 results for error scores from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1. The use of a neutral grey filter did not reduce error scores for stroke or control subjects. Error bars represent ± 1SD.

Stroke Group 2 and Control Group 2 were permitted to use their optimal spectral filter during Session 2. A summary of data can be seen in Figures 6.7, 6.8 and Table 6.12.

Wilkins Rate of Reading Test	Stroke Group 2 (n = 10) Mean ± SD	Control Group 2 (n = 10) Mean ± SD
Words per min. without overlay	106 ± 20	160 ± 29
Words per min. with overlay	109 ± 21	162 ± 32
Error score without overlay	1.5 ± 1.7	0.5 ± 0.5
Error score with overlay	0.8 ± 1.5	0.7 ± 0.8

Table 6.12 Session 2 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2 using optimal spectral filter.

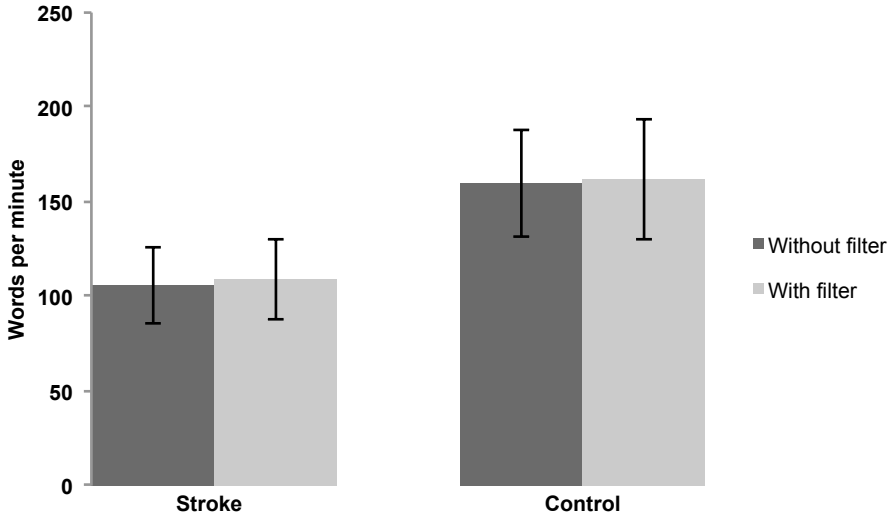

Figure 6.7 Session 2 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2. The use of a spectral filter did not improve the reading speed to a significant level in either group. Error bars represent ± 1SD.

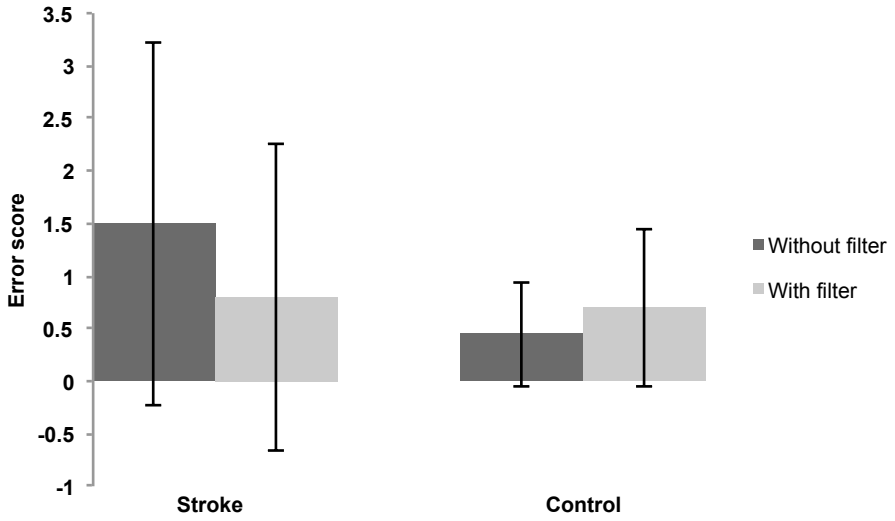

Figure 6.8 Session 2 results for error scores from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2. The use of an optimal spectral filter substantially reduced error scores for the stroke subjects. Error bars represent ± 1SD.

The within-subject analysis for the rate of reading showed no main effect for the presence of a filter ($F_{(1, 35)}$ = 0.087, P = 0.769), with no interaction between the subject type or filter presence ($F_{(1, 35)}$ = 0.109, P = 0.743). An interaction was observed for the presence of the filter and its type, with stroke and control participants reading more words per minute with the spectral filter, and less with a grey filter ($F_{(1, 35)}$ = 4.277, P = 0.046). There was no interaction found for the filter presence, participant or filter type ($F_{(1, 35)}$ = 0.489, P = 0.489). The between-subject effects showed a difference for the main effect of performance, with stroke participants reading more slowly than the controls ($F_{(1, 35)}$ = 35.387, P = 0.000), but no difference when considering the filter type ($F_{(1, 35)}$ = 0.037, P = 0.848), nor any interaction between these factors ($F_{(1, 35)}$ = 0.067, P = 0.797). For error scores, the within-subject analysis showed no main effect for the presence of the filter ($F_{(1, 35)}$ = 0.940, P = 0.339), nor any interaction between the participant type and the presence of the filter ($F_{(1, 35)}$ = 1.867, P = 0.181) or for the filter presence or its type ($F_{(1, 35)}$ = 0.665, P = 0.420). There was, however, an interaction between the filter presence, its type, and the subject group, with the stroke participants demonstrating a reduction in error scores with an optimal filter ($F_{(1, 35)}$ = 5.771, P

= 0.022). The between-subject factors showed no difference for the main effect of participant type ($F_{(1, 35)}$ = 2.921, P = 0.096), nor for filter-type ($F_{(1, 35)}$ = 0.202, P = 0.656), with no interaction ($F_{(1, 35)}$ = 0.034, P = 0.855), with the use of a filter, per se, not reducing error scores for either group.

At the end of Sessions 1 and 2, subjects were asked to indicate which filter, if any, they found to be of most benefit. A summary of these findings can be seen in Table 6.13.

Stroke subject	Filter preference	Control subject	Filter preference
1	Optimal	1	Grey
N/A	N/A	2	Nil
3	Optimal	3	Optimal
4	Optimal	4	Nil
5	Optimal	5	Optimal
6	Optimal	6	Nil
7	Nil	7	Optimal
8	Optimal	8	Nil
9	Optimal	9	Nil
10	Grey	10	Optimal
11	Optimal	11	Optimal
12	Optimal	12	Optimal
13	Nil	13	Optimal
14	Optimal	14	Optimal
15	Optimal	15	Nil
16	Nil	16	Nil
17	Optimal	17	Nil
18	Optimal	18	Nil
19	Nil	19	Nil
20	Optimal	20	Nil

Table 6.13 Subjects preference for filter type at the conclusion of the study

6.6 Results without migraine subjects

With migraine being a correlate of visual stress (Harle and Evans, 2004), the analyses were considered again with these subjects removed from the data set.

With the migraine subjects removed from the data set Stroke Group 1 (n = 9) was found to be age-matched to Stroke Group 2 (n = 8) (unpaired t-test: t = 0.007, dF = 15, P = 0.995), with Group 1 having an age range of 52-83 years (mean 68.33 SD 9.00) and Group 2 with an age-range of 43-85 (mean 68.38 SD 15.89). The time interval since their stroke (or most recent stroke) had a range of 0.83-11 years (mean 4.19 SD 3.64 years) for Stroke Group 1 and 3-12 years (mean 6 SD 2.98 years) for Stroke Group 2; these time intervals were not significantly different (unpaired t-test: t = 1.117, dF = 15, P = 0.282). Performance during the Wilkins Rate of Reading Test, based on data from the preceding study (see Chapter 5) showed no significant difference between Stroke Group 1 and Stroke Group 2 ($F_{(1, 15)}$ = 0.103, P = 0.753), with both sets of subjects improving using an optimal spectral filter ($F_{(1, 15)}$ = 15.088, P = 0.001), and no interaction between these factors ($F_{(1, 15)}$ = 0.452, P = 0.512). Error scores were the same in the two groups ($F_{(1, 15)}$ = 0.026, P = 0.874), with both showing a significant reduction in errors whilst using the filter ($F_{(1, 15)}$ = 20.049, P = 0.000); no interaction was found between these factors ($F_{(1, 15)}$ = 2.413, P = 0.141).

With the migraine subjects removed from the data set, Control Group 1 had an age-range of 38-84 years (mean 59.42 SD 17.03), and was matched with Control Group 2 (unpaired t-test: t = 0.204, dF = 15, P = 0.841), having an age-range of 40-83 years (mean 60.90 SD 12.78). The performance of these groups in the preceding study were found to be the same for the Wilkins Rate of Reading Test ($F_{(1, 15)}$ = 0.227, P = 0.640), with neither group benefiting significantly from the use of a spectral filter during this task ($F_{(1, 15)}$ = 1.463, P = 0.245), confirmed by no interaction between the two factors ($F_{(1, 15)}$ = 4.25, P = 0.057). When the error scores were considered in this task, there was no significant difference between subjects ($F_{(1, 15)}$ = 1.991, P = 0.179), with neither of the groups showing improvement with an optimal spectral filter ($F_{(1, 15)}$ = 0.754, P = 0.141), with no interaction between factors ($F_{(1, 15)}$ = 0.429, P = 0.522).

6.6.1 Session 1

Stroke Group 1 and Control Group 1 were found to be age-matched (unpaired t-test: t = 1.353, dF = 14, P = 0.197). A summary of data for Stroke Group 1 and Control Group 1 can be seen in Figures 6.9, 6.10 and Table 6.14.

Wilkins Rate of Reading Test	Stroke Group 1 (n = 9) Mean ± SD	Control Group 1 (n = 7) Mean ± SD
Words per min. without overlay	108 ± 44	148 ± 23
Words per min. with overlay	118 ± 45	147 ± 22
Error score without overlay	2.8 ± 1.9	0.9 ± 1.4
Error score with overlay	1.4 ± 1.1	1.2 ± 1.4

Table 6.14 Session 1 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1 using optimal spectral filter, with the exclusion of migraine subjects.

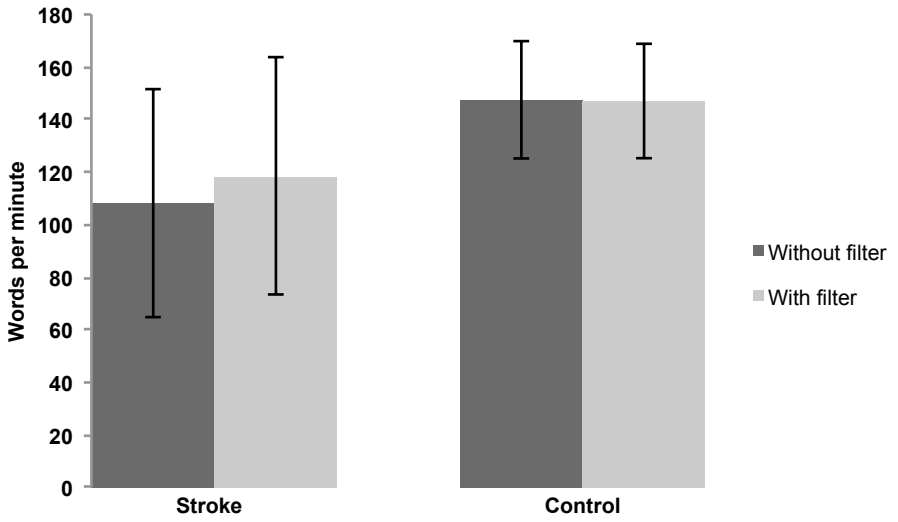

Figure 6.9 Session 1 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1, with the exclusion of migraine subjects. Stroke subjects showed an increase (>9%) in number of words read per minute when using an optimal spectral filter. Error bars represent ± 1SD.

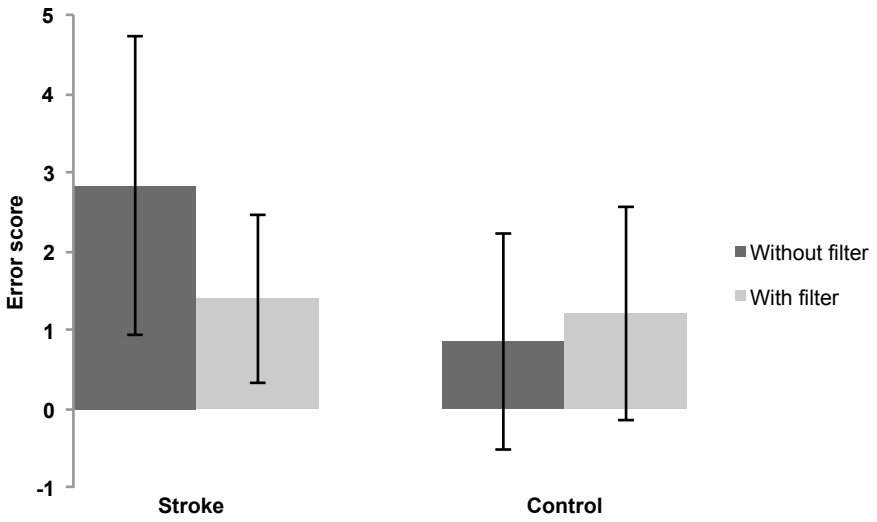

Figure 6.10 Session 1 results for error scores from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1, with the exclusion of migraine subjects. The use of an optimally determined spectral filter was found to reduce error scores for stroke subjects. Error bars represent ± 1SD.

The subjects in Group 2 were age-matched (unpaired t-test: t = 1.108, dF = 16, P = 0.284). A summary of data for Stroke Group 2 and Control Group 2 can be seen in Figures 6.11, 6.12 and Table 6.15).

Wilkins Rate of Reading Test	Stroke Group 2 (n = 8) Mean ± SD	Control Group 2 (n = 10) Mean ± SD
Words per min. without overlay	115 ± 18	155 ± 31
Words per min. with overlay	112 ± 20	158 ± 31
Error score without overlay	1.4 ± 1.5	0.6 ± 0.6
Error score with overlay	1.4 ± 1.7	0.8 ± 0.9

Table 6.15 Session 1 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2 using neutral filter, with the exclusion of migraine subjects.

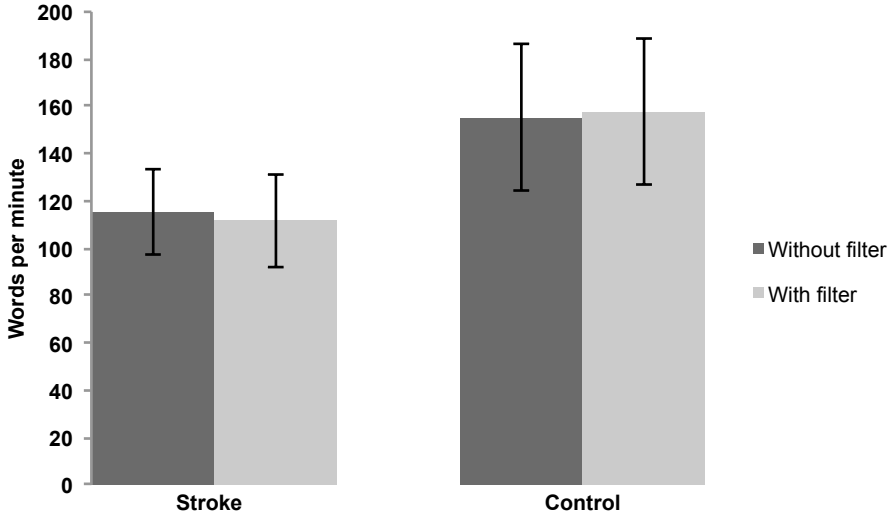

Figure 6.11 Session 1 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2, with the exclusion of migraine subjects. The use of a neutral grey filter was not beneficial for either group. Error bars represent ± 1SD.

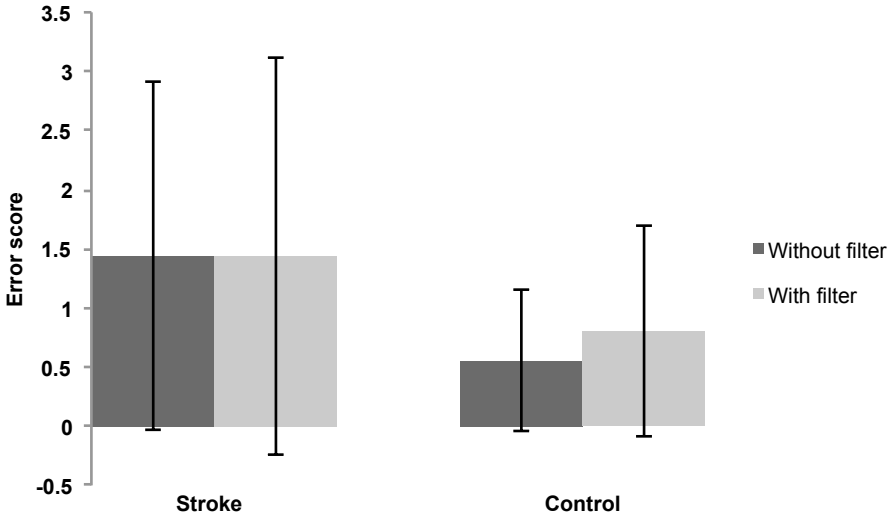

Figure 6.12 Session 1 results for error scores from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2, with the exclusion of migraine subjects. The use of a neutral grey filter did not reduce error scores for stroke or control subjects. Error bars represent ± 1SD.

The within-subject analysis for the rate of reading showed no main effect for the presence of the filter ($F_{(1, 30)} = 1.965$, $P = 0.171$), nor any significant interaction between filter and subject type ($F_{(1, 30)} = 0.586$, $P = 0.450$), as well as for the presence of filter, of both types ($F_{(1, 30)} =$

3.027, P = 0.092). There was, however, a significant interaction between the presence of the filter, the subject group, and the type of filter ($F_{(1, 30)}$ = 7.871, P = 0.009), with the stroke subjects demonstrating improvements in reading speed when using their optimal filter. The between-subject effects showed a difference between the main effect of participants performance with stroke subjects reading more slowly ($F_{(1, 30)}$ = 12.665, P = 0.001) but no difference when considering the filter type ($F_{(1, 30)}$ = 0.183, P = 0.672), nor any interaction between these factors ($F_{(1, 30)}$ = 0.171, P = 0.683). For error scores, the within-subject analysis showed no main effect for the presence of the filter ($F_{(1, 30)}$ = 1.504, P = 0.230). There was a significant interaction between filter presence and the participant type ($F_{(1, 30)}$ = 9.027, P = 0.005), but not the presence of the filter and its type ($F_{(1, 30)}$ = 3.836, P = 0.060). An interaction was shown between the filter presence, filter type, and participant ($F_{(1, 30)}$ = 5.163, P = 0.030), with the use of an optimal spectral filter reducing errors for the stroke subjects. The between-subject factors showed a difference for the main effect of participant type ($F_{(1, 30)}$ = 4.658, P = 0.039) but not for the filter-type ($F_{(1, 30)}$ = 1.475, P = 0.234), with no interaction observed ($F_{(1, 30)}$ = 0.135, P = 0.716).

6.6.2 Session 2

A summary of data for Stroke Group 1 and Control Group 1 can be seen in Figures 6.13, 6.14 and Table 6.16.

Wilkins Rate of Reading Test	Stroke Group 1 (n = 9) Mean ± SD	Control Group 1 (n = 7) Mean ± SD
Words per min. without overlay	109 ± 43	160 ± 24
Words per min. with overlay	104 ± 39	153 ± 21
Error score without overlay	1.3 ± 1.4	0.9 ± 1.7
Error score with overlay	1.4 ± 1.3	0.5 ± 0.9

Table 6.16 Session 2 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1 using a neutral filter, with the exclusion of migraine subjects.

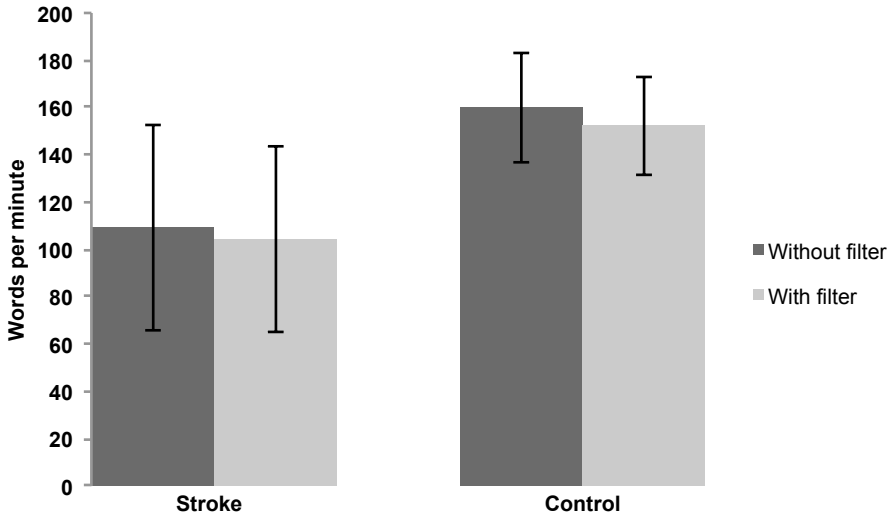

Figure 6.13 Session 2 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1, with the exclusion of migraine subjects. The use of a neutral grey filter was found to reduce reading speed in both groups. Error bars represent ± 1SD.

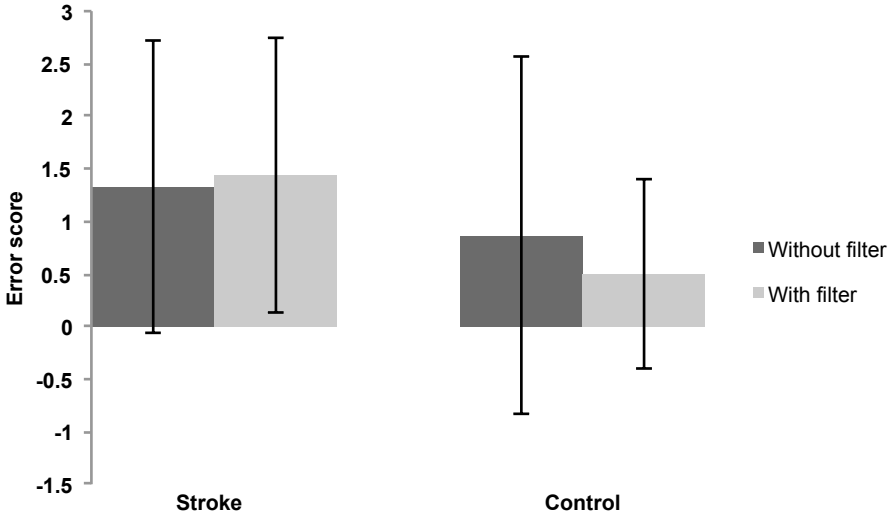

Figure 6.14 Session 2 results for error scores from the Wilkins Rate of Reading Test showing comparison of Stroke Group 1 and Control Group 1, with the exclusion of migraine subjects. The use of a neutral grey filter did not reduce error scores for stroke or control subjects. Error bars represent ± 1SD.

A summary of data for Stroke Group 2 and Control Group 2 can be seen in Figures 6.15, 6.16 and Table 6.17).

Wilkins Rate of Reading Test	Stroke Group 2 (n = 8) Mean ± SD	Control Group 2 (n = 10) Mean ± SD
Words per min. without overlay	108 ± 17	160 ± 29
Words per min. with overlay	112 ± 17	162 ± 32
Error score without overlay	1.3 ± 1.8	0.5 ± 0.5
Error score with overlay	0.5 ± 1.0	0.7 ± 0.8

Table 6.17 Session 2 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2 using optimal spectral filter, with the exclusion of migraine subjects.

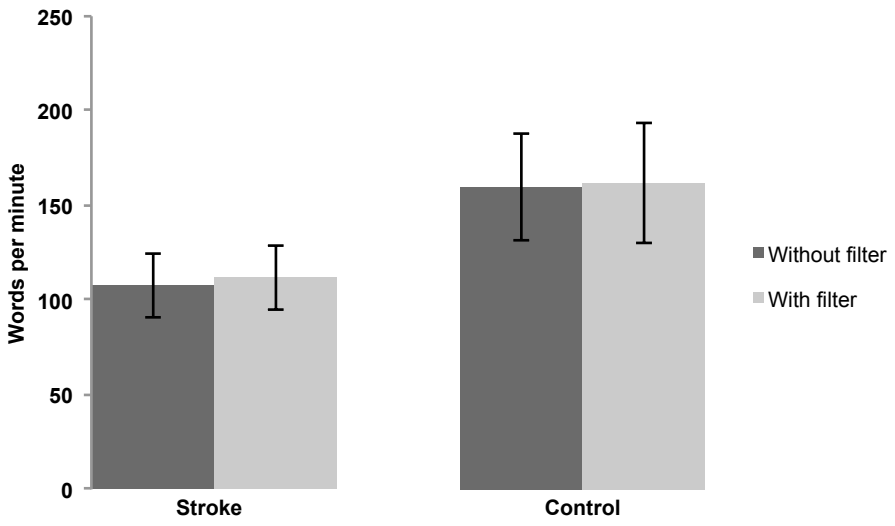

Figure 6.15 Session 2 results from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2, with the exclusion of migraine subjects. The use of a spectral filter did not improve the reading speed to a significant level in either group. Error bars represent ± 1SD.

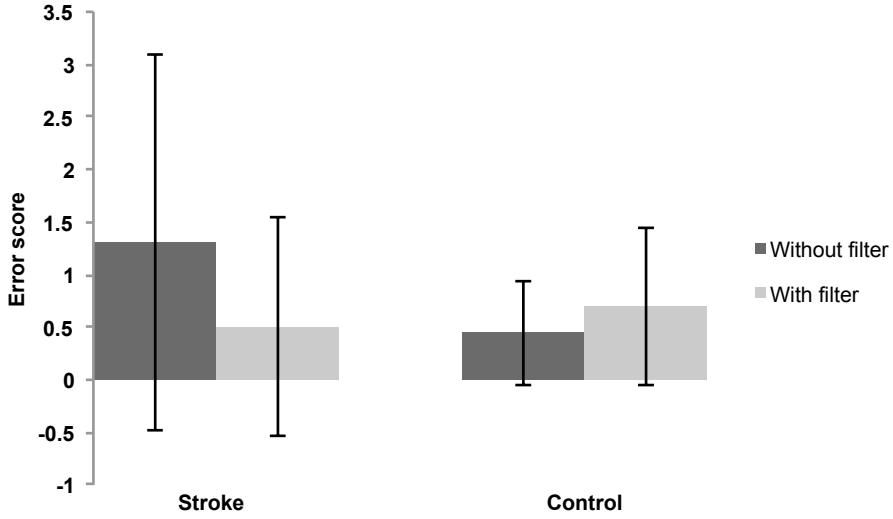

Figure 6.16 Session 2 results for error scores from the Wilkins Rate of Reading Test showing comparison of Stroke Group 2 and Control Group 2, with the exclusion of migraine subjects. The use of an optimal spectral filter substantially reduced error scores for the stroke subjects. Error bars represent ± 1SD.

The within-subject analysis for the rate of reading showed no main effect for the presence of a filter ($F_{(1, 30)} = 1.300$, $P = 0.263$), with no interaction between the participant type or filter presence ($F_{(1, 30)} = 0.811$, $P = 0.375$). An interaction was observed for the presence of the filter and its type, with stroke and control participants reading more words per minute with their optimal spectral filter, and less with a grey filter ($F_{(1, 30)} = 11.808$, $P = 0.002$). There was no interaction found for the filter presence, participant and filter type ($F_{(1, 30)} = 0.008$, $P = 0.930$). The between-subject effects showed a difference between the main effect of participants performance ($F_{(1, 30)} = 23.911$, $P = 0.000$) but no difference when considering the filter type ($F_{(1, 30)} = 0.141$, $P = 0.710$), nor any interaction between these factors ($F_{(1, 30)} = 0.007$, $P = 0.936$). For error scores, the within-subject analysis showed no main effect for the presence of the filter ($F_{(1, 30)} = 2.585$, $P = 0.118$), and no interaction between the participant type and the presence of the filter ($F_{(1, 30)} = 1.396$, $P = 0.247$) or between the filter presence and its type ($F_{(1, 30)} = 0.396$, $P = 0.534$). There was, however, an interaction between the filter presence, its type, and the subject type, with the stroke participants recording fewer errors when using an optimal filter ($F_{(1, 30)} = 9.266$, $P = 0.005$). The between-subject factors showed

no difference for the main effect of participant type ($F_{(1, 30)} = 1.679$, $P = 0.205$), nor for filter-type ($F_{(1, 30)} = 0.532$, $P = 0.472$), with no interaction ($F_{(1, 30)} = 0.222$, $P = 0.641$).

6.7 Discussion

The present study has demonstrated that following stroke, improvements in reading speed and accuracy can be achieved with prolonged use of optimal spectral filters *versus* a placebo measure; this concurs with findings in Chapter 5 which demonstrated ~6% increase in reading speed following immediate assessment with optimal filters for this subject type. In the present study, using an optimal filter for a prolonged period increased reading speed in excess of 9% for Stroke Group 1, with ~78% of subjects recording a >5% increase. When considering error scores, these more than halved for Stroke Group 1 whilst using an optimal filter. In contrast, when these same subjects were asked to substitute the optimal filter for a novel placebo filter, results showed ~4% reduction in reading speed and marginally elevated error scores; only one subject recorded a >5% increase in reading speed with the grey filter. For Control Group 1, the average increase in reading speed was <1%, with only one subject recording a >5% increase with their optimal filter and error scores increased with the filter in situ. When using the placebo filter, reading speed decreased by ~1%, although two subjects produced a >5% increase. Error scores were marginally lower in this group when using the filter. Despite increases of >5% in reading rates being predictive of likely continued use of spectral filters (Wilkins *et al.*, 1996; Wilkins *et al.*, 2001), in practice, these benefits should be assessed case-by-case, based upon an individual's perceived benefit having used the intervention for several weeks.

Stroke Group 2 conducted the study in reverse, using the placebo grey filter for a prolonged period initially, before using an optimal filter over the same time period. Whilst using the placebo measure, average reading speed reduced by ~3%; all subjects read <5% faster with the filter; error scores were marginally elevated with the filter. With access to an optimal filter,

these same subjects recorded ~3% increase in reading speed, with 30% now showing a >5% improvement. In addition, error scores virtually halved with the optimal filter. With the exclusion of migraine subjects in Stroke Group 2, the reading speed with the placebo filter decreased by ~3% but increased by ~4% with the use of an optimal filter. For Control Group 2, reading speed increased by ~2% with the placebo filter, with 30% of subjects showing a >5% improvement, although errors were higher with the filter in place. In the second part of the study, Control Group 2 recorded an ~1% increase in reading speed with their optimal filter, with 20% showing a >5% improvement, although error scores were again higher with the filter in situ.

Although both groups of stroke subjects showed benefit from optimal spectral filters, the effects were greater for those using the optimal filter prior to the grey filter, rather than *vice versa*. It could be that the use of the grey filter had a detrimental effect on reading performance, or simply generated despondency towards the potential benefit of spectral filters given their initial experience with the intended placebo intervention. Nevertheless, when subjects were asked at the end of the study to reflect on the value of the filters, ~78% of stroke subjects in the first group and 70% in the second group showed preference for the optimal filter, findings that share similarity with migraine sufferers who report improved comfort with spectral filters but not necessarily marked improvement in reading performance (Harle and Evans, 2004). Overall, only one subject felt the grey filter was the most beneficial. Typically in the literature, the change in rate of reading is the most widely reported outcome measure. Perhaps given the outcome in the present study, attention should also be given to error scores (see Chapter 9).

Further work should be considered with a larger sample as well as avoiding the potential bias of predisposed visual symptoms in subjects recruited from an optometric practice. It should be noted that despite subjects being offered the grey filter as a novel alternative, rather than an outward placebo, they might have shown prejudice towards it given their previous

experience with an optimal filter. Given that the grey filter impaired reading speed in the present study, its intended use as a placebo intervention should be, retrospectively, criticised (see Chapter 9). Although the present study was conducted with randomized control, further work with double masking could be achieved by adopting recognised techniques using precision tinted ophthalmic lenses (Wilkins *et al*, 1994).

6.8 Conclusion

The present study agrees with earlier findings that optimal spectral filters can help to rehabilitate reading performance following stroke (see Chapter 5) and that these effects are unlikely to be due to contrast reduction or the benefit of practice, whilst the use of neutral filters may be detrimental to reading ability. The utility of optimal spectral filters on other visual tasks, such as visual search, within a stroke cohort, should be considered.

7.0 The immediate effect of spectral filters on visual search following stroke

7.1 Introduction

Visual search tasks were considered in Chapter 1. In brief, these tasks typically require the subject to identify a target within multiple distractors with performance measured in terms of speed and accuracy. Visual search tasks have been utilised to identify individuals with visual stress (Singleton and Henderson, 2007), although subsequent task improvement with spectral filters does not necessarily follow (Allen *et al.*, 2008). Nevertheless, spectral filters have been shown to improve visual search performance in patients with multiple sclerosis (Newman Wright *et al.*, 2007), as well as children with below-average reading ability (Tyrell *et al.*, 1995). Visual search difficulty is dependent upon task design with some consisting of targets easily distinguished from their distractors, whereas others require more critical assessment. It has been proposed that less demanding visual search tasks require parallel neural processing, in contrast to those requiring more concentration which utilise serial processing, as described in Section 1.5.2, (Treisman and Gelade, 1980; Wolfe, 1998), although this distinction is likely to be an over-simplification (Thornton and Gilden, 2007). More importantly, is to recognise that only tasks of a certain difficulty can distinguish between those with low and high levels of visual stress (Conlon and Humphreys, 2001). Several studies have reported visual search impairment following stroke, in patients with (Keller and Lefin-Rank, 2010), and without hemianopia (Hildebrandt *et al.*, 2005). Furthermore, it seems that following stroke, serial, rather than parallel search, may be affected (Hildebrandt *et al,*, 2005). Rehabilitation of these patients typically involves eye-movement therapies or the introduction of optical devices, as well as more controversial methods such as visual field restitution (Schofield and Leff, 2009). To date, the impact of spectral filters on visual search performance following stroke has not been considered.

7.2 Objective

The preceding chapters have shown that visual stress can develop following stroke (Chapter 3; Beasley and Davies, 2012) with evidence of susceptibility to pattern glare in this cohort (Chapter 4; Beasley and Davies, 2012). Spectral filters have proved beneficial in rehabilitating reading performance in stroke subjects (Chapters 5 and 6). With evidence of improved visual search performance in a cohort with neurological disease (Newman Wright *et al*, 2007), the effect of optimal spectral filters on visual search response time and error score should be considered in a stroke group. The objective of the present study, therefore, is to determine the utility of spectral filters in a stroke group, during a visual task requiring serial search, the Circles Search Test (Allen *et al.*, 2008)

7.3 Methods

After a one-week break (see Appendix 4), the stroke and control subjects recruited for the study described in Chapter 4, undertook the tasks in the present study, concurrently with those tasks described in Chapter 5. The stroke and control subjects for the present study were retained from preceding studies with the nature of the cohort described elsewhere (see Chapter 4). All subjects selected an optimal spectral filter by the recognised method of successive elimination (Wilkins, 2003) in an earlier study (see Chapter 5). The examiner was not masked from the subjects. Subjects were asked to complete the Circles Search Test as described in Chapter 2, firstly with their optimal spectral filter, then without a filter, without again, and finally with, using a different version of the test each time.

7.4 Statistical Analysis

All data were tested for normality and analysed with appropriate tests, using the commercially available software, PASW, *v*. 18, IBM, New York, U.S.A. (Armstrong *et al.*, 2011; Armstrong *et al.*, 2002). A two-factor mixed ANOVA design was used, incorporating one between-subject factor: stroke or control participant, and one within-subject factor: filter

present or absent. Outcome measures were the task response time and error score, both with and without an overlay. A significance level of $\alpha = 0.05$ was used throughout the analysis. Statistical power was calculated using G* Power (version 3.1.3, Franz Faul, Universität Kiel, Germany). Data for error scores were transformed to improve normality using $x` = \sqrt{(x + 0.5)}$, where x is the recorded error score, and x` represents its transformed value.

7.5 Results

Detailed data from the questionnaire and the Circles Search Test, for the stroke and control participants can be seen in Tables 7.1 and 7.2, respectively.

Stroke Subject	Age	Gender	Optimum spectral filter	Response time (s) Without overlay	Response time (s) With overlay	Error score Without overlay	Error score With overlay
1	83	Female	Yellow	69.0	54.0	1.0	0.5
2	38	Female*	Mint green	107.0	60.0	2.5	0.0
3	64	Female	Pink	40.5	37.0	0.0	0.0
4	72	Male	Orange	87.5	70.0	7.0	8.5
5	71	Male	Mint green	45.5	40.0	0.0	0.0
6	52	Male	Aqua	57.5	52.5	1.0	0.0
7	77	Female	Yellow	57.5	55.5	0.0	0.0
8	65	Male	Blue	55.5	53.0	0.0	0.5
9	62	Male	Yellow	60.0	67.5	0.0	0.5
10	69	Female	Purple	73.0	71.0	0.0	0.0
11	56	Female**	Lime green	34.5	58.0	0.0	2.0
12	49	Female	Purple	96.5	80.5	1.5	3.0
13	76	Female	Mint green	57.5	65.5	0.5	1.5
14	43	Male	Aqua	60.0	46.0	2.5	2.5
15	81	Female	Aqua	61.5	69.0	0.0	0.0
16	80	Female	Purple	71.5	63.5	0.5	0.0
17	74	Female	Yellow	133.0	114.0	3.0	1.0
18	72	Male**	Lime green	64.5	62.5	0.0	0.0
19	59	Male	Purple	70.0	53.0	2.0	2.0
20	85	Male	Pink	40.0	37.0	0.0	0.0

Table 7.1 Circles Search Test for stroke subjects showing response time and error score with and without an optimally selected spectral filter.
* Previous use of spectral filter and precision tint. ** Migraine sufferer.

Control Subject	Age	Gender	Optimum spectral filter	Response time (s) Without overlay	Response time (s) With overlay	Error score Without overlay	Error score With overlay
1	45	Female**	Lime green	49.5	65.0	0.0	1.0
2	38	Male	Blue	19.5	21.0	0.0	0.0
3	63	Male	Blue	39.0	41.5	0.0	0.5
4	68	Female	Aqua	51.5	51.0	0.0	0.0
5	70	Female	Blue	45.0	40.5	2.5	6.0
6	55	Female	Rose	27.5	32.0	0.0	0.5
7	84	Female	Yellow	109.5	117.5	6.5	6.0
8	36	Female**	Blue	31.0	41.5	0.0	0.0
9	38	Male	Blue	26.0	26.5	0.0	0.0
10	62	Female**	Rose	26.0	25.5	0.0	0.0
11	55	Male	Orange	39.0	50.0	0.5	0.0
12	60	Male	Lime green	46.0	58.0	3.0	2.0
13	50	Male	Orange	29.5	31.0	0.0	0.0
14	68	Female	Blue	41.5	46.0	1.0	2.0
15	83	Male	Rose	28.5	35.5	2.0	0.5
16	61	Male	Orange	35.5	33.5	0.0	1.0
17	60	Male	Pink/ Rose	40.5	38.5	0.0	0.0
18	54	Female	Yellow	41.0	32.5	2.0	1.0
19	40	Female	Mint green	49.5	34.5	0.0	0.0
20	78	Female	Blue	23.0	21.0	0.0	0.0

Table 7.2 Circles Search Test for control subjects showing response time and error score, both with and without an optimally selected spectral filter.
** Migraine sufferer.

As discussed in the preceding studies (see Chapters 4-6), one of the stroke participants (Subject 2) had reported during the initial questionnaire that she had previously used spectral filters and continued to use precision tinted lenses on an on-going basis. As the prolonged use of filters may have potentially altered performance on the test, the data for this subject were removed from the analyses. With the removal of this subject, the mean age of the stroke group (mean 67.89 SD 11.97 years) was higher than the control participants (mean 58.40 SD 14.46 years), (unpaired t-test: $t = 2.227$, $df = 37$, $P = 0.032$).

A summary of data can be seen in Figures 7.1, 7.2 and Table 7.3.

Circles Search Test	Stroke (n = 19) Mean ± SD	Control (n = 20) Mean ± SD
Response time without overlay (s)	65.0 ± 22.5	39.9 ± 18.9
Response time with overlay (s)	60.5 ± 17.7	42.1 ± 21.2
Error score without overlay	1.0 ± 1.7	0.9 ± 1.7
Error score with overlay	1.2 ± 2.0	1.0 ± 1.8

Table 7.3 Results from the Circles Search Test for stroke and control subjects.

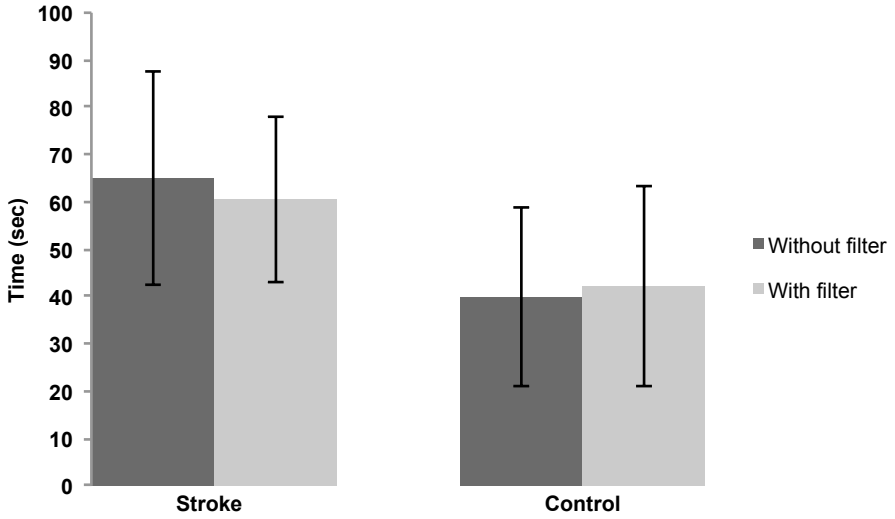

Figure 7.1 Results for response time from the Circles Search Test for stroke and control subjects. The spectral filter enabled the stroke subjects to complete the task faster, whereas the control subjects performed better without the filter. Error bars represent ± 1SD.

The analysis for the main effects showed that stroke subjects were unable to complete the task as quickly as the controls ($F_{(1, 37)}$ = 11.937, P = 0.001). The main effect for the presence of a spectral filter did not improve response time ($F_{(1, 37)}$ = 0.606, P = 0.441), although an interaction between the factors demonstrated that the stroke participants performed the task faster with a spectral filter, whereas the control group were faster without the filter ($F_{(1, 37)}$ = 5.139, P = 0.029).

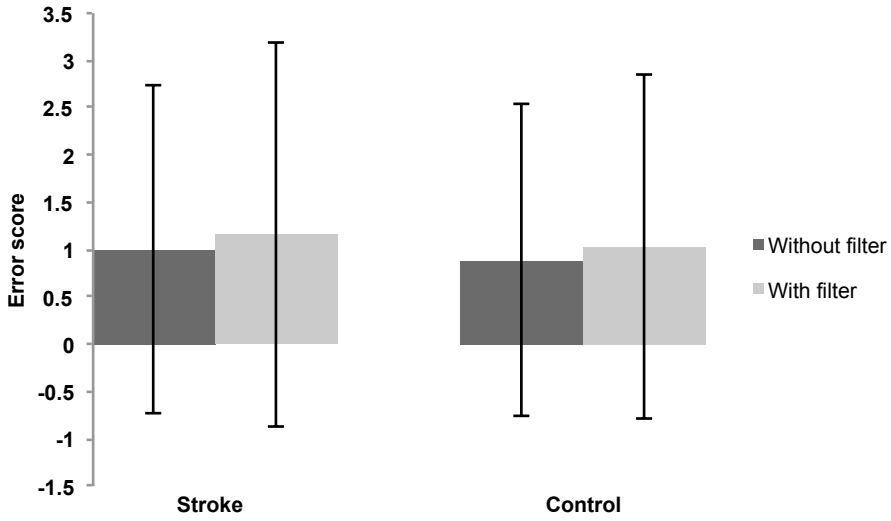

Figure 7.2 Results for error scores from the Circles Search Test for stroke and control subjects. The use of the spectral filter did not improve error scores for the stroke or the control participants. Error bars represent ± 1SD.

Analysis showed no difference in error scores between subject type ($F_{(1, 37)} = 0.083$, $P = 0.775$), both with and without a spectral filter ($F_{(1, 37)} = 0.960$, $P = 0.334$). The interaction between factors showed that the use of a spectral filter did not reduce error scores for either the stroke or control group ($F_{(1, 37)} = 0.009$, $P = 0.926$).

A comparison of data for males and females were also considered (see Figures 7.3, 7.4 and Table 7.4).

Visual Search Task	Male (n = 9) Mean ± SD	Female (n = 10) Mean ± SD
Response time without overlay (s)	60.1 ± 13.8	69.5 ± 28.3
Response time with overlay (s)	53.5 ± 11.5	66.8 ± 20.3
Error score without overlay	1.4 ± 2.3	0.7 ± 1.0
Error score with overlay	1.6 ± 2.8	0.8 ± 1.1

Table 7.4 Results from the Circles Search Test showing gender comparison for stroke subjects.

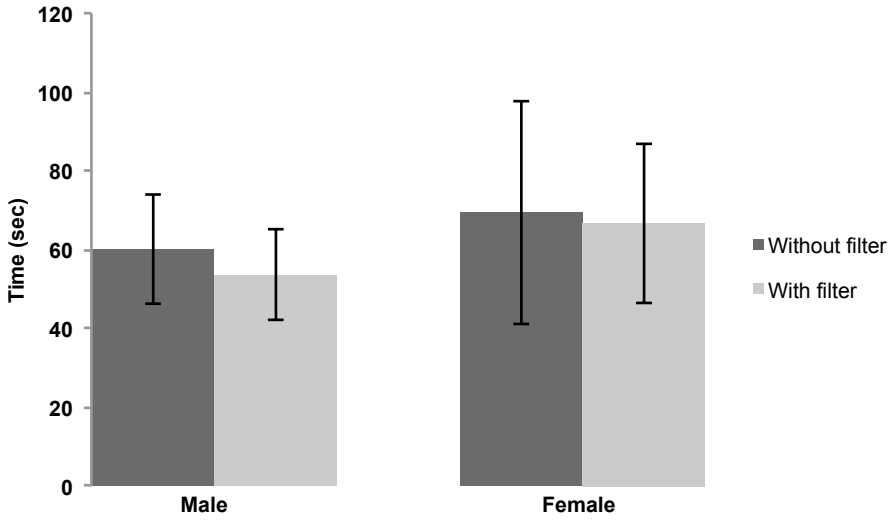

Figure 7.3 Results for response time from the Circles Search Test showing gender comparison for stroke subjects. Response times were not significantly different for male and female subjects, with neither benefitting from using a spectral filter. Error bars represent ± 1SD.

Analysis of variance showed that the spectral filter did not improve response time ($F_{(1, 17)}$ = 3.307, P = 0.087), with no difference between the males and females ($F_{(1, 17)}$ = 1.666, P = 0.214), and no significant interaction between the two factors ($F_{(1, 17)}$ = 0.595, P = 0.451).

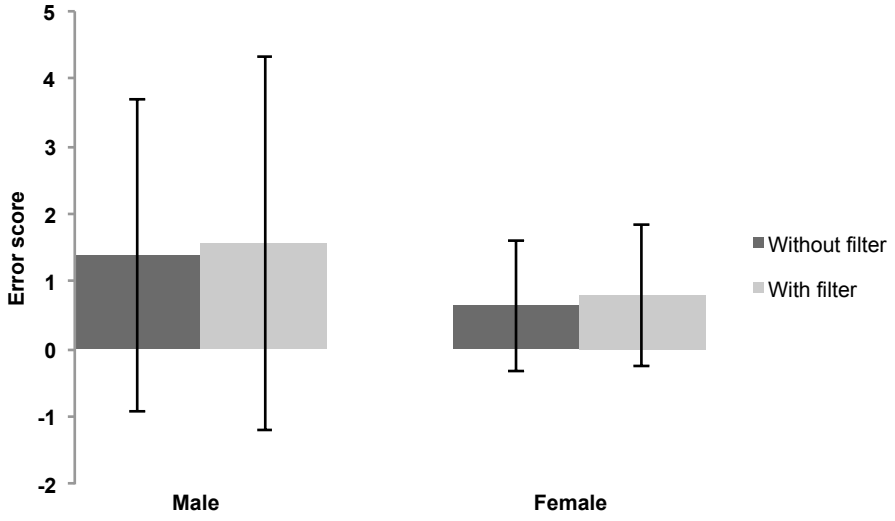

Figure 7.4 Results for error scores from the Circles Search Test showing gender comparison for stroke subjects. The error scores for the males and females were not significantly different, with neither group benefitting from using a spectral filter. Error bars represent ± 1SD.

The results showed that the spectral filter did not reduce errors for either males or females, ($F_{(1, 17)}$ = 0.335, P = 0.571), with no difference between gender performance ($F_{(1, 17)}$ = 0.518, P = 0.481), confirmed by no interaction between the factors ($F_{(1, 17)}$ = 0.017, P = 0.897).

As migraine has an association with visual stress (Harle and Evans, 2004), as well as visual search (Conlon and Humphreys, 2001), the analyses were considered again with the exclusion of these subjects. The groups were found to be age-matched for the stroke subjects (mean 68.35 SD 12.29 years) and the control group (mean 60.29 SD 14.18 years), (unpaired t-test: t = 1.770, df = 32, P = 0.086).

The results showed (see Table 7.5 and Figure 7.5) that stroke subjects were slower than the control group at completing the task ($F_{(1, 32)}$ = 10.174, P = 0.003). The main effect for the use of a filter did not have an impact on task performance ($F_{(1, 32)}$ = 3.631, P = 0.066). However, an interaction between factors demonstrated that the stroke subjects completed the task more quickly with the spectral filter, whereas the control group were slower with the filter ($F_{(1, 32)}$ = 7.302, P = 0.011). The effect of the filter on response time was considered with the stroke group in isolation and the migraine subjects excluded. Results showed an improved response time with the spectral filter in situ for this cohort (paired t-test: t = 2.889, df = 16, p = 0.011).

Visual Search Task	Stroke (n = 17) Mean ± SD	Control (n = 17) Mean ± SD
Response time without overlay (s)	66.8 ± 22.6	40.7 ± 20.1
Response time with overlay (s)	60.5 ± 18.7	41.8 ± 22.0
Error score without overlay	1.1 ± 1.8	1.0 ± 1.8
Error score with overlay	1.2 ± 2.1	1.2 ± 1.9

Table 7.5 Results from the Circles Search Test for stroke and control groups with the exclusion of migraine subjects.

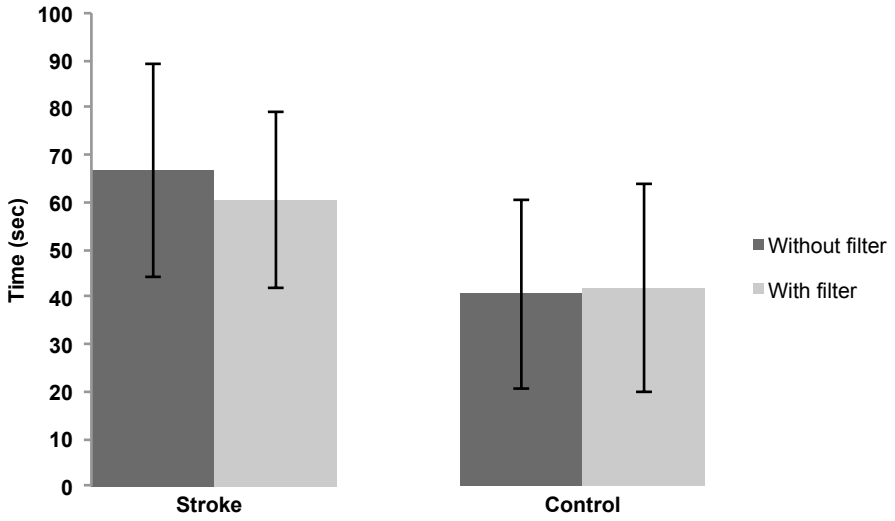

Figure 7.5 Results for response time from the Circles Search Test for stroke and control groups, with the exclusion of migraine subjects. The spectral filter improved response time for the stroke subjects only. Error bars represent ± 1SD.

When the error scores were evaluated (see Table 7.5 and Figure 7.6), the filter was not found to be of benefit ($F_{(1, 32)}$ = 0.139, P = 0.712); this was the case for both sets of participants ($F_{(1, 32)}$ = 0.016, P = 0.900), with no interaction between factors ($F_{(1, 32)}$ = 0.111, P = 0.741).

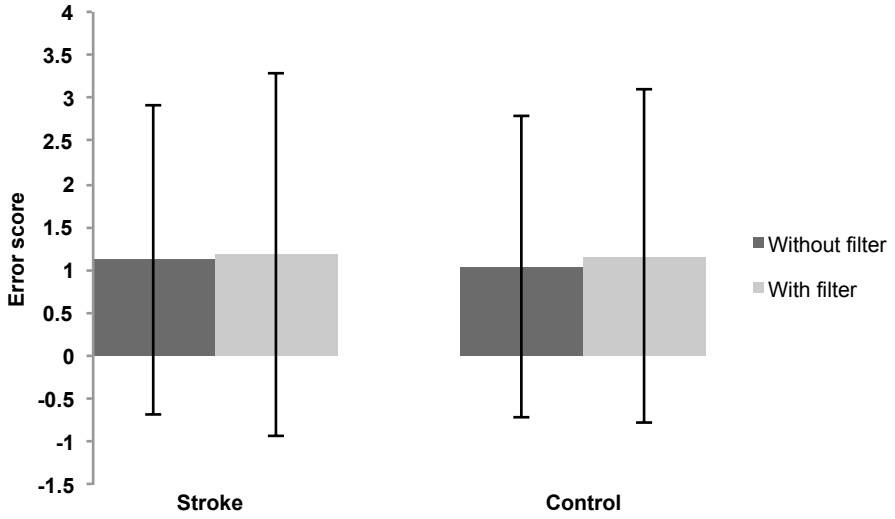

Figure 7.6 Results for error scores from the Circles Search Test for stroke and control subjects, with the exclusion of migraine subjects. The use of the spectral filter did not have a significant impact on reducing errors for the stroke or control group. Error bars represent ± 1SD.

7.6 Discussion

In agreement with earlier work, the present study has shown that stroke subjects demonstrate impaired visual search ability (Keller and Lefin-Rank, 2010; Hildebrandt *et al*, 2005). The present data has shown that spectral filters can improve response time of a visual search task when comparing stroke subjects to a healthy control group. However, it is noteworthy that the control subjects demonstrated slower response times with the spectral filter; a finding that has been replicated for control subjects in a similar study (Newman Wright *et al*, 2007); this finding may be due to contrast reduction or subject's despondency towards an intervention that they felt was not required. Importantly, when the data were considered for the stroke subjects in isolation, the improvement in response time with the spectral filter, did not reach levels of statistical significance. However, an interesting finding emerged when migraine subjects were excluded from the data set. Analysis showed a statistically significant improvement in response time when using the spectral filter, in the stroke group, with migraine subjects excluded; this outcome suggests a general response time advantage for migraine sufferers during visual search, a finding supported by an earlier study (Wray *et al*, 1995), although in contrast to others (Conlon and Humphreys, 2001).

The present study has shown that the use of a spectral filter did not reduce error scores for the stroke or control group. It seems that participants were prepared to sacrifice time in order to identify all of the targets correctly; this is not unexpected, and a higher error score would perhaps be expected if the number of targets were unknown. However, these results are in contrast to those in a comparable study with multiple sclerosis patients, where error scores were reduced (Newman Wright *et al*, 2007). Nevertheless, the present findings are in accordance with other work which failed to show improvements using spectral filters, in response time or error score, for subjects with high levels of visual stress (Allen *et al*, 2008). Equivocal outcomes may be due to differences in subject type for each study, or simply a reflection of precise instruction given prior to the task, i.e. emphasis on speed or accuracy. In

the present study, the subjects were well aware that they needed to identify one target on each row of distractors and were, therefore, prepared to exhaust the search, at the expense of response time, in order to reduce errors. With statistical power calculated at 86%, the findings in the present study are unlikely to be due to insufficient sample size.

In the future, measures of visual search should be undertaken with a larger subject group, as well as the impact of other visual deficits on task performance, such as hemianopia. It should be noted that some of the sample were recruited from an optometric practice and it may be expected that these participants may have a higher predisposition to stroke-related visual symptoms, leading to an over-estimate of visual search deficit in this group. Acknowledging that visual search performance declines with age (Madden, 2007), the inter-group differences in the present study may be over-estimated, given that the controls were some 10 years younger than the stroke subjects, although with the exclusion of migraine subjects these groups were indeed age-matched. The present study did not consider the potential influence of co-existing ocular conditions that may have impaired visual search, such as glaucoma (Smith *et al*, 2011).

7.7 Conclusion

The present study has shown that spectral filters can improve response time during visual search following stroke but only when the data set is considered with migraine subjects excluded. It seems that although visual search measures have been shown to distinguish between those with low and high visual stress (Singleton and Henderson, 2007), the subsequent benefit that particular individuals may obtain from spectral filters appears less certain (Allen *et al*, 2008), especially when considering different outcome measures and the precise nature of the cohort. Further work is suggested to consider the effect of prolonged use of optimal spectral filters in a stroke group, on visual search ability, in comparison to a placebo intervention.

8.0 The effect of prolonged spectral filter use on visual search following stroke

8.1 Introduction

The outcome from the experiment in Chapter 7 has shown that stroke subjects demonstrate improved response time during a visual search task whilst using an optimal spectral filter, in a cohort with migraine subjects excluded. Further testing of this hypothesis is required, by considering the prolonged effect of spectral filters on visual search, compared with a placebo measure.

8.2 Objective

The purpose of the study in this chapter is to consider the effect of prolonged use of an optimal spectral filter compared with a placebo filter on visual search ability in a stroke cohort compared with an age- and gender-matched control group, using a cross over experimental design.

8.3 Methods

After a two-week break (see Appendix 4), the stroke and control subjects recruited for the preceding study (see Chapter 7) undertook the tasks in the present study, concurrently with those tasks described in Chapter 6. The cohort had undertaken a visual search task, namely the Circles Search Test (see Chapter 2), in the preceding study, with and without an optimal spectral filter. The examiner was not masked from the subjects. The present study required the subjects to undertake the Circles Search Test over two sessions to satisfy the cross over design. Participants were randomly allocated to one of two groups during an earlier study (see Chapter 6), nominally called Groups 1 and 2 respectively; the subjects were unaware which group they had been allocated to. One participant in Stroke Group 1 had reported

using a spectral filter and latterly, precision tinted lenses, on a regular basis, since having her stroke a few years prior and her data were excluded from the analyses. Stroke Group 1 (n = 9) had an age range of 52-83 years (mean 68.33 SD 9.00) and was matched (unpaired t-test: t = 0.147, dF = 17, P = 0.833) to Stroke Group 2 (n = 10), 43-85 years (mean 67.50 SD 14.63). The time interval since their stroke (or most recent stroke) had a range of 0.83-11 years (mean 4.19 SD 3.64 years) for Stroke Group 1 and 1.5-12 years (mean 5.45 SD 2.99 years) for Stroke Group 2; these intervals were not significantly different (unpaired t-test: t = 0.832, dF = 17, P = 0.417). From the initial questionnaires, two migraine sufferers were identified within Stroke Group 2. Control Group 1 (n = 10) had an age-range of 36-84 years (mean 55.90 SD 16.26) and was matched to Control Group 2 (n = 10) (unpaired t-test: t = 0.764, df = 18, 0.454), with an age-range of 40-83 years (mean 60.90 SD 12.78). Three migraine sufferers were identified within Control Group 1.

Subjects were given a one week interval between the previous and the present study at which point Group 1 were issued with their optimal spectral filter, whereas Group 2 were issued with a grey filter with a comparable photopic reflectance. The grey filter served as a valid placebo measure given that it is rarely found to be of benefit (Wilkins, 2003). The subjects were asked to use their allocated filter whilst undertaking visual tasks, such as reading, over a two-week period before returning to undertake the Circles Search Test for the first time in the present study. For this session, subjects were asked to complete the task using their allocated filter, then without, without again, and finally with, using a different version of the test each time. At the end of the first session, subjects returned their allocated filter, prior to a two-week break, at which point the groups were crossed over; Group 1 were issued with a grey filter and Group 2 were issued with their optimal filter to use for a two-week period before returning to repeat the Circles Search Test in the same manner as the first session using their newly assigned filters.

8.4 Statistical Analysis

All data were tested for normality and analysed with appropriate tests, using the commercially available software, PASW, *v*. 18, IBM, New York, U.S.A. (Armstrong *et al.*, 2011; Armstrong *et al.*, 2002). A three-factor mixed ANOVA design was used, incorporating two between-subject factors: (1) stroke or control participant; (2) optimal filter group or grey filter group; and one within-subject factor: filter present or absent (Armstrong *et al.*, 2011; Armstrong *et al.*, 2002). Outcome measures were task response time, with and without a filter, along with the corresponding error score. A significance level of $\alpha = 0.05$ was used throughout the analysis. Data for error scores were transformed to improve normality using $x` = \sqrt{(x + 0.5)}$, where x is the recorded error score, and x` represents its transformed value. Statistical power was calculated using G* Power (version 3.1.3, Franz Faul, Universität Kiel, Germany).

8.5 Results

8.5.1 Sub-group comparison

In the preceding study (see Chapter 7), Stroke Groups 1 and 2 completed the Circles Search Test with response times that were not significantly different ($F_{(1, 17)} = 0.955$, $P = 0.342$) and error score ($F_{(1, 17)} = 0.243$, $P = 0.629$). For Control Groups 1 and 2, response times for the Circles Search Test were the same ($F_{(1, 18)} = 0.544$, $P = 0.470$) as well as error scores ($F_{(1, 18)} = 0.581$, $P = 0.456$).

8.5.2 Session 1

Stroke Group 1 and Control Group 1 were allocated an optimal spectral filter to use for two weeks, prior to undertaking the Circles Search Test; these groups were found to be age-matched (unpaired t-test: t = 2.028, df = 17, P = 0.06). Detailed data for the Circles Search Test in Session 1 for Stroke Group 1, Stroke Group 2 and Control Group 1 and Control Group 2 can be seen in Tables 8.1, 8.2, 8.3, and 8.4, respectively.

Stroke Subject	Age	Gender	Filter type	Response time (s) Without overlay	Response time (s) With overlay	Error score Without overlay	Error score With overlay
1	83	Female	Yellow	75.0	71.0	0.0	1.0
3	64	Female	Pink	37.0	31.5	0.5	0.0
4	72	Male	Orange	67.5	75.0	8.0	8.0
5	71	Male	Mint green	39.5	32.0	0.0	0.0
6	52	Male	Aqua	46.5	46.0	0.0	0.0
7	77	Female	Yellow	39.5	46.5	0.0	0.0
8	65	Male	Blue	46.5	45.5	0.0	0.0
9	62	Male	Yellow	56.5	49.5	0.0	0.0
10	69	Female	Purple	56.0	73.5	4.0	3.5

Table 8.1 Session 1 results from the Circles Search Test for Stroke Group 1.

Stroke Subject	Age	Gender	Filter type	Response time (s) Without overlay	Response time (s) With overlay	Error score Without overlay	Error score With overlay
11	56	Female*	Grey	26.0	32.0	0.0	0.5
12	49	Female	Grey	84.0	89.0	2.0	3.0
13	76	Female	Grey	52.5	50.5	0.0	0.0
14	43	Male	Grey	49.5	56.0	3.5	3.5
15	81	Female	Grey	76.0	71.0	0.0	0.0
16	80	Female	Grey	65.0	71.5	0.5	0.5
17	74	Female	Grey	117.5	110.0	4.5	3.5
18	72	Male*	Grey	43.0	48.0	0.5	0.5
19	59	Male	Grey	42.0	40.0	0.0	2.0
20	85	Male	Grey	31.0	36.0	0.0	0.0

Table 8.2 Session 1 results from the Circles Search Test for Stroke Group 2.
* Migraine sufferer.

Control Subject	Age	Gender	Filter type	Response time (s) Without overlay	Response time (s) With overlay	Error score Without overlay	Error score With overlay
1	45	Female*	Lime green	35.5	42.0	0.5	1.0
2	38	Male	Blue	22.5	24.0	0.0	0.0
3	63	Male	Blue	26.0	39.0	0.0	0.0
4	68	Female	Aqua	87.0	73.0	2.0	2.0
5	70	Female	Blue	37.0	40.0	2.0	4.0
6	55	Female	Rose	24.0	22.0	0.5	0.0
7	84	Female	Yellow	80.0	60.5	2.5	3.5
8	36	Female*	Blue	24.0	29.5	0.0	0.0
9	38	Male	Blue	23.0	31.5	0.0	0.0
10	62	Female*	Rose	23.0	24.5	0.0	0.5

Table 8.3 Session 1 results from the Circles Search Test for Control Group 1.
* Migraine sufferer.

Control Subject	Age	Gender	Filter type	Response time (s) Without overlay	Response time (s) With overlay	Error score Without overlay	Error score With overlay
11	55	Male	Grey	38.0	38.0	0.0	0.0
12	60	Male	Grey	45.0	43.5	0.5	1.5
13	50	Male	Grey	26.5	29.0	0.0	0.5
14	68	Female	Grey	33.0	39.0	0.0	1.5
15	83	Male	Grey	36.0	37.0	1.0	1.5
16	61	Male	Grey	23.0	29.0	0.0	0.0
17	60	Male	Grey	38.5	31.5	0.0	0.0
18	54	Female	Grey	28.5	30.5	0.0	0.0
19	40	Female	Grey	31.5	32.0	0.0	0.0
20	78	Female	Grey	24.0	24.0	0.0	0.0

Table 8.4 Session 1 results from the Circles Search Test for Control Group 2.

A summary of data for Stroke Group 1 and Control Group 1 can be seen in Figures 8.1, 8.2 and Table 8.5.

Visual Search Task	Stroke Group 1 (n = 9) Mean ± SD	Control Group 1 (n = 10) Mean ± SD
Response time without overlay (s)	51.6 ± 13.2	38.2 ± 24.5
Response time with overlay (s)	52.3 ± 16.9	38.6 ± 16.7
Error score without overlay	1.4 ± 2.8	0.8 ± 1.0
Error score with overlay	1.4 ± 2.7	1.1 ± 1.5

Table 8.5 Session 1 results from the Circles Search Test, showing comparison of Stroke Group 1 and Control Group 1 using an optimal spectral filter.

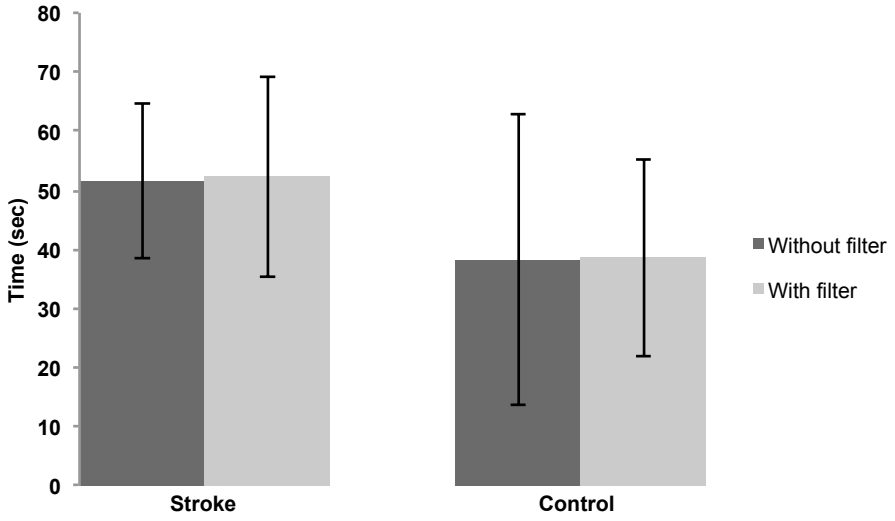

Figure 8.1 Session 1 results for Circles Search Test response time showing comparison of Stroke Group 1 and Control Group 1. The use of an optimal spectral filter did not improve performance for either group. Error bars represent ± 1SD.

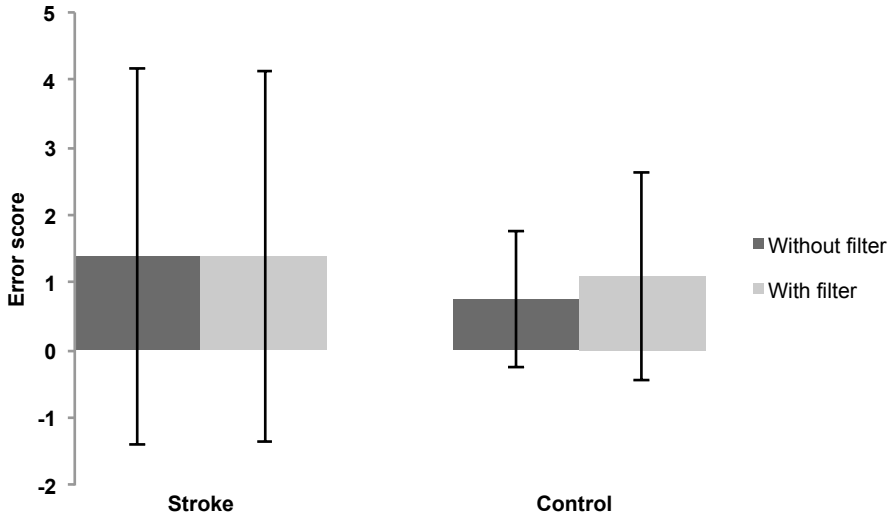

Figure 8.2 Session 1 results for error scores from the Circles Search Test showing comparison of Stroke Group 1 and Control Group 1. The use of an optimally determined

spectral filter did not reduce error scores for stroke or control subjects. Error bars represent ± 1SD.

Stroke Group 2 and Control Group 2 were allocated a neutral, grey filter to use for two weeks, prior to undertaking the Circles Search Test; these groups were found to be age-matched (unpaired t-test: t = 1.074, df = 18, P = 0.297).

A summary of data for Stroke Group 2 and Control Group 2 can be seen in Figures 8.3, 8.4 and Table 8.6.

Visual Search Task	Stroke Group 2 (n = 10) Mean ± SD	Control Group 2 (n = 10) Mean ± SD
Response time without overlay (s)	58.7 ± 27.7	32.4 ± 7.1
Response time with overlay (s)	60.4 ± 25.0	33.4 ± 5.9
Error score without overlay	1.1 ± 1.7	0.2 ± 0.3
Error score with overlay	1.4 ± 1.5	0.5 ± 0.7

Table 8.6 Session 1 results from the Circles Search Test showing comparison of Stroke Group 2 and Control Group 2, using a neutral filter.

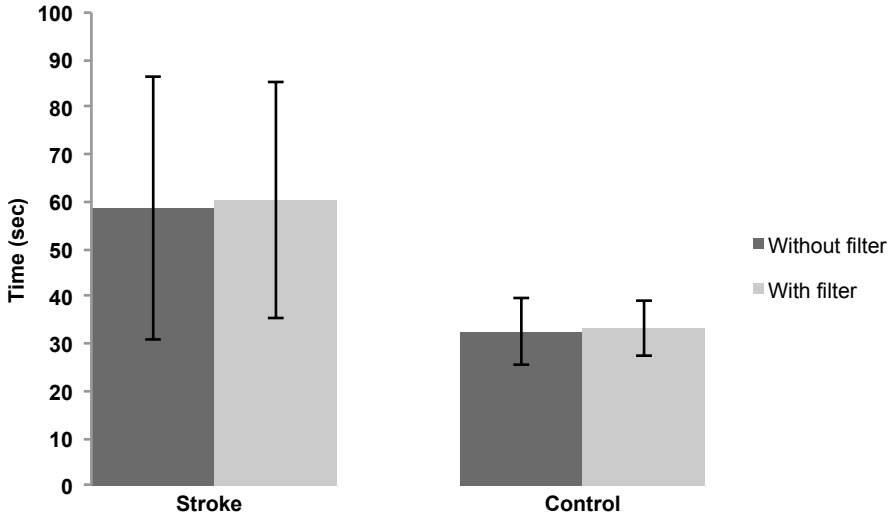

Figure 8.3 Session 1 results for Circles Search Test response time showing comparison of Stroke Group 2 and Control Group 2. The use of a neutral grey filter was not beneficial for either group. Error bars represent ± 1SD.

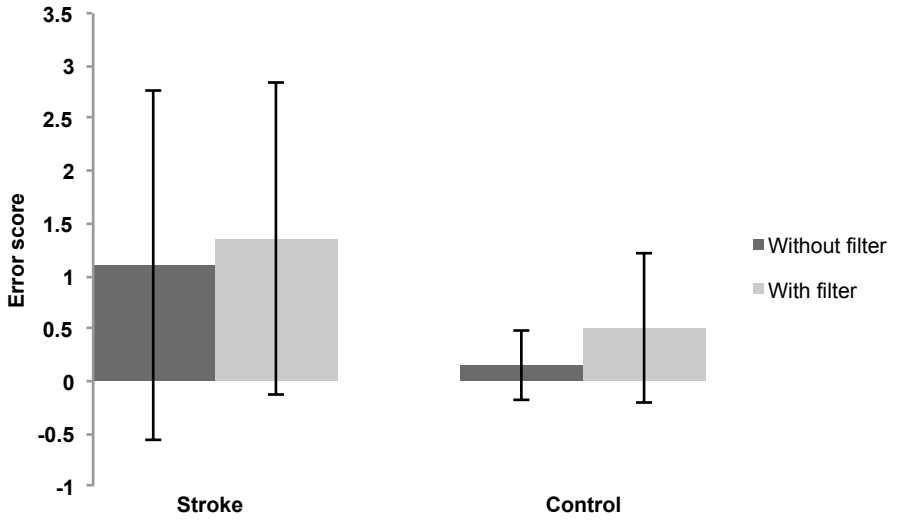

Figure 8.4 Session 1 results for error scores from the Circles Search Test showing comparison of Stroke Group 2 and Control Group 2. The use of a neutral grey filter increased error scores for stroke and control subjects. Error bars represent ± 1SD.

For response time, the within-subject analysis showed no main effect for the presence of the filter ($F_{(1, 35)} = 0.674$, P = 0.417), nor any significant interaction between filter and subject type ($F_{(1, 35)} = 0.058$, P = 0.811), or presence of filter, regardless of its type ($F_{(1, 35)} = 0.115$, P = 0.737). There was also a lack of interaction between the presence of the filter, subject type, and the type of filter ($F_{(1, 35)} = 0.011$, P = 0.919). The between-subject effects showed a difference for the main effect of participants performance, with control subjects completing the task more quickly than stroke subjects ($F_{(1, 35)} = 11.473$, P = 0.002) but no difference when considering the filter type ($F_{(1, 35)} = 0.031$, P = 0.862), nor any interaction between these factors ($F_{(1, 35)} = 1.227$, P = 0.276). For error scores, the within-subject analysis showed a main effect for the presence of the filter ($F_{(1, 35)} = 6.026$, P = 0.019), a reflection of increased errors with the filter in situ. There was no interaction between the use of the filter and the subject type ($F_{(1, 35)} = 0.655$, P = 0.424), nor the presence of the filter and its type ($F_{(1, 35)} = 1.068$, P = 0.309), and also a lack of interaction between the filter presence, filter type, and participant ($F_{(1, 35)} = 0.113$, P = 0.739). The between-subject factors showed no difference for

the main effect of participant type ($F_{(1, 35)} = 1.204$, $P = 0.280$), or for the filter-type ($F_{(1, 35)} = 0.262$, $P = 0.612$), with no interaction observed ($F_{(1, 35)} = 0.616$, $P = 0.438$).

8.5.3 Session 2

After a two-week break, the subjects were crossed over, with Stroke and Control Groups 1 given a grey filter to use for two weeks and Stroke and Control Groups 2 provided with an optimal filter to use over the same time period. The groups were then recalled to repeat the Circles Search Test.

Detailed data for the Circles Search Test in Session 2 for Stroke Group 1, Stroke Group 2, and Control Group 1 and Control Group 2, can be seen in Tables 8.7, 8.8, 8.9, and 8.10, respectively.

Stroke Subject	Age	Gender	Filter type	Response time (s) Without overlay	Response time (s) With overlay	Error score Without overlay	Error score With overlay
1	83	Female	Grey	54.0	62.0	0.0	0.0
3	64	Female	Grey	41.5	33.5	0.5	0.0
4	72	Male	Grey	66.5	73.0	8.0	8.0
5	71	Male	Grey	30.5	32.5	0.5	0.0
6	52	Male	Grey	38.0	43.5	0.0	0.0
7	77	Female	Grey	37.5	38.5	0.5	0.0
8	65	Male	Grey	50.5	46.0	0.0	0.0
9	62	Male	Grey	38.5	63.5	0.0	0.0
10	69	Female	Grey	41.0	55.0	5.5	5.5

Table 8.7 Session 2 results from the Circles Search Test for Stroke Group 1.

Stroke Subject	Age	Gender	Filter type	Response time (s) Without overlay	Response time (s) With overlay	Error score Without overlay	Error score With overlay
11	56	Female*	Lime green	23.5	28.0	0.0	0.0
12	49	Female	Purple	90.5	84.0	1.0	1.0
13	76	Female	Mint green	47.5	46.0	0.0	0.0
14	43	Male	Aqua	61.0	46.5	4.0	1.0
15	81	Female	Aqua	63.0	69.0	0.0	0.0
16	80	Female	Purple	42.0	55.0	0.0	0.5
17	74	Female	Yellow	108.0	98.5	3.0	4.0
18	72	Male*	Lime green	49.5	46.0	1.0	0.5
19	59	Male	Purple	48.0	56.5	0.5	0.0
20	85	Male	Pink	31.0	30.5	0.0	0.5

Table 8.8 Session 2 results from the Circles Search Test for Stroke Group 2.
* Migraine sufferer.

Control Subject	Age	Gender	Filter type	Response time (s) Without overlay	Response time (s) With overlay	Error score Without overlay	Error score With overlay
1	45	Female*	Grey	26.5	34.0	0.0	0.5
2	38	Male	Grey	24.5	24.0	0.0	0.0
3	63	Male	Grey	28.0	27.5	0.0	0.0
4	68	Female	Grey	40.5	53.5	0.0	0.0
5	70	Female	Grey	28.5	25.0	2.0	4.0
6	55	Female	Grey	18.5	20.5	0.0	0.5
7	84	Female	Grey	50.5	59.5	1.0	1.5
8	36	Female*	Grey	18.5	21.5	0.0	0.0
9	38	Male	Grey	18.0	18.0	0.0	0.0
10	62	Female*	Grey	27.5	26.5	0.0	0.0

Table 8.9 Session 2 results from the Circles Search Test for Control Group 1.
* Migraine sufferer.

Control Subject	Age	Gender	Filter type	Response time (s) Without overlay	Response time (s) With overlay	Error score Without overlay	Error score With overlay
11	55	Male	Orange	29.0	30.5	0.0	0.0
12	60	Male	Lime green	43.5	55.0	1.0	3.0
13	50	Male	Orange	21.0	23.0	0.0	0.0
14	68	Female	Blue	32.0	45.0	0.5	0.0
15	83	Male	Rose	24.0	33.0	0.0	0.5
16	61	Male	Orange	25.0	32.0	0.0	0.0
17	60	Male	Pink/Rose	26.0	30.0	0.0	0.0
18	54	Female	Yellow	23.0	23.0	0.0	0.0
19	40	Female	Mint green	32.5	31.0	0.0	0.0
20	78	Female	Blue	22.0	22.5	0.0	0.0

Table 8.10 Session 2 results from the Circles Search Test for Control Group 2.

A summary of data for Stroke Group 1 and Control Group 1 can be seen in Figures 8.5, 8.6 and Table 8.11.

Visual Search Task	Stroke Group 1 (n = 9) Mean ± SD	Control Group 1 (n = 10) Mean ± SD
Response time without overlay (s)	44.2 ± 10.9	28.1 ± 10.3
Response time with overlay (s)	49.7 ± 14.4	31.0 ± 14.2
Error score without overlay	1.7 ± 3.0	0.3 ± 0.7
Error score with overlay	1.5 ± 3.0	0.7 ± 1.3

Table 8.11 Session 2 results for the Circles Search Test showing comparison of Stroke Group 1 and Control Group 1 using a neutral filter.

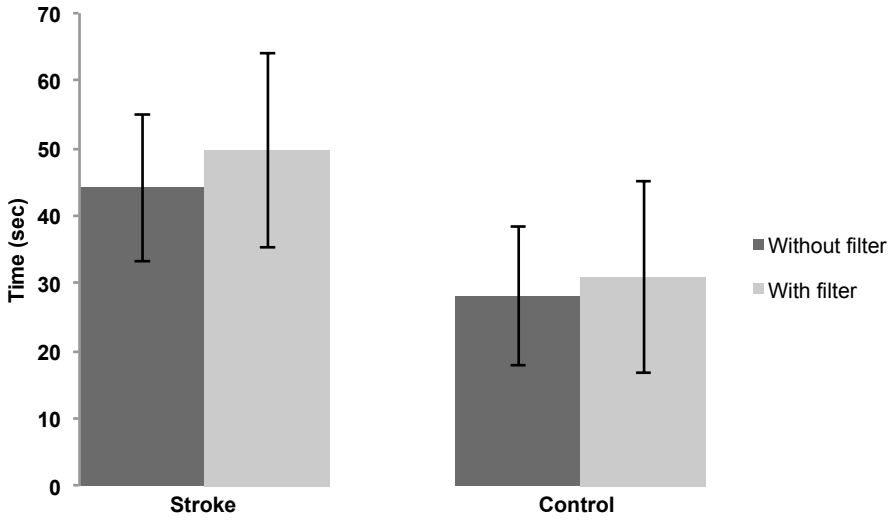

Figure 8.5 Session 2 results for Circles Search Test response time showing comparison of Stroke Group 1 and Control Group 1. The use of a neutral grey filter was not beneficial for either group. Error bars represent ± 1SD.

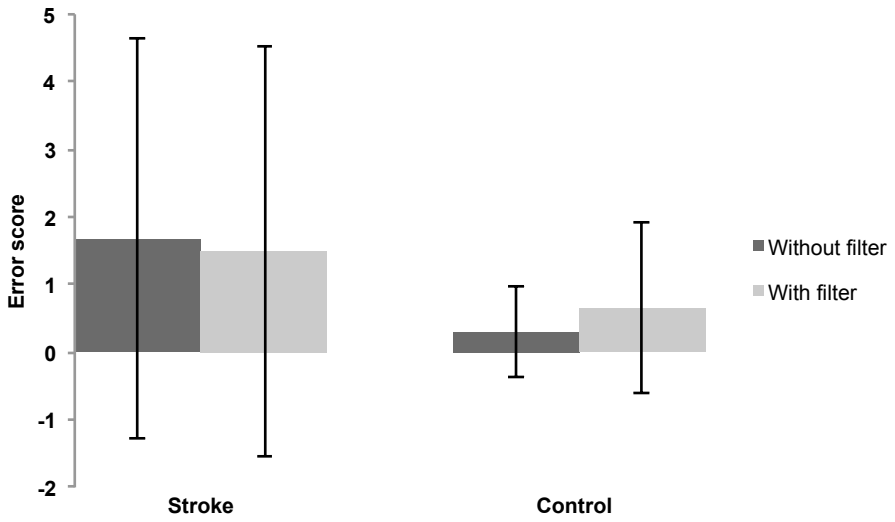

Figure 8.6 Session 2 results for error scores from the Circles Search Test showing comparison of Stroke Group 1 and Control Group 1. The use of a neutral grey filter did not reduce error scores for stroke or control subjects.

Stroke Group 2 and Control Group 2 were permitted to use their optimal filter for Session 2.

A summary of data can be seen in Figures 8.7, 8.8 and Table 8.12.

Visual Search Task	Stroke Group 2 (n = 10) Mean ± SD	Control Group 2 (n = 10) Mean ± SD
Response time without overlay (s)	56.4 ± 25.9	27.8 ± 6.8
Response time with overlay (s)	56.0 ± 22.3	32.5 ± 10.3
Error score without overlay	1.0 ± 1.4	0.2 ± 0.3
Error score with overlay	0.8 ± 1.2	0.4 ± 0.9

Table 8.12 Session 2 results from the Circles Search Test showing comparison of Stroke Group 2 and Control Group 2 using optimal spectral filter.

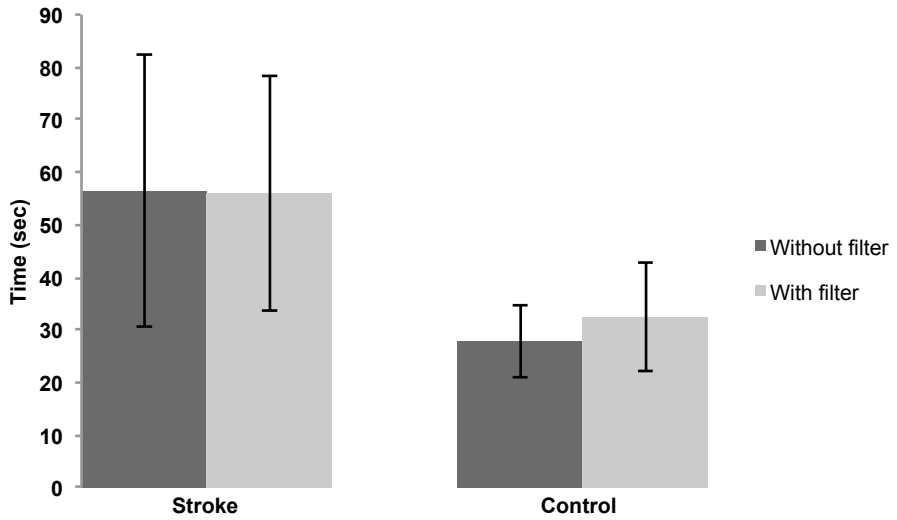

Figure 8.7 Session 2 results for Circles Search Test response time showing comparison of Stroke Group 2 and Control Group 2. The use of an optimal spectral filter did not improve the performance to a significant level in either group. Error bars represent ± 1SD.

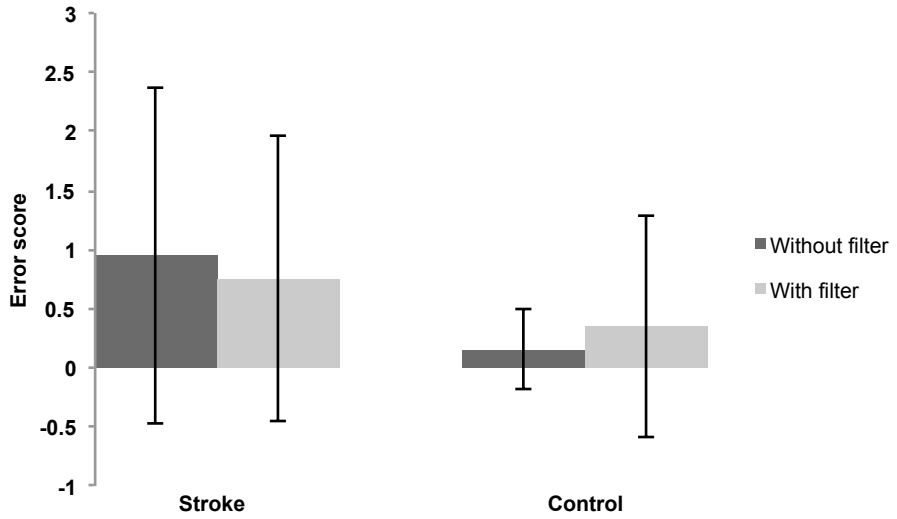

Figure 8.8 Session 2 results for error scores from the Circles Search Test showing comparison of Stroke Group 2 and Control Group 2. The use of an optimal spectral filter did

not reduce error scores for either group. Subjects were prepared to exhaust the search, at the expense of response time, in order to reduce errors. Error bars represent ± 1SD.

For response time, the within-subject analysis showed a main effect for the presence of a filter ($F_{(1, 35)} = 7.182$, $P = 0.011$) with subjects completing the task faster overall without a filter. There was no interaction between subject type and filter use ($F_{(1, 35)} = 0.278$, $P = 0.601$), nor for the presence of the filter and its type ($F_{(1, 35)} = 0.749$, $P = 0.393$). There was no interaction between the filter presence, participant and filter type ($F_{(1, 35)} = 2.640$, $P = 0.113$). The between-subject effects showed a difference between the main effect of subject performance with the stroke group taking longer to complete the task ($F_{(1, 35)} = 19.743$, $P = 0.000$) but no difference when considering the filter type ($F_{(1, 35)} = 1.009$, $P = 0.322$), nor any interaction between these factors ($F_{(1, 35)} = 0.778$, $P = 0.384$). For error scores, the within-subject analysis showed no main effect for the presence of the filter ($F_{(1, 35)} = 0.067$, $P = 0.798$), although an interaction between the participant type and the presence of the filter was observed ($F_{(1, 35)} = 4.801$, $P = 0.035$) with errors reduced for the stroke subjects with a filter, but for controls, they increased. The reduction in error score for stroke subjects considered in isolation did not reach significance for the placebo filter (Wilcoxon Singed Rank Test: df = 8, P = 0.083) nor the optimal filter (paired t-test: t = 0.583, df = 9, P = 0.574). There was no interaction between the filter presence and its type ($F_{(1, 35)} = 0.029$, $P = 0.865$), nor between the filter presence, its type, and subject type ($F_{(1, 35)} = 0.428$, $P = 0.517$). The between-subject factors showed no difference for the main effect of participant type ($F_{(1, 35)} = 2.516$, $P = 0.122$), nor for filter-type ($F_{(1, 35)} = 0.430$, $P = 0.516$), with no interaction ($F_{(1, 35)} = 0.012$, $P = 0.912$).

8.5.4 Intersession results

For Stroke and Control Group 1, a comparison of response times without a filter showed significant intersession improvement from baseline measures without a filter in the preceding

study (see Chapter 7) through to the final session without a filter in the present study ($F_{(2, 34)}$ = 12.058, P = 0.000); this was the case for stroke and control subjects ($F_{(2, 34)}$ = 0.301, P = 0.742) from the initial session in the preceding study to the first session in the present study (P = 0.044) as well as from the first to the second session in the present study (P = 0.011), with obvious improvement from baseline measures to final measures (P = 0.000). Stroke and Control Group 2 also demonstrated significant intersession response time improvement without a filter ($F_{(2, 36)}$ = 16.404, P = 0.000) for stroke and control subjects ($F_{(2, 36)}$ = 0.886, P = 0.421); this was the case from the initial session in the preceding study to the first session in the present study (P = 0.002) but not between the first and the second sessions (P = 0.084), although a significant improvement from baseline to final session measures (P = 0.000).

Error score intersession results did not show improvement for Group 1 ($F_{(2, 34)}$ = 0.215, P = 0.808), for stroke or control subjects ($F_{(2, 34)}$ = 1.650, P = 0.207); this was the case for initial measures without a filter in the preceding study to the first session without a filter in the present study (P = 0.572), as well as from the first to the second session (P = 0.403) and also from baseline to final measure (P = 0.882). For Group 2, there were improvements in error score between sessions ($F_{(2, 36)}$ = 0.390, P = 0.045), for stroke and control subjects ($F_{(2, 36)}$ = 2.394, P = 0.106) but only reaching significance for baseline to final session measures (P = 0.044) and not for initial session in the preceding study to first session in the present study (P = 0.081), or for Session 1 to Session 2 in the present study (P = 0.697).

8.6 Results without migraine subjects

With the migraine subjects removed from the data set Stroke Group 1 (n = 9) was found to be age-matched to Stroke Group 2 (n = 8) (unpaired t-test: t = 0.007, dF = 15, P = 0.995), with Group 1 having an age range of 52-83 years (mean 68.33 SD 9.00) and Group 2 with an age-range of 43-85 (mean 68.38 SD 15.89). The time interval since their stroke (or most recent stroke) had a range of 0.83-11 years (mean 4.19 SD 3.64 years) for Stroke Group 1

and 3-12 years (mean 6 SD 2.98 years) for Stroke Group 2; the time intervals were not significantly different (unpaired t-test: t = 1.117, dF = 15, P = 0.282). Response times during the Circles Search Test in the preceding study (see Chapter 7) were similar for Stroke Group 1 and Stroke Group 2 ($F_{(1, 15)}$ = 1.476, P = 0.243), with both sets of subjects improving with the use of an optimally-selected spectral filter ($F_{(1, 15)}$ = 8.177, P = 0.012), with no interaction between these factors ($F_{(1, 15)}$ = 0.349, P = 0.564). Error scores were not significantly different between these two groups ($F_{(1, 15)}$ = 0.458, P = 0.509), with neither group showing a significant reduction in errors whilst using a filter ($F_{(1, 15)}$ = 0.000, P = 0.984), with no interaction between these factors ($F_{(1, 15)}$ = 0.018, P = 0.895).

With the migraine subjects removed from the control data set, Group 1 had an age-range of 38-84 years (mean 59.42 SD 17.03), and was matched to Group 2 (unpaired t-test: t = 0.204, dF = 15, P = 0.841), having an age-range of 40-83 years (mean 60.90 SD 12.78). Response times for these groups during the Circles Search Test in the preceding study (see Chapter 7) were not significantly different ($F_{(1, 15)}$ = 0.686, P = 0.421), with neither group benefiting from using a spectral filter during the task ($F_{(1, 15)}$ = 0.470, P = 0.503), confirmed by no interaction between the two factors ($F_{(1, 15)}$ = 0.095, P = 0.762). For error scores, the groups were not significantly different ($F_{(1, 15)}$ = 0.380, P = 0.547), with neither showing improvement with an optimal filter ($F_{(1, 15)}$ = 0.578, P = 0.459) and no interaction between factors ($F_{(1, 15)}$ = 2.449, P = 0.138).

8.6.1 Session 1

Stroke Group 1 and Control Group 1 were age-matched (unpaired t-test: t = 1.353, dF = 14, P = 0.197). A summary of data for Stroke Group 1 and Control Group 1 can be seen in Figures 8.9, 8.10 and Table 8.13.

Visual Search Task	Stroke Group 1 (n = 9) Mean ± SD	Control Group 1 (n = 7) Mean ± SD
Response time without overlay (s)	51.6 ± 13.2	42.8 ± 28.3
Response time with overlay (s)	52.3 ± 16.9	41.4 ± 18.9
Error score without overlay	1.4 ± 2.8	1.0 ± 1.1
Error score with overlay	1.4 ± 2.8	1.4 ± 1.8

Table 8.13 Session 1 results from the Circles Search Test showing comparison of Stroke Group 1 and Control Group 1 using optimal spectral filter, with the exclusion of migraine subjects.

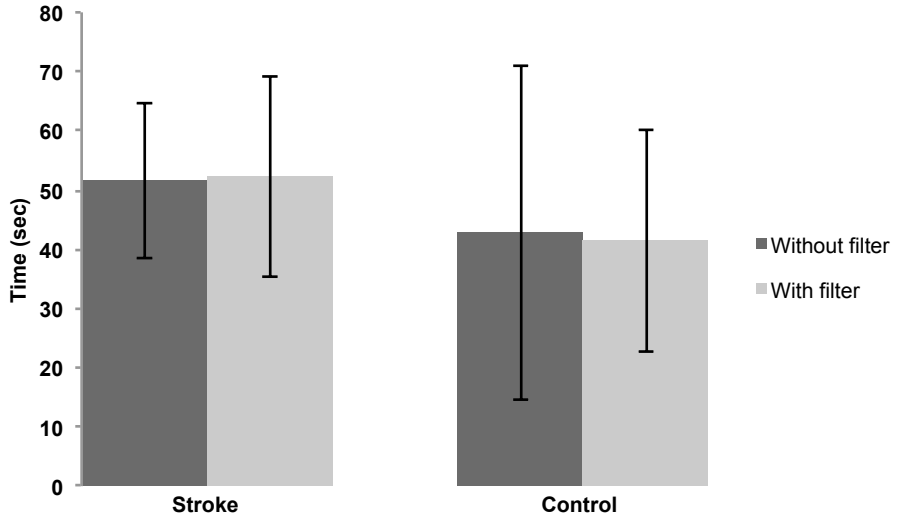

Figure 8.9 Session 1 results for Circles Search Test response time showing comparison of Stroke Group 1 and Control Group 1, with the exclusion of migraine subjects. The use of an optimal spectral filter did not improve the time taken for the either group. Error bars represent ± 1SD.

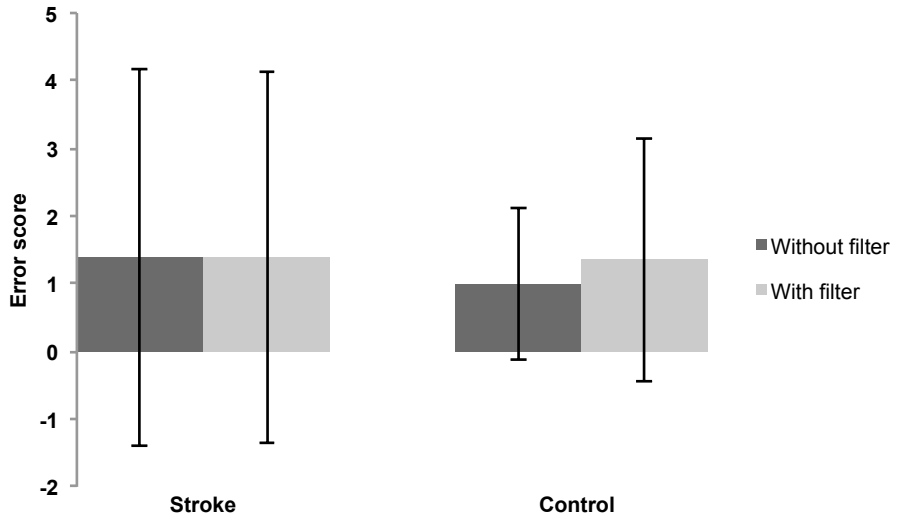

Figure 8.10 Session 1 results for error scores from the Circles Search Test showing comparison of Stroke Group 1 and Control Group 1, with the exclusion of migraine subjects.

The use of an optimally determined spectral filter did not reduce error scores for either group. Error bars represent ± 1SD.
The stroke and control subjects in Group 2 were age-matched (unpaired t-test: t = 1.108, dF = 16, P = 0.284). A summary of data for Stroke Group 2 and Control Group 2 can be seen in Figures 8.11, 8.12 and Table 8.14).

Visual Search Task	Stroke Group 2 (n = 8) Mean ± SD	Control Group 2 (n = 10) Mean ± SD
Response time without overlay (s)	64.7 ± 27.6	32.4 ± 7.1
Response time with overlay (s)	65.5 ± 25.2	33.4 ± 5.9
Error score without overlay	1.3 ± 1.8	0.2 ± 0.3
Error score with overlay	1.6 ± 1.6	0.5 ± 0.7

Table 8.14 Session 1 results from the Circles Search Test showing comparison of Stroke Group 2 and Control Group 2 using neutral filter, with the exclusion of migraine subjects.

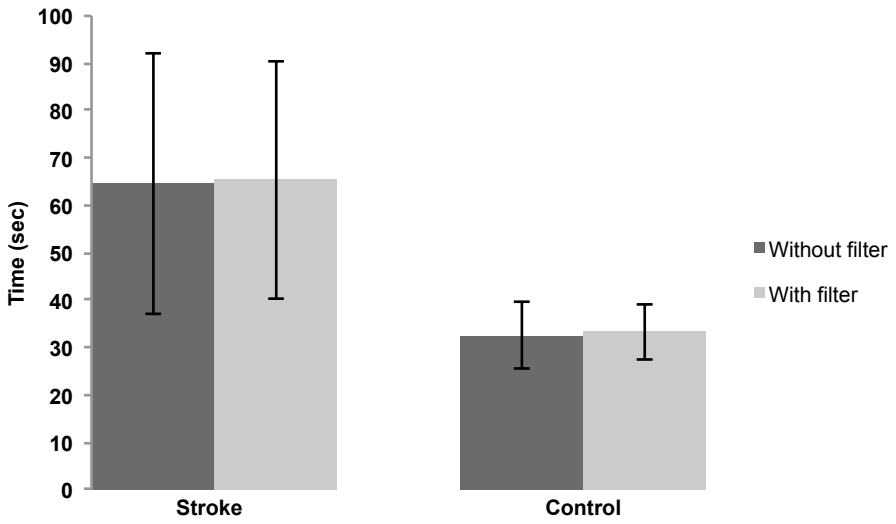

Figure 8.11 Session 1 results for the Circles Search Test response time showing comparison of Stroke Group 2 and Control Group 2, with the exclusion of migraine subjects. The use of a neutral grey filter was not beneficial for either group. Error bars represent ± 1SD.

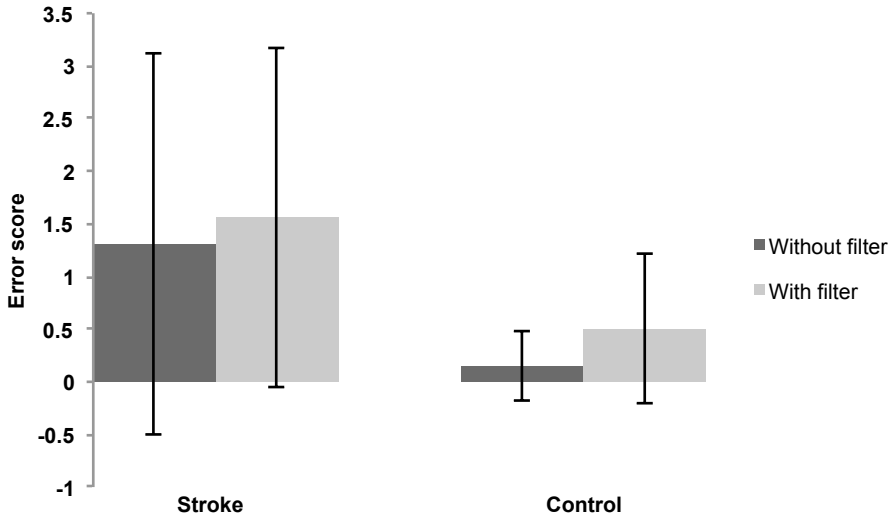

Figure 8.12 Session 1 results for error scores from the Circles Search Test showing comparison of Stroke Group 2 and Control Group 2, with the exclusion of migraine subjects. The use of a neutral grey filter did not reduce error scores for stroke or control subjects. Error bars represent ± 1SD.

For response time, the within-subject analysis showed no main effect for the presence of the filter ($F_{(1, 30)} = 0.046$, $P = 0.831$), nor any significance shown for the interaction between filter and participant ($F_{(1, 30)} = 0.137$, $P = 0.714$), as well as for the presence of filter, of both types ($F_{(1, 30)} = 0.209$, $P = 0.651$). An interaction between the presence of the filter, the participant, and the type of filter was not observed ($F_{(1, 30)} = 0.179$, $P = 0.676$). The between-subject effects showed a difference between the main effect of participants performance, with the control subjects completing the task faster than the stroke subjects ($F_{(1, 30)} = 10.901$, $P = 0.002$) but no difference in their performance when considering the filter type ($F_{(1, 30)} = 0.096$, $P = 0.759$), nor any interaction between these factors ($F_{(1, 30)} = 3.099$, $P = 0.089$). For error scores, the within-subject analysis showed no main effect for the presence of the filter ($F_{(1, 30)} = 3.876$, $P = 0.058$), with no interaction between filter presence and the participant type ($F_{(1, 30)} = 0.337$, $P = 0.566$), nor the presence of the filter and its type ($F_{(1, 30)} = 1.085$, $P = 0.306$). No interaction was shown between the filter presence, filter type, and participant ($F_{(1, 30)} = 0.009$, $P = 0.924$). The between-subject factors showed no difference for the main effect of participant type ($F_{(1, 30)} = 0.825$, $P = 0.371$) nor for the filter-type ($F_{(1, 30)} = 0.247$, $P = 0.623$), with no interaction observed ($F_{(1, 30)} = 1.164$, $P = 0.289$).

8.6.2 Session 2

A summary of data for Stroke Group 1 and Control Group 1 in this session can be seen in Figures 8.13, 8.14 and Table 8.15.

Visual Search Task	Stroke Group 1 (n = 9) Mean ± SD	Control Group 1 (n = 7) Mean ± SD
Response time without overlay (s)	44.2 ± 10.9	29.8 ± 11.9
Response time with overlay (s)	49.7 ± 14.4	32.6 ± 16.7
Error score without overlay	1.7 ± 3.0	0.4 ± 0.8
Error score with overlay	1.5 ± 3.0	0.9 ± 1.5

Table 8.15 Session 2 results from the Circles Search Test showing comparison of Stroke Group 1 and Control Group 1 using neutral filter, with the exclusion of migraine subjects.

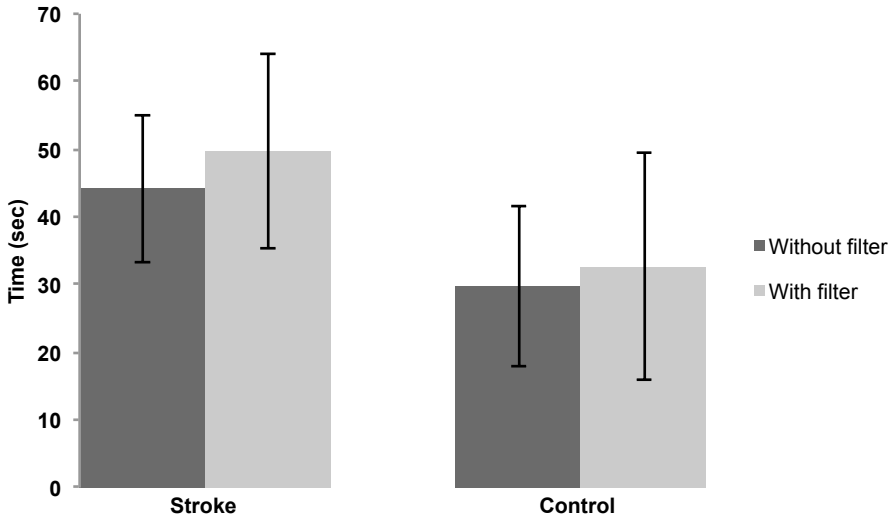

Figure 8.13 Session 2 results for Circles Search Test response time showing comparison of Stroke Group 1 and Control Group 1, with the exclusion of migraine subjects. The use of a neutral grey filter did not improve task performance for either group. Error bars represent ± 1SD.

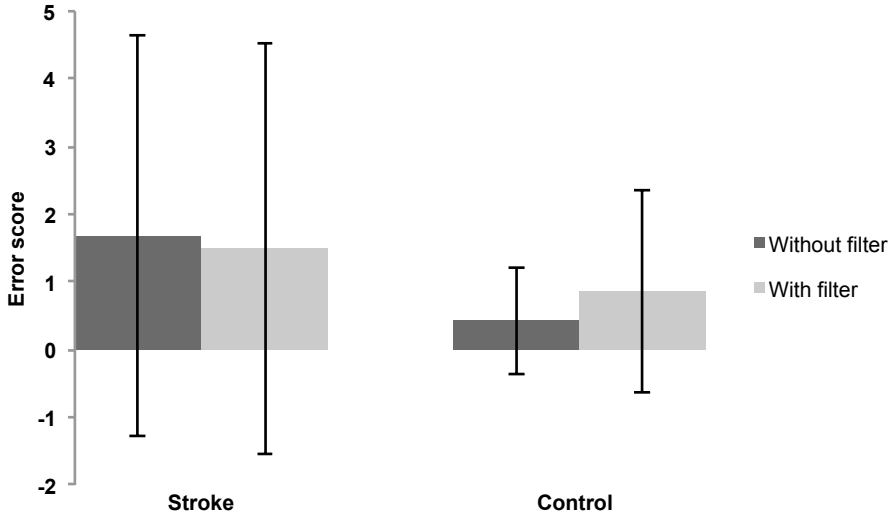

Figure 8.14 Session 2 results for error scores from the Circles Search Test showing comparison of Stroke Group 1 and Control Group 1, with the exclusion of migraine subjects. The use of a neutral grey filter did not benefit either group. Error bars represent ± 1SD.

A summary of data for Stroke Group 2 and Control Group 2 can be seen in Figures 8.15, 8.16 and Table 8.16.

Visual Search Task	Stroke Group 2 (n = 8) Mean ± SD	Control Group 2 (n = 10) Mean ± SD
Response time without overlay (s)	61.4 ± 25.9	27.8 ± 6.8
Response time with overlay (s)	60.8 ± 22.1	32.5 ± 10.3
Error score without overlay	1.1 ± 1.6	0.2 ± 0.3
Error score with overlay	0.9 ± 1.3	0.4 ± 0.9

Table 8.16 Session 2 results from the Circles Search Test showing comparison of Stroke Group 2 and Control Group 2 using an optimal spectral filter, with the exclusion of migraine subjects.

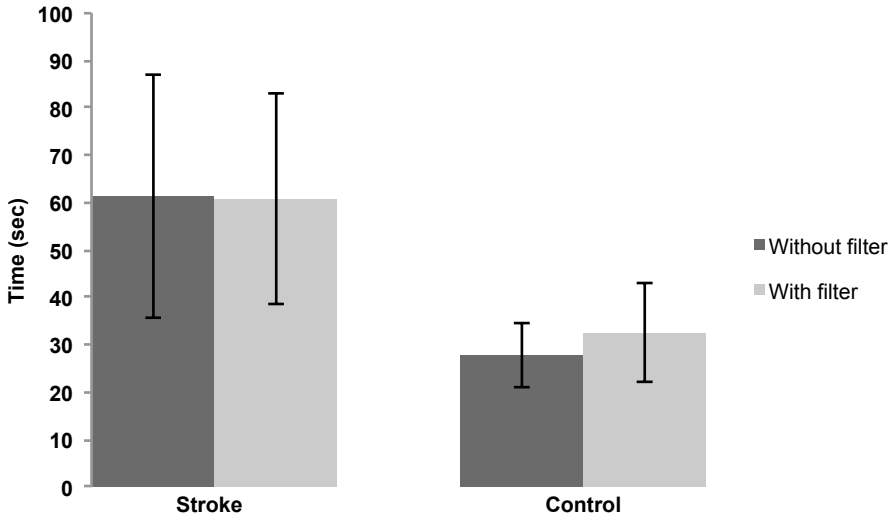

Figure 8.15 Session 2 results for Circles Search Test response time showing comparison of Stroke Group 2 and Control Group 2, with the exclusion of migraine subjects. The use of an optimal spectral filter did not improve the task speed to a significant level in either group. Error bars represent ± 1SD.

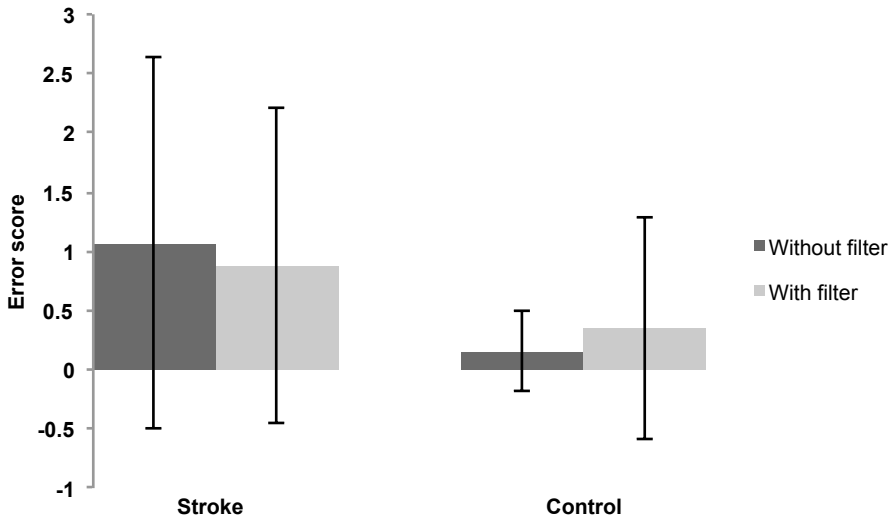

Figure 8.16 Session 2 results for error scores from the Circles Search Test showing comparison of Stroke Group 2 and Control Group 2, with the exclusion of migraine subjects. The use of an optimal spectral filter did not reduce error scores for either group. Error bars represent ± 1SD.

The within-subject analysis for the main effect showed an increased response time with the filter in situ ($F_{(1, 30)} = 5.197$, $P = 0.030$). No interaction was observed between the participant

type or filter presence ($F_{(1, 30)}$ = 0.232, P = 0.634), nor for the presence of the filter and its type, ($F_{(1, 30)}$ = 0.603, P = 0.443). There was also no interaction found for the filter presence, participant and filter type ($F_{(1, 30)}$ = 2.198, P = 0.149). The between-subject effects showed a difference between the main effect for participant type ($F_{(1, 30)}$ = 19.962, P = 0.000) but no difference when considering the filter type ($F_{(1, 30)}$ = 0.221, P = 0.158), nor any interaction between these factors ($F_{(1, 30)}$ = 2.092, P = 0.158). For error scores, the within-subject analysis showed no main effect for the presence of the filter ($F_{(1, 30)}$ = 0.142, P = 0.709), and no interaction between the participant type and the presence of the filter ($F_{(1, 30)}$ = 3.721, P = 0.063) or between the filter presence and its type ($F_{(1, 30)}$ = 0..023, P = 0.879). There was also, no interaction between the filter presence, its type, and the participant, ($F_{(1, 30)}$ = 0.545, P = 0.466). The between-subject factors showed no difference for the main effect of participant type ($F_{(1, 30)}$ = 1.714, P = 0.200), nor for filter-type ($F_{(1, 30)}$ = 0.404, P = 0.530), with no interaction observed either ($F_{(1, 30)}$ = 0.035, P = 0.853).

8.7 Discussion

The present study has shown, in agreement with earlier work (Keller and Lefin-Rank, 2010; Hildebrant *et al.*, 2005) and concurs with the results in Chapter 7, that visual search ability is adversely affected as a result of stroke. The present study failed to demonstrate a response time advantage for a stroke cohort using optimal spectral filters, with no difference in performance when compared to a placebo filter. In fact, following a cross over from an optimal to a placebo filter for the first group and *vice versa* for the second group, response times increased with the use of a filter, regardless of its type; these findings were replicated within the control group and persisted with the removal of migraine subjects from the analyses. It is noteworthy that slower response times during visual search with spectral filters have been reported in a similar study, for control subjects at least (Newman Wright *et al.*, 2007).

For error scores, the present study failed to show any benefit from the introduction of spectral filters. Indeed, errors either increased or remained unchanged for stroke subjects and increased for control subjects, regardless of the filter type; this outcome was replicated following removal of migraine subjects from the data set. Statistical power calculated at ~86% suggests that the outcome is unlikely to be due to an insufficient sample, with a large enough cohort to detect a medium effect size. The findings in the present study are supported by earlier work that failed to show improvements using spectral filters for error score or response time in subjects with high levels of visual stress (Allen et al, 2008), although this is in contrast to the error score reduction with optimal spectral filters noted in multiple sclerosis sufferers in a study using the Circles Search Test (Newman Wright *et al.*, 2007).

The present findings are confounded by an expectation that subjects would be more responsive with an optimal filter they had self-selected rather than a novel filter issued by the investigator. It is worth noting incremental improvements for inter-session response time, from baseline measures in the preceding study (see Chapter 7) through to the final session in the present study, suggesting significant practice effects; these findings may obscure potential benefits of optimal spectral filters on visual search performance.

The present study was limited by potential bias of recruiting some of the cohort from an optometric practice given that these subjects may be predisposed to visual symptoms. The design of the study lacked masking and further work could be undertaken utilising double masked techniques adopted by others using precision tinted ophthalmic lenses (Wilkins et al, 1994). Subjects were not subdivided on the basis of visual field defects or motor deficits, nor were participants screened for potential co-existing ocular conditions that may impact on visual search ability, such as glaucoma (Smith et al, 2011) and this presents an opportunity for further work.

8.8 Conclusion

It seems that neither optimal nor neutral filters offer advantage for stroke subjects and may have a detrimental effect on visual search ability in terms of response time and error score. These adverse outcomes may be due to contrast reduction or simply a reflection of task design (see Chapter 9).

9.0 General discussion

The aim of the programme of research has been to investigate pattern glare susceptibility following stroke and to elucidate the effect of optimal spectral filters on the speed and accuracy of reading and visual search performance in this subject group. The present work has shown an association between elevated levels of pattern glare and stroke, the symptoms of which can be ameliorated with the use of spectral filters. The initial case report in Chapter 3 provided justification for the investigations in the experimental chapters that followed. An interesting feature of the isolated case history was the need to modify the tint characteristics following further stroke events and it would useful to establish if this is a common occurrence in multiple stroke victims. The experiments in the present thesis have shown elevated levels of pattern glare with immediate and prolonged improvements in reading speed and error reduction in a stroke cohort using optimal spectral filters. Despite the grey filter (see Chapters 6 and 8) having similar photopic reflectance to the coloured filters, its intended use as a valid placebo intervention is called into question given its negative effect on reading speed and visual search performance. Furthermore, the study design lacked masking and future-work as a double-masked randomised trial should be undertaken using precision tinted lenses with sub-optimal and neutral lenses as controls. Ultimately, it would be desirable, in collaboration with neurological researchers, to undertake a neurophysiological study to measure the impact of precision tints on cortical activity in a stroke cohort. The marked reduction in error scores (see Chapters 5 and 6) with optimal filters for stroke subjects undertaking the Wilkins Rate of Reading Test creates an argument for wider reporting of this outcome measure in studies of this type. Often in the literature, greater emphasis is given to the number of words correctly read by the subject. Whilst this gives the measure of reading speed it does not give the same insight into task fluency that the reporting of error scores do. Undoubtedly, providing details of both outcome measures gives the reader a greater sense of how the subject performed during the task.

Clearly, more work is required to consider the utility of precision tinted lenses in a wider stroke group with further questions to answer. The association between pattern-related visual stress and other visual defects resulting from stroke, such as visual field defects and binocular vision anomalies should be determined with the influence of prescribing spectral filters on the long-term outcomes of these co-existing visual deficits being considered. In the present thesis, the majority of subjects were longstanding stroke patients (see Section 4.3) and it would be prudent for future work to consider the impact of time interval on symptoms of visual stress by recruiting stroke victims of recent diagnosis. In particular, to establish perhaps, if symptoms are maximal soon after the stroke event with spontaneous resolution in some patients, or more importantly, does the timely intervention with spectral filters improve the long-term prognosis for reading in these individuals? Further studies should also consider the site of the stroke event and also aetiology in relation to visual stress symptoms, although these considerations are of less significance in a clinical management context, however, given that patients are typically unaware of this specific detail when presenting to the optometrist. An earlier study has reported that spectral filters can improve speech, motor coordination, seizures, word retrieval, communication, as well as reducing anxiety and irritability following traumatic brain injury, including stroke, although these outcomes are based on symptom journals (Tosta and Johnson, 2009). An opportunity exists for a multidisciplinary study to investigate these findings with a more robust scientific design.

Given the evidence of cortical hyperexcitability following transient ischaemic attack (Koerner and Meinck, 2004), it would be useful to explore levels of pattern glare in these subjects. A study modeled on the experiment in Chapter 4 using the Pattern Glare Test could be easily undertaken. The Pattern Glare Test is an excellent clinical tool although a potential limitation of the test is that some patients, particularly those with impaired cognitive function, may find it difficult to differentiate between the subtleties of the questions asked during the test. For example, a subject may be unable to distinguish between ‘fading’, ‘shimmering/flickering’ or ‘shadowy shapes’. An alternative proposal for future work, to reduce ambiguity in these

instances, would be to use a psychometric method of assessment such as the Likert scale, as shown in Appendix 5. The subject would be asked to rate each pattern in turn from being comfortable to uncomfortable to view, on a scale of 1 to 10, respectively, thus producing a score for each pattern. It would be anticipated that as with the conventional scoring system, subtracting the score for the high spatial frequency grating from the mid spatial frequency grating, thereby normalising the subject, may be of most diagnostic value. Naturally, this proposal would require validation and normative values to be established. In addition to the potential merits of the Likert scale system, this scoring method would also lend itself to the formation of a Pattern Glare Application, suitable for a tablet pc platform making the test accessible to a wide, multidisciplinary, audience. The test in this format could be self-completed or undertaken by those without direct expertise, with the result indicating if the subject had a normal or high level of pattern glare, directing appropriately, those requiring further investigation to a clinician, namely a local optometrist.

Despite the outcome for visual search measures agreeing with earlier studies that stroke subjects suffer impairment to visual search ability, the potential for task improvement with optimal spectral filters remains equivocal. Preliminary findings in Chapter 7 showed early promise with subjects recording improved response time with an optimal spectral filter. However, further investigation with subjects using filters over a prolonged period gave contrasting findings with no reduction in response time or error scores when using an optimal filter during visual search; these conflicting outcomes may be a reflection of task design given that significant practice effects were noted. Indeed, three subjects commented, albeit within the control group, that whilst undertaking the visual search task for the final time, they felt primed by previous experience. The spatial frequency content of the Circles Search Test does fall within the range to potentially induce a visually stressful response in susceptible subjects (unpublished data, Wilkins, 2012) and performance may, therefore, be expected to improve with an optimal filter. It would be prudent for future studies of similar design to use further versions of the Circles Search Test to mitigate for practice effects. Further, perhaps a

modification to the design, with random placement of *unknown* target numbers would enable further insight into the utility of spectral filters in this subject group. A design of this type presents a different dilemma for the subject, i.e. deciding whether to exhaust the search for targets at the expense of response time or risk increased error scores in order to limit task completion time.

9.1 Conclusion

The outcome from the present thesis and the publications that have followed provide the optometric community with the knowledge to better serve the stroke patients they encounter in routine practice. An awareness that stroke patients may present with pattern related visual stress will allow for appropriate assessment and management of symptoms with conventional interventions such as spectral filters and precision tinted lenses. Optometrists are well placed to undertake these assessments as well as eliminating less obscure causes of presenting symptoms in these cases (Evans, 2005).

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Appendix 1

Ethical approval

Response from AOREC

13th January 2010

Project title: ***Susceptibility to pattern glare and the effect of spectral filters on rate of reading and visual search in stroke patients***

Reference Number: Beasley OD
Researchers: Dr Leon Davies and Mr Ian Beasley

I am pleased to inform you that the Audiology / Optometry Research Ethics Committee has approved the above named project.

The details of the investigation will be placed on file. You should notify The Committee of any difficulties experienced by the volunteer subjects, and any significant changes which may be planned for this project in the future.

Yours sincerely

AOREC

Ethical approval (amendments)

Aston University
Life & Health Sciences

Response from AOREC

5th August 2010

Project title: Susceptibility to pattern glare and the effect of spectral filters on rate of reading and visual search in stroke patients

Reference Number: Beasley OD (amendments)
Researchers: Dr Leon Davies and Mr Ian Beasley

I am pleased to inform you that the Audiology / Optometry Research Ethics Committee have approved the amendments to the above named project.

The details of the investigation will be placed on file. You should notify The Committee of any difficulties experienced by the volunteer subjects, and any significant changes which may be planned for this project in the future.

Yours sincerely,

Dr Leon N. Davies
Chair AOREC

Appendix 2

Date: _____

Consent form and guidance notes – version 002

Research workers, school and subject area responsible

Dr. Leon N. Davies, Life & Health Sciences, Vision Sciences, Aston University
Mr. Ian G. Beasley, Life & Health Sciences, Vision Sciences, Aston University

Project Title

Susceptibility to pattern glare and the effect of spectral filters on rate of reading and visual search in stroke patients

Invitation

You are being invited to take part in a research study. Before you decide if you wish to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?

In everyday life, many people experience discomfort when looking at certain types of images, such as viewing repetitive striped patterns on wall paper, or when ironing striped shirts. This is termed 'pattern glare' and for susceptible people this can result in visual stress, giving rise to symptoms of eyestrain, headaches and glare, along with illusions of colours, shape and motion.

The primary goal of clinical research is to produce new knowledge that will help others in the future. The purpose of this study is to determine whether stroke patients are more susceptible to pattern glare than the general population, resulting in visual stress. The study will investigate the effects of pattern glare on the performance of everyday visual tasks such as reading. Finally, the project will investigate if these effects can be modified by using high quality coloured filters, with the aim of reducing visual stress.

Where will the study take place?

If you decide to participate in the project, you will be required to attend at the research venue, Eyesite Eyecare Centres, 26 Warwick Road, Kenilworth, CV8 1HE, at a mutually convenient time.

It would be possible for alternative arrangements to be made if you are unable to attend this research venue. For example, the research could be conducted at a Stroke Association support group centre or within your own home.

What will happen to me if I take part?

By volunteering to participate in this study, you will be invited to attend our practice on four occasions, for about half an hour each time, to undertake short visual tasks of a varying nature which are detailed below:

Session 1: Pattern Glare Test

At this session, you will be asked to provide brief details about your clinical history. For example, it is important for us to know about any history of stroke, if you have been discharged from the care of your consultant, if you have ever had an epileptic fit, if you are a migraine sufferer, along with a few other details of a similar nature. This will be followed by a short assessment, called the Pattern Glare Test. This test involves viewing a series of three striped patterns and recording any symptoms that they may produce such as, patterns, colours, shimmering or other effects.

It is estimated that this session will take no longer than thirty minutes.

Session 2: Coloured Overlay Assessment, Rate of Reading and Visual Search

This session will be arranged one week after session 1.

This assessment will consist of some simple visual tasks comparing your performance when viewing with and without coloured overlays (spectral filters).

To begin with, you will be shown a series of different coloured overlays in a sequence to determine which offers you the greatest visual comfort. Your Rate of Reading will then be measured. This involves reading a passage of simple random words over a one minute period, both with and without your chosen coloured overlay. Finally for this session, you will be asked to perform a Visual Search task. This will test your ability to spot circles which are randomly placed within rows of ovals, with your time and accuracy measured. Once again, your performance in this test will be compared both with and without your chosen coloured overlay.

It is estimated that this session will take around thirty minutes.

Allocation of coloured overlays

One week after session 2, you will be randomly allocated to one of two groups. You will be issued with a specific overlay to use when reading, as you wish, for a period of two weeks.

Session 3: Rate of Reading and Visual Search

At this point, you will have been using your assigned coloured overlay for two weeks and it is important to assess its effects.

Your Rate of Reading test will be repeated as in session 2, both with and without the coloured overlay that you were issued with. The Visual Search test will also be repeated, both with and without your assigned coloured overlay.

At the end of this session, which will take around twenty minutes, your coloured overlay needs to be returned.

Reallocation of coloured overlays

After a two week break, you will now be issued with a different coloured overlay. Once again, this is to be used for a two week period whilst reading and you can choose to use it as often as you wish.

Session 4: Rate of Reading and Visual Search

You will have been using your newly assigned coloured overlay for two weeks and it is important to compare its effects with the first overlay you were issued with.

Your Rate of Reading test will be repeated for a final time as in sessions 2 and 4, both with and without the second coloured overlay that you were issued with after session 3. The Visual Search test will also be repeated, both with and without your newly assigned coloured overlay.

At the end of this final session, you will be asked if you wish to keep either of the two overlays for future use, and your preference will be recorded.

This session will take around twenty minutes.

You will not be required to carry out any further tasks.

Are there any potential risks in talking part in the study?

There is a risk of breaching privacy and confidentiality in relation to the results in these assessments. This risk will be minimised by keeping your data secure and anonymous at all times. Other members of the research team will only be given access to the data, after your identity has been removed.

Some individuals may experience some nausea or dizziness during some of the assessments but steps will be taken to reduce the potential effects of this. It is worth noting that these tests are used routinely in day-to-day practice to identify individuals susceptible to visual stress with a view to providing long-term visual solutions which may be of benefit. It must be emphasised though, that the potential benefit to any individual participating in this project cannot be predicted.

Important

It has been reported that a few people with photosensitive epilepsy have suffered seizures as a result of undertaking these tests. If you have a history of epilepsy, then you will be excluded from the tests as a precaution for your safety.

Do I have to take part?

No, you do not have to participate if you do not wish to do so. You are free to withdraw at any time from the project.

Expenses and payments

There are no expenses or payments for participation in this project.

Will my taking part in this study be kept confidential?

Privacy and confidentiality will be protected vigorously to the extent permissible by law. We cannot, however, guarantee privacy or confidentiality.

What will happen to the results of the research study?

We aim to publish the results of this project. However, there will be no reference to any individual's performance in any publication. If publication is achieved then you will be contacted to see if you wish to receive a copy.

Who is organising and funding the research?

The project is being conducted by a research team at Aston University. There is no funding for this research project.

Who has reviewed the study?

The research has been submitted and granted approval by the Audiology and Optometry Ethics Committee at Aston University.

Who do I contact if something goes wrong or I need further information

Please contact the principal investigator, Dr Leon N. Davies (l.n.davies@aston.ac.uk).

Who do I contact if I wish to make a complaint about the way in which the research is conducted?

If you have any concerns about the way in which the study has been conducted, then you should contact Secretary of the University Research Ethics Committee on j.g.walter@aston.ac.uk or telephone 0121 204 4665.

Personal Identification Number for this study: Beasley OD

CONSENT FORM

Title of Project: Susceptibility to pattern glare and the effect of spectral filters on rate of reading and visual search in stroke patients

Research Venue: Eyesite Eyecare Centres, 26 Warwick Road, Kenilworth, CV8 1HE

Name of Investigator(s):

Dr. Leon N. Davies
Mr. Ian G. Beasley

Please initial box

1. I confirm that I have read and understand the information sheet dated ..... ☐ (version 002) for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, ☐ without giving any reason, without my legal rights being affected.

3. I agree to take part in the above study. ☐

_____	_____	_____
Name of Research Participant	Date	Signature
_____	_____	_____
Name of Person taking Consent	Date	Signature

1 copy for research participant; 1 copy for supervisor

Appendix 3

Patient code: _____

Session 1 – Initial questionnaire

Patient age: Gender: Last eye exam: Next eye exam due:

1. Have you ever suffered from a stroke?

If no, go to question 4

If yes, go to section 2.

2. Please record below the approximate dates of when the stroke(s) occurred.

3. Have you been discharged from the medical care of the stroke unit?

4. Do you suffer from or have you ever suffered from epileptic seizures (fits)?

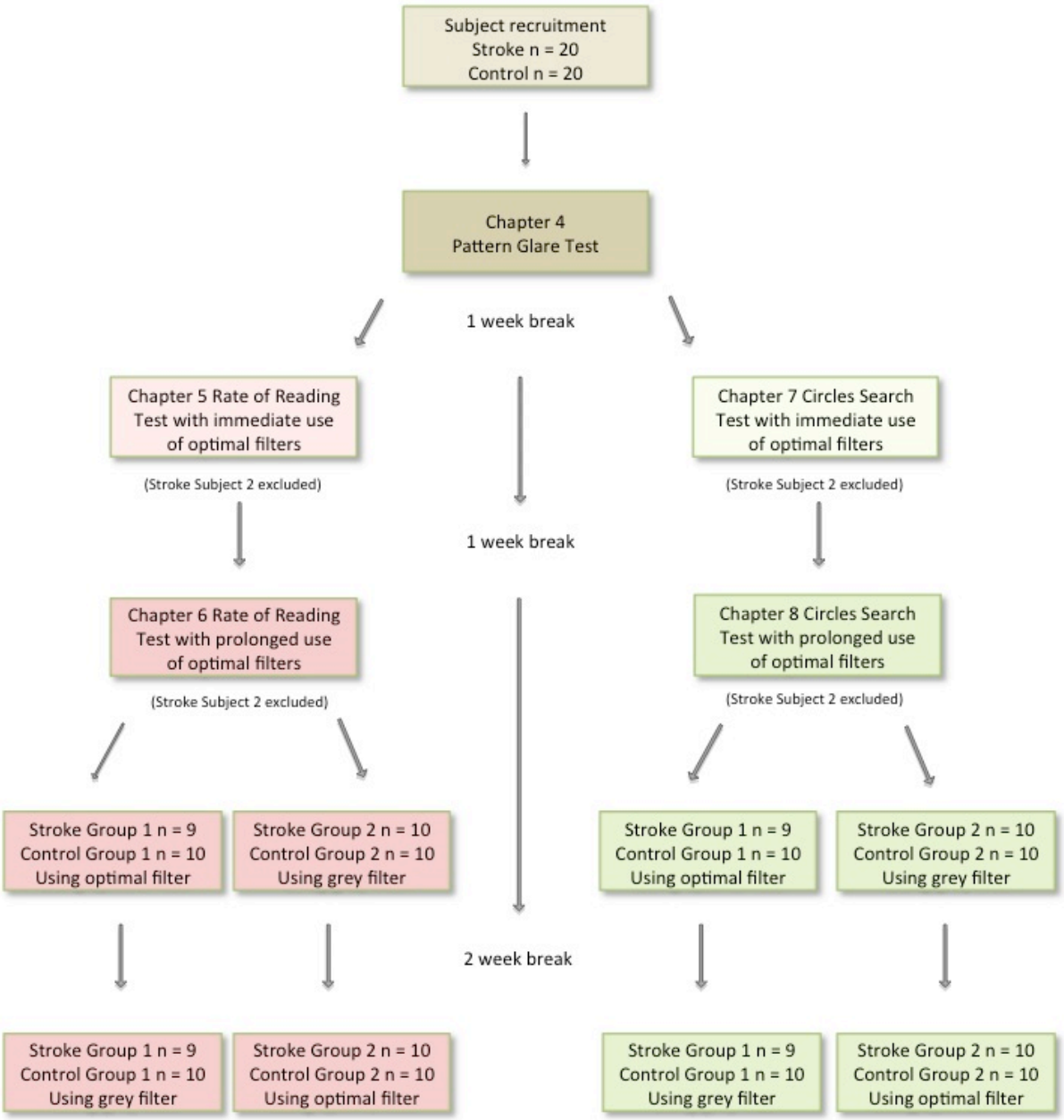
5. Are you diagnosed as a migraine sufferer?

6. Have you been diagnosed with multiple sclerosis?

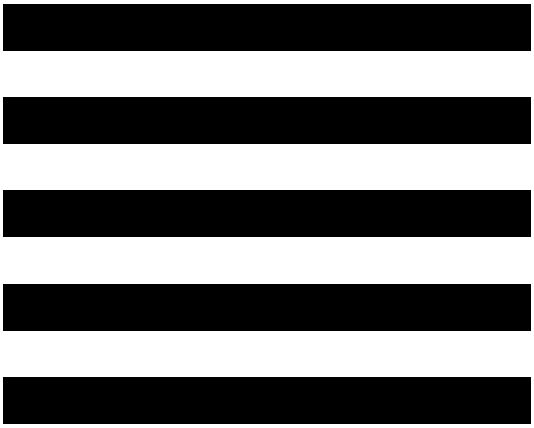
7. Have you been diagnosed with autism?

8. Have you ever received a psychologist's diagnosis of Dyslexia?

Appendix 4 Programme of research

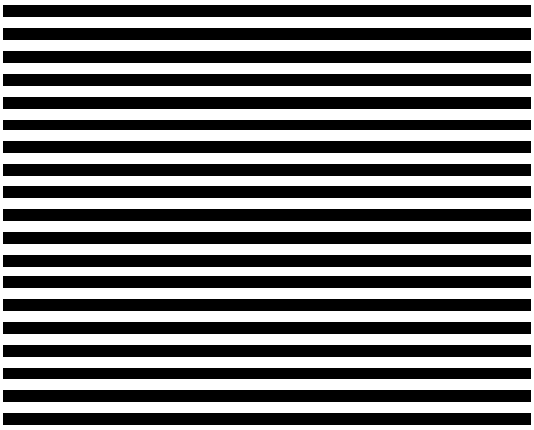


Appendix 5 Patten Glare Test using Likert scale scoring method



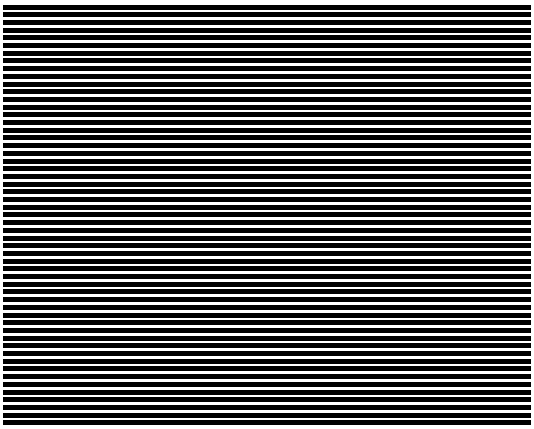
Please rate how comfortable you find this image to view

Comfortable 1 2 3 4 5 6 7 8 9 10 **Uncomfortable**



Please rate how comfortable you find this image to view

Comfortable 1 2 3 4 5 6 7 8 9 10 **Uncomfortable**



Please rate how comfortable you find this image to view

Comfortable 1 2 3 4 5 6 7 8 9 10 **Uncomfortable**

Supporting publications

Beasley IG & Davies LN (2012) Susceptibility to pattern glare following stroke. J Neurol 259:1832-1839

Beasley IG and Davies LN (2012) Visual stress symptoms secondary to stroke alleviated with spectral filters and precision tinted ophthalmic lenses: a case report. Clin Exp Optom DOI:10.1111/j.1444-0938.2012.00794.x (Epub ahead of print)