The Efficacy of Visuomotor Compensatory Training for Individuals with Visual Field Defects

AZUWAN MUSA

The Efficacy of Visuomotor Compensatory Training for Individuals with Visual Field Defects

Azuwan Musa

A thesis submitted for the Degree of Doctor of Philosophy

Durham University, Psychology Department

2018

Abstract

Several approaches have been developed to help patients with partial visual field defects to cope with their visual loss, and the most effective are those that encourage the person to move their eyes more efficiently. This thesis sought to examine the efficacy of a multiplatform compensatory training called Durham Reading and Exploration (DREX) in the rehabilitation of these individuals. Overall, the thesis focuses on two primary aims which include establishing whether the DREX training app completed on either a computer or a touchscreen tablet can be an effective treatment for homonymous visual field defects (HVFDs) caused by brain injury, as well as validating the assessment tasks that have been incorporated into the app. The results from Studies 1 to 3 show that DREX training is clinically effective for HVFD rehabilitation, and the training effect in patients trained using a touchscreen tablet is equivalent to patients trained with a computer, with a meaningful improvement in the quality of life which remains stable over a period of three months. In Studies 4 to 6, the built-in assessments tasks are found to be reliable and valid and can be used confidently to monitor the training progression and outcomes. Study 7 explores the novel observation that DREX training is also beneficial for patients with other types of partial visual field defects like tunnel vision and central visual field loss, demonstrating that this training could potentially be offered to a wider low vision population. Finally, studies 8 and 9 explore whether the blurring of vision, a common comorbid visual impairment in patients with visual field defect, could affect the visual exploration performance and the outcomes of visual exploration training. From these results it is clear that blurring of vision did reduce the search efficacy, but searching behaviour can still be improved with the training. Taken together, the findings from this suite of studies indicate that DREX is an effective and inexpensive treatment for visual field defects in a variety of etiologies, however the comorbid impairments that could affect the rehabilitation should be identified to maximise efficacy of this treatment.

Table of Contents

List of Figures

Chapter 1

Chapter 2

Chapter 6

Chapter 7

List of Tables

Chapter 2

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Declaration

I confirm that no part of the material offered has previously been submitted by me for a degree in this or any other University. Any material generated through collaboration clearly acknowledges the work of others.

Parts of Chapter 2 were presented at the Vision 2017 Congress, The Hague, The Netherlands (25 – 29 June 2017) and Organisation for Psychological Research Into Stroke (OPSYRIS) Meeting in Leeds, UK (5 October 2017) – Oral presentation.

Parts of Chapter 7 were presented at the EPS Workshop on Oculomotor Readiness and Covert Attention in Durham, UK (5 – 6 April 2016) – Poster presentation.

Copyright

Acknowledgement

I am very grateful to a lot of people for their support throughout my PhD journey and the production of this thesis. The highest gratitude to my supervisors, Dr. Alison Lane and Professor Amanda Ellison for their constant guidance and encouragement. You are among the awesome people I have ever met in UK. Thank you for being patience and understanding, and for teaching me that every mistake is just a learning experience. I am forever indebted to the best supervision over the last three and half years. I really appreciate it from the bottom of my heart. I would also like to thank my clinical supervisor, Dr. Neil Archibald for his support and contribution, and all staffs from the participating NHS trusts and Sight Services. I could never have done this without help and support from Dr. Stephen Dunne, a fantastic member of the DREX team – Thanks mate!

I wholeheartedly thank the greatest gift I have had, my parents, Musa Said and Rekiah Abdullah for their warm hugs, pleasing smiles and encouraging words, and for all the countless times they have been there for me. To my wonderful siblings, I love you so much! I cannot thank you enough for their amazing support, unconditional love and care. I could not imagine my life without you. My deepest appreciation belongs to my wife, Nor Fatin Asyiqin Mohamed Azhari and my son, Nuh Azuwan, who have always been my strength. I do not know how I can ever thank you dear for being such a loving and caring person. Special thanks to my Durham My++ friends, who have been an awesome mates and colleagues. I hope you would have been proud.

Chapter 1

General Introduction

1.1 Homonymous visual field defect (HVFD)

A homonymous visual field defect (HVFD) is a chronic manifestation of brain damage like stroke, and the prognosis of visual recovery is very poor. Every year 8.3% to 16% of stroke patients in the UK are affected by HVFDs, mainly homonymous hemianopia (Gilhotra, Mitchell, Healey, Cumming, & Currie, 2002; Rowe et al., 2013), and as a result they experience difficulties in everyday life such as navigating in their environment safely, reading and instrumental activities like shopping. This can lead to patients becoming withdrawn, reliant on carer support, and subsequently depressed (MacIntosh, 2003). In short, their visual loss creates significant impairments in functioning and a reduction in quality of life. This indicates a great need for an effective and evidence-based treatment option to ameliorate the disabilities they experience due to their visual loss. Furthermore, specific treatment strategies are necessary to maximise patients' functional ability and their independence (Anderson & Rizzo, 1994), and the overall aim of this thesis is to explore such an intervention and factors associated with its efficacy.

The visual field is the extent of an area over which vision is possible with the eyes fixated centrally. A visual field defect is defined as a loss of vision in a particular area of the visual field and is caused by a disturbance in the flow of information between the retina and the striate cortex. The visual field loss depends on the location of the damage; unilateral post-chiasmatic injury causes deficits in both monocular hemifields contralateral to the side of injury, resulting in homonymous field defects (see Figure 1.1), while unilateral pre-chiasmatic pathway damage affects the ipsilesional field. Post-chiasmatic

injury, which includes detrimental insult to the visual thalamus, optic radiation or primary visual cortex (Zhang, Kedar, Lynn, Newman, & Biousse, 2006), causes HVFDs in nearly 90% of patients (Zihl, 2010).

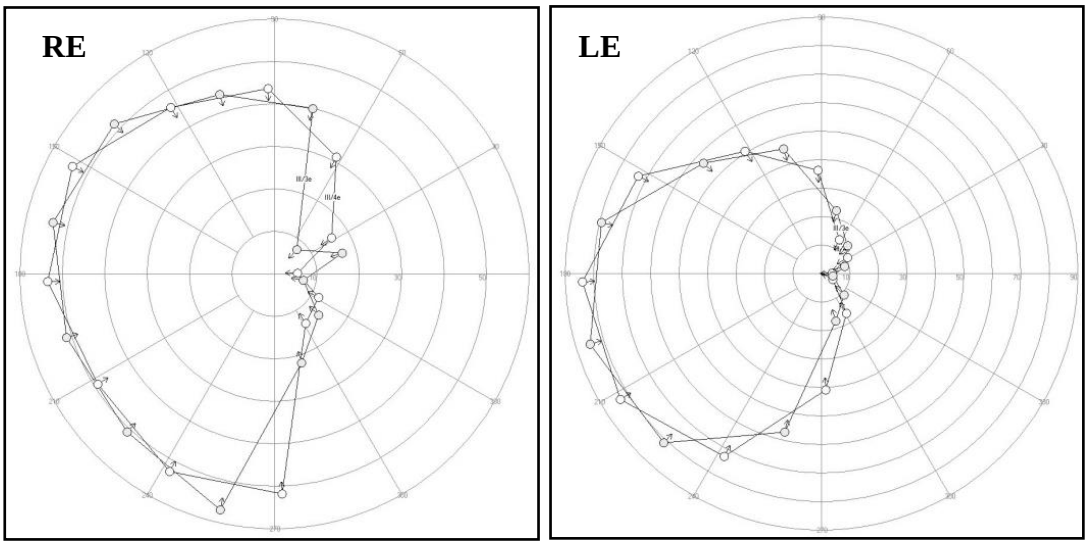


Figure 1.1 Diagram illustrating an example Goldmann perimetry for a person with right homonymous hemianopia. Not to scale.

There are several types of HFVDs: homonymous hemianopia (left or right hemifield loss), homonymous quadrantanopia (left or right upper or lower quadrant field loss), and paracentral scotoma (restricted vision in the parafoveal visual field). The common form of visual field loss after brain injury is homonymous hemianopia (58.2%) followed by quadrantanopia (17.4%) and paracentral scotoma (10.3%; Rowe et al., 2013; Zihl, 2010). The homonymous hemianopia can either be complete or incomplete, and with or without macular sparing. Complete hemianopia means the entire half of the visual field is impaired while incomplete hemianopia has wider intact visual field depending on the location and severity of the lesion. In most cases, incomplete hemianopia is frequently reported (60.7%; Zhang, Kedar, Lynn, Newman, & Biousse, 2006) and potentially has a better chance for early spontaneous recovery (Gray et al., 1989). Macular sparing, however, is a small area of functioning vision at the centre of vision of the affected

hemifield, denoted in a degree of visual angle (°), which usually does not exceed 5°. It is caused by incomplete damage to the anterior portions of the post-chiasmatic visual pathway and is found in almost 60% of patients with homonymous hemianopia (Zihl, 2010).

The most common etiology of homonymous hemianopia in adults is stroke, which is the consequence of posterior cerebral artery ischemia and occipital lobe infarction (Zhang et al., 2006). Pambakian and Kennard (1997) reported that visual field loss is normally caused by lesions of occipital lobe (40%) and parietal lobe (30%), and less frequently due to damage of the optic tract and lateral geniculate nucleus (5%). Other causes of homonymous hemianopia include traumatic brain injury (Zihl, 2010), tumours and multiple sclerosis (Zhang et al., 2006). Most people with visual field loss are not aware of their visual field deficits; only 45% of them reported the symptoms (Rowe et al., 2013). Since visual loss caused by acquired brain injury is often irreversible, patients might live with disabilities due to the visual loss for their remaining life. Stroke incidence is likely to rise with an aging population (Gilhotra, Mitchell, Healey, Cumming, & Currie, 2002), therefore more patients will be affected, and the demand for quick and effective rehabilitation will increase.

1.1.1 Eye movement behaviour in HVFDs

Saccades are rapid, ballistic eye movements that transfer fixation between one object and another. In humans, important visual information from the surroundings is gathered by moving the eyes in a step-wise fashion, often with several saccades (Land, Mennie, & Rusted, 1999). The fixation in each saccade allows the image of the object focused at the fovea, the central region of the retina that has the highest spatial resolution, either unconsciously or reflectively (Findlay & Walker, 1999), so that information from the visual scene could be correctly interpreted. However, the speed of a saccade towards a

target may be slower for some patients with HVFDs than those with normal vision (Barbur, Forsyth, & Findlay, 1988; Meienberg, Zangemeister, Rosenberg, Hoyt, & Stark, 1981; Walker, Mannan, Maurer, Pambakian, & Kennard, 2000). Many patients with HVFDs produce inaccurate saccades, typically falling short of the target, even when making repeated saccades between static targets of known location (Meienberg et al., 1981; Zihl, 2010). Approximately 71% of patients with unilateral hemianopia demonstrated saccadic dysmetria to the affected side, the loss of accuracy to perform ballistic eye movements to fixate a target which was characterised by saccadic hypometria in the majority of patients (Zihl, 2010), while all patients with bilateral visual field loss showed saccadic hypometria in both affected sides. Consequently, patients may ignore important parts of the surroundings in both affected and intact hemifields (Ishiai, Furukawa, & Tsukagoshi, 1987). For example, patients may not be able to avoid obstacles in the good side when focusing too much to the affected side, indicating a serious disability.

For an individual with a HVFD, one could envisage that accurate scanning using saccades into the blind hemifield would be a beneficial technique to compensate for visual loss and gather important information. If the saccadic execution is impaired, then the capability to perform this compensation will be limited, resulting in a greater functional deficit. Therefore, behaviours such as frequent saccades and head movements into the blind hemifield have been correlated with better visual search performance in some cases including driving (Tant, Cornelissen, Kooijman, & Brouwer, 2002) and navigation (Zihl, 1995b). Moreover, it has been confirmed that patients with superior saccadic amplitudes, longer scan paths, more fixations and more gaze shifts on vehicles performed better at a collision avoidance task (Papageorgiou, Hardiess, Mallot, & Schiefer, 2012). Hence, scanning with gaze shifts signifies an important strategy that can mitigate the impact of

HVFDs and there are also promising results that search training can make eye movements more efficient (further details in the Compensatory training section).

1.1.2 The impacts of HVFDs

1.1.2.1 Visual exploration

One of the undesirable behavioural consequences of HVFDs is impairment of visual exploration (Zihl, 1995b). Patients cannot gain a complete overview of their environment which often causes difficulties in navigating congested or new areas, exploring their surroundings, and finding relevant items. The problems of visual exploration can be recognised by longer scan paths and smaller saccades when performing visual tasks (Tant, Cornelissen, Kooijman, & Brouwer, 2002; Zihl, 2010), including counting dots (Zihl, 1995b), detecting moving targets in a three-dimensional virtual environment (Riley, Kelly, Martin, Hayhoe, & Huxlin, 2007), and viewing natural and blurred images (Pambakian et al., 2000). Many patients typically show unsystematic and ill-sustained scanning patterns compared to healthy people (Kerkhoff, Munssinger, & Meier, 1994; Meienberg, Zangemeister, Rosenberg, Hoyt, & Stark, 1981). Patients also make more saccades towards the blind field, but the saccades are less systematic, resulting in increased search time when performing visual tasks like detection and localisation (Chedru, Leblanc, & Lhermitte, 1973; Mannan, Pambakian, & Kennard, 2010). About 60-70% of patients showed impaired and disorganised scanning performance (Kerkhoff, 1999; Zihl, 2010), which may limit their ability to quickly comprehend the environment to avoid hazards.

1.1.2.2 Reading

A fluent reader requires a central intact visual field of at least 4° horizontally and 2° vertically from the central fixation point. Reading disorders in patients with HVFDs

(known as hemianopic dyslexia) result from the impairment of the parafoveal field region that forms a perceptual window for reading. The reading window typically extends 3 to 4 characters to the left of central fixation and 7 to 11 characters to the right. Since these perceptual windows are asymmetrical, right sided HVFDs cut a larger part of the reading window thereby causing greater impairment than left-sided HVFDs (Papageorgiou & Tsironi-Malizou, 2017).

Hemianopic dyslexia is the most significant behavioural difficulty experienced by patients with HVFDs besides impaired visual exploration (Schuett, Heywood, Kentridge, & Zihl, 2008b; Zihl, 1995a). Patients often have reduced reading speed, miss words, demonstrate guessing errors, and have an inefficient eye scanning pattern (McDonald, Spitzyna, Shillcock, Wise, & Leff, 2006; Spitzyna et al., 2007; Zihl, 1995a). Left-to-right readers with a right-sided hemianopia have particularly impaired fluency due to poor visual processing from the right visual field that makes locating the end of the word or line difficult (Leff, 2004; Zihl, 1995a), and in some patients reading is almost letter by letter (Miller et al., 2005). These patients often experience problems shifting their gaze systematically from left-to-right; the normal oculomotor reading pattern is replaced by many small and irregular saccades to the right (Schuett et al., 2008b). Since parafoveal vision is used to plan saccades and obtain information about forthcoming words, patients with 4° to 5° of macular sparing tend to have fewer difficulties in reading than those with macular splitting (Zihl, 2010; see Figure 1.2). Although less severe, left-to-right readers with a left hemianopia have difficulty returning to the beginning of the subsequent line and may instead start reading midway through a line of text. Patients show a higher percentage of repetition of saccades and fixations to the left that impairs reading speed (Zihl, 1995a).

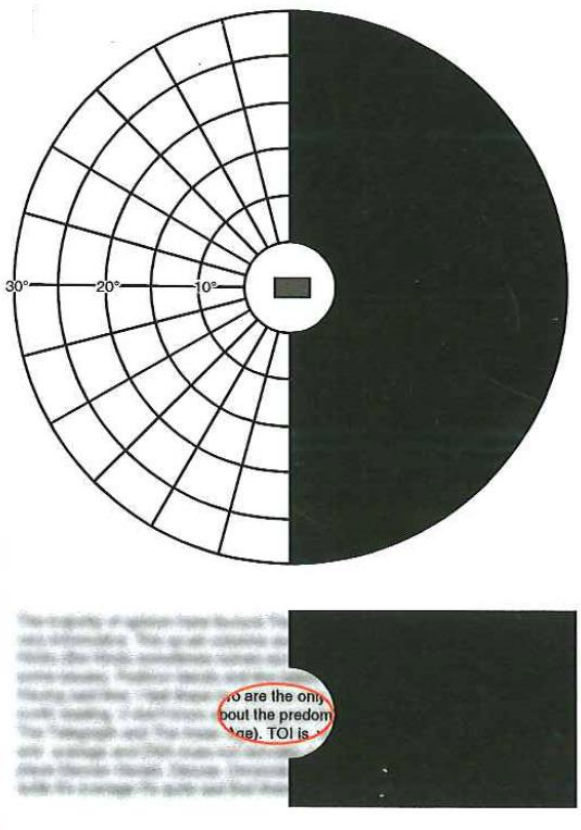


Figure 1.2 Figure illustrating the sample case of macular sparing where the reading ability is still intact even though the homonymous hemianopia is complete (Papageorgiou & Tsironi-Malizou, 2017)

1.1.2.3 Activities of daily living (ADL)

Patients with HVFDs often want to see and behave as they did before the brain injury, so they can continue doing things that they used to enjoy such as reading books, navigating alone and even driving. A study investigating the probability of regaining functional independence at the point of discharge between patients with or without HVFD found that the probability of independent walking decreased from about 30% for patients without a HVFD, to only 3% for patients with a HVFD (Reding & Potes, 1988). In general, the probability of regaining full independence decreased from 50% to 10% for patients with a HVFD, and the probability of attaining reasonable independence reduced from 70% to 50%. Furthermore, Patel and co-workers (2000) revealed that hemianopic patients suffered a profound functional implication in at least three common daily living activities

as confirmed by Barthel score, Function Independence Measure and the achievement of independence.

Kerkhoff et al. (1990) assessed visual disabilities in a group of individuals with hemianopia and found that approximately 80% of patients complained of problems in everyday life. In one of the HVFD cohorts studied by Zihl (2010), difficulties such as bumping into obstacles and losing your way particularly in unfamiliar surroundings are frequently reported by those with impaired visual search times. Warren (2009) studied a sample of 46 patients with HVFDs without significant inattention or motor deficit who were referred to a low vision clinic. 41% reported difficulties performing personal hygiene tasks independently, and 13% were unable to self-feed. Other than that, the difficulties to conduct basic instrumental activities like shopping (94%), managing finances (89%), preparing meals (50%), and driving (98%) were also reported. Most interestingly, reading difficulty and inability to navigate effectively were claimed to be the origin of many of the problems reported and HVFD is strongly associated with a decreased performance in these activities (Chen et al., 2009; Gall, Lucklum, Sabel, & Franke, 2009; Papageorgiou et al., 2007).

1.1.2.4 Socio-emotional status

The loss of independence due to vision loss (Papageorgiou et al., 2007), fear, anxiety, and isolation from the community (Warren, 2009) can cause large emotional and social problems. Social seclusion may preclude patients from reintegrating themselves with the community and also prevent positive psychological modification towards disability (Warren, 2009). Furthermore, since HVFDs are associated with a poor functional prognosis (Gray et al., 1989), patients may experience long-term neuropsychological sequelae such as depression (Pohjasvaara et al., 1998). The depression can be exacerbated by functional impairments such as reading difficulties (Papageorgiou et al., 2007) and this

can potentially create a remarkable amount of subjective inconvenience in everyday life. While depression is identified to greatly reduce the QoL of many stroke patients (Carson et al., 2000), its impact on patients' participation and motivation towards visual rehabilitation remains unknown. Therefore, information about patients' emotional state before and after visual rehabilitation training is useful to better understand the relationship between HVFDs and socio-emotional well-being as well as the possible impact of rehabilitation.

1.1.3 Spontaneous recovery

HVFDs can improve over time, but recovery of the visual field is highly varied (Zihl, 1995). Zhang and colleagues (2006) found that the maximal period of spontaneous recovery was normally three months and not significantly associated with either cause of defect or lesion location. Visual field recovery has been reported to occur as early as the first 10 days (Ali, Hazelton, Lyden, Pollock, & Brady, 2012; Cassidy, Bruce, Lewis, & Gray, 1999; Gray et al., 1989), and can extend to one year after stroke (Sabel & Trauzettel-Klosinksi, 2005). However, only 15.8% show complete recovery; most recovery is partial and involves the central visual field (Cassidy et al., 1999). A large-scale multicentre study in the UK revealed that 8% of stroke patients achieved recovery after 2 weeks and 29% showed partial improvement within 3 months (Rowe et al., 2013). Patients with less macular sparing exhibited much poorer spontaneous improvement over time, probably due to more severe and widespread damage to the visual cortex. Even those with 10 degrees of macular sparing at the early stage generally only improve up to an additional 7 degrees of sparing (Zihl & Von Cramon, 1985; Zihl, 2010). This result of poor spontaneous recovery of visual fields proposes that the primary visual cortex has fairly poor plasticity, at least in the adult human brain.

Since recovery from HVFDs is rare, the question arises as to whether patients can compensate for their visual field loss using other behavioural strategies. Patients can do

this by modifying the eye movement strategies, which is done by making broad searching, larger eye movements towards the blind hemifield (Pambakian et al., 2000). Early studies concluded that people with chronic hemianopia are able to create saccades to targets in the blind hemifield, although the saccades are much slower compared to the saccades generated when the targets are presented in the seeing hemifield (Gassel & Williams, 1963; Meienberg et al., 1981). These reflexive saccades are the forms of a strategic adaptation to the hemianopia, indicating some remaining input processing which is commonly known as 'blindsight' (Weiskrantz, 2004).

Simpson, Abegg and Barton (2010) investigated the visual search performance of healthy subjects with simulated hemianopia and revealed a substantial improvement after only 5 to 7 trials. More efficient search strategies developed as the subject learned to increase the number of fixations into the blind hemifield, which started with a rapid improvement followed by a more stable improvement over time. However, many patients are not able to adopt this strategy spontaneously. Zihl (1995b) suggested that the failure of compensation mechanisms was persistent, and patients still showed increased difficulties in visual search (e.g. dysmetric saccades).

A few long standing HVFD patients can create many rapid fixations towards their blind hemifield to compensate the visual loss, reflecting the development of a spontaneous compensatory strategy 6 months after acquiring the condition (Pambakian et al., 2000), but the strategy developed does not lead to demonstrable functional benefits (Chedru et al., 1973), and visual searching in the impaired field remains more time-consuming (Ishiai et al., 1987). So, many patients still struggle to spontaneously compensate their visual loss. Awareness about the presence of visual loss is important for spontaneously compensating, however many patients are not aware of their visual defect, especially in the initial stages (Townend et al., 2007), and this is why behavioural oculomotor adaptations are only observed in a small number of patients. Therefore, patients need to train their impaired

oculomotor movement consciously through a specific eye movement training. The training will allow them to develop more efficient oculomotor strategies to enhance the visual awareness.

Alternatively, patients may also create an eccentric fixation as the behavioural adaptation, which was found useful in approximately one quarter of cases (Trauzettel-Klosinski, 1997). Basically, the eye is moved 1° to 2° towards the blind field slightly from the centre, such that the image will fall into the area of intact visual field near to the fovea (Trauzettel-Klosinski, 2017). Patients with good central vision (especially HVFDs with macular splitting), will gain most from this technique, especially during reading, but only approximately 18% of patients have reported a positive gain (Leff, 2004; Reinhard, Damm, Ivanov, & Trauzettel-Klosinski, 2014; Trauzettel-Klosinski, 1997).

In short, there is no agreement as to when the maximal recovery from visual impairments occurs, many patients do not experience a sufficient spontaneous recovery of visual field nor demonstrate spontaneous behavioural adaptations. Since recovery remains limited, HVFDs continue to cause negative impacts on patients' behavioural functions and QoL. Therefore, a rehabilitation which is effective and transferable to ADL is needed to reduce visual disabilities caused by the visual field loss.

1.1.4 Rehabilitation for HVFDs

There are three primary approaches that have been focused on in many studies: restorative treatment, substitutive treatment and compensatory treatment (see reviews - Hanna, Hepworth, & Rowe, 2017; Lane, Smith, & Schenk, 2008). Restorative treatment is the most controversial approach and aims to improve visual loss by direct stimulation on the impaired visual field. Substitutive treatment involves expansion of the visual field using an optical aid. The last approach is compensatory training, which teaches patients to compensate the visual loss by creating systematic eye movements. A Cochrane review

identified compensatory saccadic training as the most promising approach and worthy of further investigation (Pollock et al., 2011), and as such forms the basis of the research presented in this thesis.

Compensatory training is based on the oculomotor behaviour of hemianopic patients whose saccades are demonstrably small and unsystematic (Zihl, 1995), and the training helps them to learn to create sufficiently large eye movements in the blind hemifield to compensate for the visual impairment. In some saccadic training, patients have to locate lights along the horizontal plane which are gradually shifted towards the periphery (Kerkhoff et al., 1992b; 1994; Zihl, 1995b). In other types of saccadic training, patients have to carry out visual search using more systematic and accurate saccades, which are achieved by training patients to voluntarily explore ranges of visual stimuli on computer screens (Aimola et al., 2014; Lane et al., 2010; Pambakian, Mannan, Hodgson, & Kennard, 2004; Zihl, 1995b) or an extended board screen (Nelles et al., 2001). The positive effect on compensatory saccade strategies is observed in 70 to 90% of patients as early as 4 to 5 weeks after starting of training, and some patients require only approximately 30 to 40 minutes training per each session to gain such benefit (Schuett, Heywood, Kentridge, Dauner, & Zihl, 2012; Zihl, 2010). Although different strategies have been introduced to train eye movements to become more systematic and efficient, the aim is the same, and the results are very consistent.

Training systematic eye movement strategies results in more organised visual exploration and efficient searching time (Zihl, 2010). Roth et al. (2009) investigated the impacts of compensatory training in visual exploration performance as compared to a control, light detection training. Patients showed a significant decrease in visual search response time and an increase in the number of fixations in the blind hemifield. With such changes, patients become more aware of their surroundings and are able to accurately detect specific items located in the impaired area. Furthermore, the compensatory training

can also increase the area of visual search by up to 30° (Bouwmeester, Heutink, & Lucas, 2007; Kerkhoff et al., 1994). Importantly, the improvements in visual exploration are still present after 12 weeks (Schuett et al., 2012) and 8 months (Nelles et al., 2001) follow-up, signifying relatively long-term stability of the systematic compensatory training effects.

Specific compensatory training can enhance the reading skill of people with hemianopic dyslexia by encouraging them to pay more attention and create more systematic reading eye movements. The therapeutic effect of compensatory reading training has been reported in several controlled (Aimola et al., 2014; de Haan, Melis-Dankers, Brouwer, Tucha, & Heutink, 2015; Rowe et al., 2017; Spitzyna et al., 2007) and non-controlled (Ong et al., 2015; Schuett, Heywood, Kentridge, & Zihl, 2008a; Zihl, 1995a) studies. A significant improvement in static reading speeds in relation to controls was found in a study using a small-field optokinetic nystagmus therapy, employing a moving text to improve saccades (Spitzyna et al., 2007), with higher amplitudes of saccades towards the right, direction-specific effect. Patients also showed improvement in reading speed with reduced reading mistakes after an unsupervised (Aimola et al., 2014; Ong et al., 2015), web-based (Ong et al., 2015), and non-text (Schuett et al., 2008a) reading training.

Reading and exploration are typically trained separately by two specific, distinct training paradigms. While exploration training requires the use of large saccades and a spatially organised searching pattern to increase the field of view, improvement of reading needs more practice using accurate, systematic and frequent horizontal eye movements such as left-to-right text reading training (Schuett, Kentridge, Zihl, & Heywood, 2009). Indeed, it has been shown that visual search training does not translate to improved reading speed (Lane et al., 2010; Roth et al., 2009) and vice versa (Schuett et al., 2012). Aimola et al. (2014) developed a training that incorporated visual exploration and reading training together in one package and significant improvements in both skills were reported after

both had been trained. For the reading task, the eye movement was trained systematically following horizontal and left-to-right direction, while the exploration task required patients to develop their own eye movement strategies in completing the visual search task. The cognitive components of the tasks remained largely the same in terms of making decisions and responding.

Subjective (Kerkhoff et al., 1994; Lane et al., 2010; Nelles et al., 2001) and objective measures of ADL (Pambakian et al., 2004; Aimola et al., 2014; de Haan et al., 2015) have been found to improve after compensatory training. For example, patients gained more confidence in navigating alone and avoiding obstacles (Zihl, 2010), and the ability to read (Lane et al., 2010) and return to work (Kerkhoff et al., 1994) were also increased. In a controlled trial comparing compensatory training, restorative training and standard care, Mödden et al. (2012) found that patients with an improved visual search showed significantly increased ability to perform basic routine tasks such as dressing, eating and navigating. This indicates the transferability of compensatory training benefits to ADL. Apart from positive self-reported improvements, patients also reported an improvement in mobility during mobility-related tests, with minimal difficulties after the compensatory training (de Haan et al., 2015; de Haan, Melis-Dankers, Brouwer, Tucha, & Heutink, 2016); it was easier for them to detect an object presented at periphery, which is a much-needed skill during walking. Tant and colleagues (2002) also included mobility assessments in their study and they found an improvement in visual-spatial performance among patients during driving. In short, patients gain more confidence, independence and overall comfort especially in mobility and basic ADLs. As previously mentioned, research should further explore the impact of compensatory training on a specific emotional problem such as depression which could perhaps provide new insight about the training.

One concern about compensatory training is that very few patients have access into this type of training. If available, the compensatory training is often provided in a clinical

setting, which can be costly and time-consuming. However, advancements in technology have provided new opportunities for improving the accessibility of the training. For instance, the web-based training investigated by Ong et al. (2015) provides a free online training, with people training using a personal computer and minimal clinical input. Other approaches like audio-visual stimulation via telerehabilitation (Tinelli, Cioni, & Purpura, 2017) provide remote rehabilitation such that training involving specialised multisensory stimulation can be done independently at home. Most recently, anti-saccade training (Lévy-Bencheton et al., 2016) by stimulation of consciously controlled attention in combination with a saccadic adaptation technique resulted in positive therapeutic effects on different behavioural tasks. However, the efficacy of these sorts of technological training tools need to be evaluated in a controlled trial.

1.2 Durham Reading and Exploration (DREX) training app

1.2.1 The development of the DREX training app

A computer-based compensatory saccadic training programme (Durham Reading and Exploration; DREX) has been developed by Durham University to help people with HVFDs. Preliminary versions of the training demonstrated positive therapeutic effects and improved quality of life (Aimola et al., 2014; Lane et al., 2010). The development of the DREX app began with the evaluation of a computer-based training in a supervised, randomised controlled clinical trial (Lane et al., 2010). The study recruited 46 patients, in which 23 completed exploration training while the remaining 23 patients (control group) completed attention training followed by exploration training. The training was completed using a laptop computer and the duration of each training ranged between 3.5 and 4 weeks. The results revealed that the exploration training significantly improved visual search as assessed with a find the number task, whilst the attentional control training did not. Unfortunately, neither exploration nor attention training improved reading performance.

This study highlighted that the exploration skill can be successfully trained using a computer programme, and also suggested that an effective training programme should train both exploration and reading skills. Consequently, the training was modified by combining reading and exploration training in one package, which patients completed at home without supervision (Aimola et al., 2014). The training was still computer-based, and this time was completed within approximately 9 weeks. This study was a randomised controlled trial comparing a reading-exploration group with a control attention-based training group. The study revealed that reading and exploration skills were significantly improved after training such that the performance in the find-the-number search and reading tasks increased by at least 12.87% in the intervention group. Furthermore, most of items in the visual impairment questionnaire showed significant improvement indicating the positive impact of training on ADLs.

The significant findings from the earlier projects led to the development of a new DREX training app, with the aim of making the training more accessible and user friendly than the earlier versions. DREX encompasses an integrated reading and exploration programme, which intends to retain patients' compliance for the therapy while improving both skills efficiently at once. In addition, DREX is a self-adjusting training app which has been designed to be compatible with both personal computers and touchscreen tablets. The training tasks and durations remaining largely equivalent to the previous versions, but modifications made as necessary to reflect the different mechanisms of responding (e.g., button press or tapping the screen). Patients can install the app onto any computing device that they currently have with no extra cost, so they can do the training conveniently at their own pace. Patients do not need to be supervised, therefore they can complete the training at home without clinical input or cost. The app also has simple built-in self-assessments including perimetry, visual search, reading and quality of life scales allowing users to track

their progress over time. The details of the training and assessment components of the DREX training app are described in Chapter 2.

1.3 Research questions

1.3.1 The effectiveness of the multiplatform DREX training app.

The aim of Study 1 (Chapter 2) is to investigate the effectiveness of the new multiplatform DREX training app in the rehabilitation of individuals with a HVFD in a three-arm randomised controlled trial: visuomotor training on a touchscreen device, computer-based training with a mouse-click, and standard care. The impact of DREX training on the primary behavioural functions of reading and visual exploration will be evaluated, alongside the secondary outcomes of subjective ADLs, and these are predicted to improve in accordance with the results of previous studies. The study will also investigate the training benefits to mood and depression as an indicator of wider quality of life, and also explore whether baseline depression score and motivation can predict the outcome of training.

1.3.2 The transferability between visual exploration and reading training

It has been mentioned earlier that studies have shown that visual search training does not translate to improved reading speed (Lane et al., 2010; Roth et al., 2009), and training reading does not improve exploration (Schuett et al., 2012). Aimola et al. (2014) reported significant improvements in both skills after they had both been trained, but did not investigate what benefit each part of the training had in isolation. Therefore, the aim of Study 2 (Chapter 3) is to investigate the transferability of training-related improvement between visual exploration and reading using the DREX training app in both computer and touchscreen tablet formats.

1.3.3 The long-term benefits of DREX training

With respect to rehabilitation, concerns are not only over the efficacy of an intervention, but also the ability of a treatment to have lasting gains for everyday functioning. A systematic review on the treatment option for post-stroke visual impairment has addressed the need to include follow-up assessments in order to precisely capture the effectiveness of the treatments and transferability of the improved skills to ADL (Hanna et al., 2017). In most studies that include follow-up assessment, the effects of compensatory training on visual exploration performance have persisted. For example, Roth et al. (2009) found that search performance improved in the blind hemifield and this was maintained or even enhanced 6-week post-training, and furthermore patients had learned to consistently apply the search strategy into the everyday tasks. Other studies reported that the improvement was maintained after one month (Bolognini, Rasi, Coccia, & Làdavas, 2005; Mannan et al., 2010), 8 months (Nelles et al., 2001a), or even one year (Passamonti, Bertini, & Làdavas, 2009) post-training. Although improvement of visual exploration was frequently reported at the follow-up assessment, it is still unknown if this objective improvement does correlate with the subjective improvement. Considering the importance of follow-up assessment for demonstrating the value of a rehabilitation tool, Study 3 (Chapter 4) aims to evaluate the long-term effects (3-month post-training) of the new DREX app with respect to both objective and subjective functioning.

1.3.4 The reliability of the built-in assessments in DREX training app

App-based perimetry has been introduced recently for screening stroke-related visual impairments (Spofforth, Codina, & Bjerre, 2017) and diagnosing hemianopia (Koiava et al., 2012). One study comparing the results of app-based perimetry and conventional Humphrey Visual Field analyser (HVF) revealed that app-based perimetry is effective to detect moderate to severe visual field loss, and both findings were highly

correlated (Johnson et al., 2017). In terms of the sensitivity and specificity of the app-based perimetry in detecting visual field loss, Koiava et al. (2012) found that the app-based version is highly sensitive and specific for the undamaged field, but the values slightly reduced for the damaged field and thus the suggestion to add more testing stimuli to the present version to improve detection of visual field loss has been made. Other than perimetry, wed-based visual search assessment has also been introduced to evaluate the outcome of visual search therapy which was completed online (Ong et al., 2015), and this assessment was validated previously (Jacquin-Courtois, Bays, Salemme, Leff, & Husain, 2013). The study demonstrated that the app-based visual search assessment was able to accurately measure the visual search performance indicating the effectiveness and usefulness of the app-based assessment in assessing visual search. Although the ADL scales were included in the study as a part of the assessments, the validity of the scales is unknown. There is very little information about the use of self-assessment in HVFD rehabilitation as most of the treatments were done in clinic or laboratory such that the conventional assessments which require supervision and input from therapist were used.

In the DREX training app there are four main self-assessments that have been incorporated to measure the extent of visual field loss (perimetry), visual search, reading, and quality of life. These assessments will allow the user to monitor their own progress and understand the benefits they have gained. Furthermore, there is also a mechanism whereby this data can be shared with the clinical team, such as doctors, optometrists and occupational therapists, enabling them to track patients' progression remotely and make suggestions to improve training experience. The aim of Chapter 5 (Studies 4 to 6) is to validate the assessment measures that have been built into the app by comparing improvements on these with other standardised and previously used outcome measures. Validating the assessment measures that have been built into the app will allow us to

determine if these can be used effectively for monitoring the benefits of the training remotely.

1.3.5 The efficacy of DREX training for other partial visual field defects

The behavioural consequences of visual field loss appear to be comparable regardless of the cause. Impairment of visual search among those with other partial visual field defects such as glaucoma, retinitis pigmentosa and age-related macular degeneration (AMD) has been demonstrated (Jacko et al., 2000; Smith, Glen, & Crabb, 2012; Vargas-Martin & Peli, 2006; Whittaker, Cummings, & Swieson, 1991); patients were unable to effectively scan their surroundings, read and mobilise independently as a consequences of impaired visual search, and their visual search was described as slow and longer than the normal subjects (Kuyk, Liu, & Fuhr, 2005). The visual field loss not only impaired their behavioural function but also their quality of life (Taylor, Hobby, Binns, & Crabb, 2016) which has a wider impact on patients participation in society, emotional well-being, and independence.

In 2015, there were an estimated 253 million people with visual impairment globally, and around 3 to 4% of them suffered from either glaucoma or AMD (Ackland, Resnikoff, & Bourne, 2017) that affects mainly the elderly population. These estimates indicate the substantial global burden of these diseases that suggests immediate improvement of eye care service as well as the provision of effective rehabilitation strategies to ameliorate visual disabilities (Wong et al., 2014). Therefore, numerous treatment options have been introduced to rehabilitate glaucoma, retinitis pigmentosa and AMD including compensatory training which was found to be clinically effective (Ivanov et al., 2016; Janssen & Verghese, 2016; Liu, Kuyk, & Fuhr, 2007; Parmeggiani et al., 2011). For example, the study on the effects of visual compensatory training on retinitis pigmentosa patients was recently conducted in a controlled trial by Ivanov and co-workers

(2016). They reported a positive therapeutic impact of exploratory saccade training on mobility among retinitis pigmentosa patients such that patients demonstrated faster visual search and improved ability to avoid obstacles which were persistent up to 6 weeks post-training. Despite promising effects of compensatory training, it is not widely offered and accessible to many patients. At present, the training was done in a specialised clinic which is both costly and laborious. Therefore, the DREX app, which is free and accessible, could be advantageous to these patients.

Study 7 (Chapter 6) reports a proof of principle case series investigating the effect of DREX training in the rehabilitation of visual exploration and reading impairments in patients with tunnel vision, central visual field loss and bitemporal visual field loss. If successful, DREX could be offered to many patients at no cost. The outcomes of this study will also allow us to make specific modifications where necessary to the training itself in order to optimise the efficacy of training for these patient populations.

1.3.6 The effects of blurred vision on the outcomes of visual exploration training

Blurring of vision is the main cause of visual impairment worldwide (Pascolini & Mariotti, 2012) and one of the most common co-morbid visual problems present in many patients, including those with visual field loss after stroke (Rowe et al., 2013). It is well-established that the blurring of vision can be treated simply by an optical aid like spectacles and contact lenses. Recently, an increasingly popular medical procedure like refractive laser surgery became one of the preferred treatment options to restore clearer vision permanently, however this procedure is very expensive (Hashmani et al., 2017; Wilkinson, Cozine, Khan, & Kahn, 2017). Despite the advancement of technology in treating blurred vision, many patients are still unable to achieve satisfactory visual quality because the blurred vision is not merely resulting from the optical blur, but rather the pathological diseases like macular disorders that cause permanent blurred vision

(Shingleton & O'Donoghue, 2000). Therefore, optical corrections including spectacles somehow do not provide any advantage to these patients.

It has been demonstrated that blurred vision has adverse impact on visual searching in moderate to profound visual impairment patients (Kuyk et al., 2005; Skeel, Nagra, VanVoorst, & Olson, 2003) which was described as slow and time-consuming. A study by Liu et al. (2007) on the effect of visual search training on individuals with profound visual impairment revealed that impaired visual search resulting from reduced central vision can be trained using a visual compensatory training. However, the evidence on the effects of blurred vision on visual search is still lacking, and it is unknown at what level of blurred vision the training is most impactful, and equally, what level of blur becomes detrimental to training. It is important to know the level of visual acuity that is essential to give a maximum training effect so that clinicians and therapists could predict the outcomes of the vision rehabilitation more accurately. This will also enable patients with an acceptable level of blurred vision to carry on with the training and gain benefits from it, whereas perhaps alternatives need to be sought in cases where the level of blur is too severe for training to be effective. Therefore, the aim of Chapter 7 (Studies 8 and 9) is to investigate whether optically induced blurred vision could affect the performance of visual search and to study the effect of training under blurring conditions on visual search performance. Most importantly, the outcomes of this study will assist in the decision making as to whether DREX training is suitable and could be given to the HVFD patients who also have uncorrected refractive errors or permanent blurred vision.

Chapter 2

Study 1 - A randomised controlled trial comparing the effectiveness of Durham Reading and Exploration (DREX) training in the rehabilitation of individuals with HVFDs.

2.1 Introduction

Saccadic compensatory treatment is at present the only evidence-based treatment for HVFDs (Hanna & Rowe, 2017, Trauzettel-Klosinski, 2017). Nowadays, the modes of training for HVFDs have pragmatically changed from a large display to a small laptop or computer screen, which has become a favourable mode of treatment by many patients and therapists (Hanna, Hepworth, & Rowe, 2017; Pollock et al., 2011). Using a computer to train independently at home increases both training ease and accessibility, and could potentially reduce the overall therapy cost (Aimola et al., 2014).

At the moment, there are only three clinically accepted online compensatory training tools which are available for use: Neuro Eye Coach from Nova Vision Inc. (Sahraie, Smania, & Zihl, 2016) which concentrates on training visual exploration, and Read-Right (Ong et al., 2012) and Eye-Search (Ong et al., 2015) from University College of London which train reading and visual exploration respectively. The cost of the Neuro Eye Coach training programme is around USD450.00 for a complete training package, while the Read-Right and Eye-Search are accessible for free. In terms of the training strategies, Neuro Eye Coach employs pop-out, complex and conjunction search tasks such that patients are instructed to find a target among distractors like searching for an X amongst Os (Sahraie et al., 2016). Eye-Search however uses a ramp-step paradigm where patients are asked to pursue a smooth moving stimulus followed by a quick gaze shift to an unpredictable location (Ong et al., 2015). Read-Right is a web-based reading training to

enhance reading speed that encourages patients to gradually train their reading speed using laterally scrolling text (Ong et al., 2012). Currently, Nova Vision Inc. has yet to introduce a compensatory reading training. Trauzettel-Klosinski (2017) proposed that a good training programme should aim to enhance both reading and visual exploration because the impairment of these skills are the most frequently reported behavioural problems among the patients (Rowe et al., 2009; Zihl, 2010). An integrated training package therefore seems to be the best treatment approach which is not only practical and more beneficial for patients with such impairments, but could also save more therapy time and money (Aimola et al., 2014; Rowe et al., 2016; Suter, 2016). At present, the DREX training app is the first training app that combines these two components.

The present computer training options outlined above are still limited to those who have a constant access to the internet (Ong et al., 2012; Ong et al., 2015; Sahraie et al., 2016), so not everyone who requires treatment can train using this mode of training. Therefore, the DREX training app addressed this point in its development; access to the internet is only required at the point of download, and after that the app is usable without an online connection. Other than free access to the training, the DREX training app is offered in multiple platforms: a computer version, as well as a new touchscreen version available for iPads and Android tablets. The touchscreen version uses different visuomotor skills, where vision and hand movements work together to produce an action like tapping a target on the screen. The tablet version of the training could provide more advantages over computer-based ones in terms of the ease of use and device convenience. Furthermore, touchscreen tablets are now becoming more popular so more likely that people have these, and touchscreen technology is more intuitive for people who may have limited experience with technology including the elderly people (Burkhard & Koch, 2012; Culén & Bratteteig, 2013; Holzinger, 2002).

Although the DREX training app has been designed to be a comprehensive and accessible training, this newly developed app has yet to be demonstrated in term of its efficacy. Therefore, a sufficiently scaled randomised controlled trial is required to investigate this and in order to thereby support its implementation in practice. The aim of the present study is to investigate the effectiveness of DREX training in the rehabilitation of individuals with HVFDs as compared to a control group not undergoing training. As previously discussed (pp. 27), earlier studies exploring the efficacy of saccadic compensatory training have reported significant improvements in visual search, reading and quality of life (Aimola et al., 2014; Hanna et al., 2017; Lane et al., 2010; Roth et al., 2009; Trauzettel-Klosinski, 2017). Consequently, it is hypothesised that the DREX training will result in significant improvements in these areas of functioning as well. In the present study, the mode of delivery of training (computer versus touchscreen tablet) is also considered to determine if these are equally effective, an issue that has not been previously addressed.

It is clear that the training success in visually impaired people could be influenced by their mood (Rovner, Zisselman, & Shmuely-Dulitzki, 1996; Williams, Brody, Thomas, Kaplan, & Brown, 1998) and motivation, a vital psychological aspect that could lead patients to poorer perceived life quality (Shuttleworth, Dunlop, Collins, & James, 1995; Watson, 2001). Generally, low mood or depression in adults with visual impairment is associated with feelings of hopelessness and disengagement from society (Tsai et al., 2003), and about one-third of elderly people who are visually impaired present with clinically significant depressive symptoms (Brody et al., 2001; Horowitz, Leonard, & Reinhardt, 2000; Rovner & Casten, 2002). So, questions like ‘do patients who have high motivation towards rehabilitation perform better in the training tasks?’ and ‘will they gain greater improvement of reading and exploration skills if their initial mood is poor?’ could provide useful information about patients' mood, motivation and perception towards

rehabilitation, and possible predictors of efficacy and outcome of the rehabilitation. Therefore, this study will assess the impact of DREX training on motivation and depression to provide new insight about the training with respect to socio-emotional functioning, as well as subjective improvement on ADL.

2.2 Methods

2.2.1 Study design

A randomised controlled design was conducted comparing the effects of visuomotor (touchscreen) DREX, computer-based DREX, and a control (standard care; see Figure 2.1). Participants in the intervention groups (visuomotor and computer-based groups) initially received visual exploration training followed by reading training in a parallel design. The assessment of the primary outcome measures (visual exploration and reading) and secondary outcome measures (self-reported questionnaires; see Assessment tasks below for details) were initially measured during the pre-training assessment (A_1) and then were repeated three times: post-exploration training (Assessment 2, A_2), post-reading training (Assessment 3, A_3), and a 3-month follow-up (Assessment 4, A_4). All assessment tasks and training were conveniently done at the participants' home. In this Chapter, only data collected from A_1 and A_3 were analysed to investigate the overall effectiveness of DREX training packages and the effects of the training on ADLs, motivation and depression. The specificity of the impact of visual exploration training (A_2) or reading training (A_3) is discussed in Chapter 3, whilst the stability of the training benefits during 3-months follow-up (A_4) is explained in Chapter 4.

The study was approved by the psychology department ethics committee at Durham University and from the NHS NRES Committee North East - Newcastle and

North Tyneside 1 (REC reference: 15/NE/0351; Appendix A). The study was registered at the ISRCTN Registry as a clinical trial: ID ISRCTN16023965.

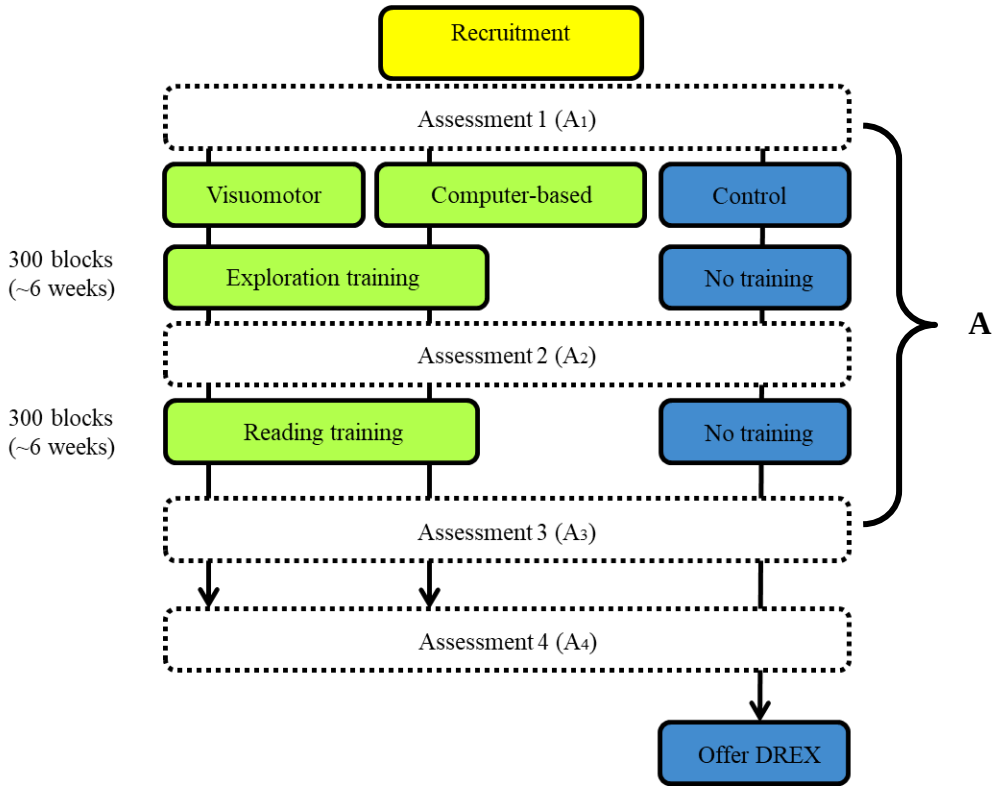


Figure 2.1 Flowchart illustrating overall study design and the specific assessment sessions that were included in Chapter 2, 3 and 4. **A** indicates the assessments (A_1 versus A_3) that were analysed in the present chapter (Chapter 2).

2.2.2 Participants

A total of 84 participants with HVFD were referred to the study, including both self-referrals and clinician referrals. Only 60 participants were eligible and included in the study (see Figure 2.2). After they had completed the pre-training assessment visit (A_1) the participants were randomly assigned into one of three study groups: intervention groups (visuomotor group and computer-based group) or control group (standard care group). The randomisation was done considering the side of the visual loss, which is known as a major contributing factor for functioning, especially with respect to reading (Schuett, Heywood, Kentridge, & Zihl, 2008a; Zihl, 2010). Firstly, patients initially were assigned into one of

two categories: left-sided loss and right-sided loss. For each of these groups, a separate random sequence was used to allocate the patient to intervention groups or control group so that the three groups received an equal number of patients from both categories.

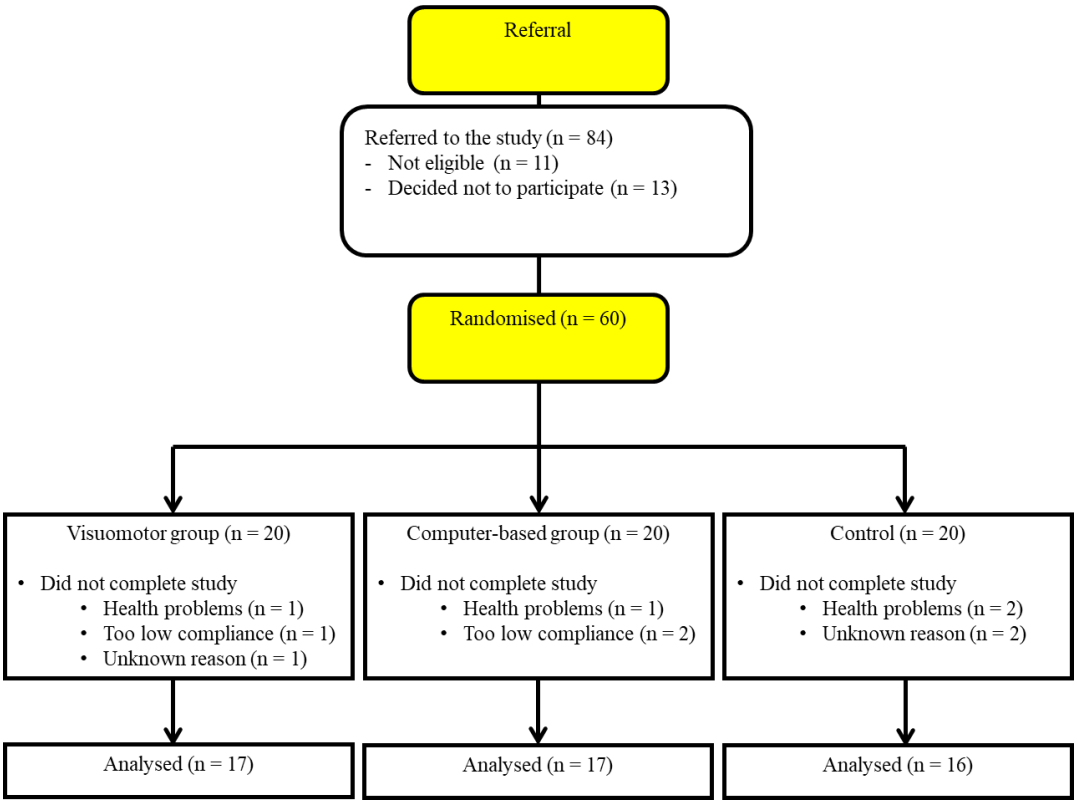


Figure 2.2 Flowchart illustrating a participant flow diagram for study in Chapter 2.

Participants were recruited from NHS services in the North East of England. Potential participants were identified by the key investigators (mainly stroke consultants, neurologists and ophthalmologists) in the Participation Identification Centres (PICs). The key investigators informed possible patients about the study by providing them with a participant invitation letter (Appendix B) and information sheet (Appendix C). These provided details of what the study involved, as well as explaining about written consent (Appendix D) to participate before they could enrol in the study. Both documents were provided to allow patients to make a fully informed decision before contacting the researchers, thereby removing any feelings of pressure to partake. With the patient's

consent, the existing medical notes were referred to assess the eligibility of participants alongside results from the tests conducted during the pre-training assessment.

2.2.2.1 Inclusion and exclusion criteria

Participants were adults aged 18 years or above who had been diagnosed with a non-progressive visual field defect due to post-geniculate injury. Currently, there was no indication that patients with pre-geniculate visual field defects benefit from the type of training which DREX can offer (Kerkhoff, 2000), and consequently, this study excluded such patients. Participants had a good cognitive ability which was confirmed from their medical records and were able to give consent; the cognitive functioning was tested using Montreal Cognitive Assessment (MoCA) or Oxford Cognitive Screen (OCS) where the clinician or occupational therapist interpreted the result based on the standard scoring of the test. The minimum time since onset of visual field defect was three months in order to reduce the possibility of spontaneous recovery of vision (Pambakian & Kennard, 1997). Those who had ocular diseases affecting the visual field or co-morbid oculomotor problems were also excluded from the study.

2.2.2.2 Classification of visual field defect

The types and sides of visual field defect were determined based on the latest perimetry result available in participants' medical notes which was then confirmed by the validated, self-administered DREX perimetry test (see Chapter 5 for more information about the testing procedures and how the perimetry test was validated). Due to the design of the DREX perimetry test, the degree of macular sparing was not measured and reported in this study. The perimetry results from their medical records did not provide sufficient details about the degree of macular sparing in every participant because the perimeter (e.g. Humphrey Visual Field Analyser, Goldmann perimetry) and testing protocol (e.g. kinetic,

static) used were largely varied. However, all perimeters were able to accurately classify the types and sides of the visual field defect which were the most crucial aspects for this home-based intervention study. Table 2.1 below shows the baseline characteristics of participants who completed the study.

Table 2.1

Baseline characteristics of participants from intervention groups and control.

	Participants Who Completed the Study			
	Visuomotor (n = 17)	**Computer-based (n = 17)**	**Control (n = 16)**	**Comparison of Groups**
Mean age, years (SD)	62.8 (15.4)	59.4 (12.8)	69.3 (12.7)	$F_{(2,49)} = 2.22$, p = 0.12
Gender, n (%)				$X^2_{(2)} = 1.59$, p = 0.45
Male	12 (70.6)	13 (76.5)	9 (56)	
Female	5 (29.4)	4 (23.5)	7 (44)	
HVFD side, n (%)				$X^2_{(2)} = 1.44$, p = 0.49
Left	7 (41.2)	8 (47.1)	9 (56.2)	
Right	10 (58.8)	9 (52.9)	7 (43.8)	
Defect type, n (%)				$X^2_{(2)} = 0.29$, p = 0.87
Hemianopia	14 (82.4)	13 (76.5)	12 (75.0)	
Quadrantanopia	3 (17.6)	4 (23.5)	4 (25.0)	
Duration* (Min,Max)	5 (3,12)	23.8 (3,240)	4.5 (3,8)	$F_{(2,49)} = 1.46$. p = 0.24
Visual Acuity$^{\alpha}$	6/7.5	6/12	6/12	
Etiology, n (%)				$X^2_{(2)} = 3.03$, p = 0.22
Ischaemic stroke	10 (58.8)	9 (52.9)	12 (75.0)	
Haemorrhagic	5 (29.4)	3 (17.6)	4 (25.0)	
Traumatic brain injury	2 (11.8)	4 (23.5)	0 (0.0)	
Tumour	0 (0.0)	1 (6.0)	0 (0.0)	

Note: Abbreviation: HVFD = homonymous visual field defect

* Duration was reported in months.

$^{\alpha}$ Visual acuity = Minimum corrected-to-normal (or normal) near visual acuity of the worst eye tested using near ETDRS chart.

2.2.2.3 Dropouts

Ten participants dropped out from the study. The main reasons for dropout were health problems (n = 4), low compliance (n = 3) and unknown (n = 3). The final sample included in analyses consisted of 50 participants: 17 visuomotor, 17 computer-based and 16 controls.

2.2.3 Outcome measures

2.2.3.1 Find-the-number search task

The find-the-number search task was the primary outcome measure and was used in a previous controlled trial (Aimola et al., 2014). The task was programmed using E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA). Participants had to scan an array of randomly displayed, non-overlapping items for a target (a number between 1 and 9). The distractors were non-numerical symbols (e.g. #, @, %, }, $, £, ?), and on half of the trials there were three distractors and the other half of trials contained seven distractors. The distractors and target were 24-point size, white and presented on a black background (see Figure 2.3), with the array displayed on a 15.6-inch laptop monitor. Once participants had identified the target they had to indicate their response as quickly as possible by pressing the corresponding keyboard key. The task consisted of 8 practice and 40 test trials. Only trials in which the correct response was provided, were used for the mean reaction time (RT) calculation.

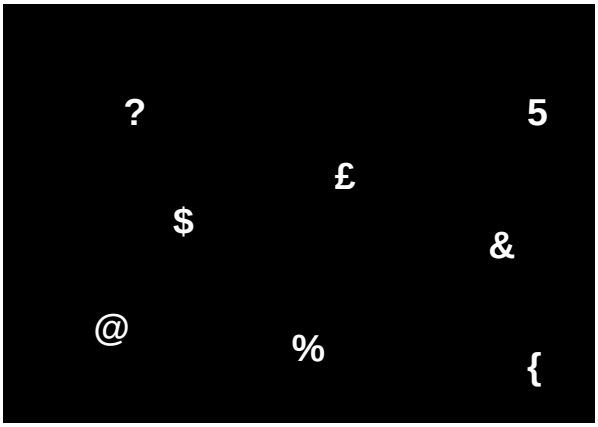


Figure 2.3 Diagram illustrating an example of a visual array used in the 'find-the-number' search task (not to scale). The target used in this example was number 5.

2.2.3.2 Paper-based reading task

Reading ability was the second outcome measure that was assessed using four modified, difficulty-matched passages (Appendix E) that have been used in the previous trials conducted at Durham University (Aimola et al., 2014; Lane et al., 2010). The paragraphs each consisted of 200 of words (in 14pt Arial font) and arranged in double-spaced, left-aligned lines printed on a white sheet of paper. The participants were asked to read one random passage aloud at each session with their best-corrected reading glasses if required. Reading time (in seconds) and the number of errors made were recorded. The corrected reading speed in words per minutes (wpm) was computed using this formula: (words read – number of errors) / time × 60.

2.2.3.3 DREX pen search task

The task consisted of 30 trials displaying either 4, 8 or 12 non-overlapping items; there were 10 trials of each set size. The arrays contained a target (a pen) in each trial and the other items were familiar everyday items like a mug, pencil, scissors and bottle. The items were distributed equally in each quadrant depending on the number of items for that trial, and the target appeared in each quadrant an equal number of times. All items were presented on a white background. Figure 2.4 shows two examples of the display.

Figure 2.4 Two examples of DREX pen search task display with a pen as the target. Not to scale.

All trials were target-present trials such that participants had to look for a hidden pen among other everyday items and click (computer-based) or tap (visuomotor) on the target in each trial. If participants could not find the pen, they had to press the spacebar (computer-based) or swipe the screen (visuomotor) to move on to the next trial. However, in a situation where participants did not give any response to the trial, the next trial began automatically after 20 seconds. Participants' RT and accuracy were recorded by the DREX system. Figure 2.5 shows the flow of the assessment procedure.

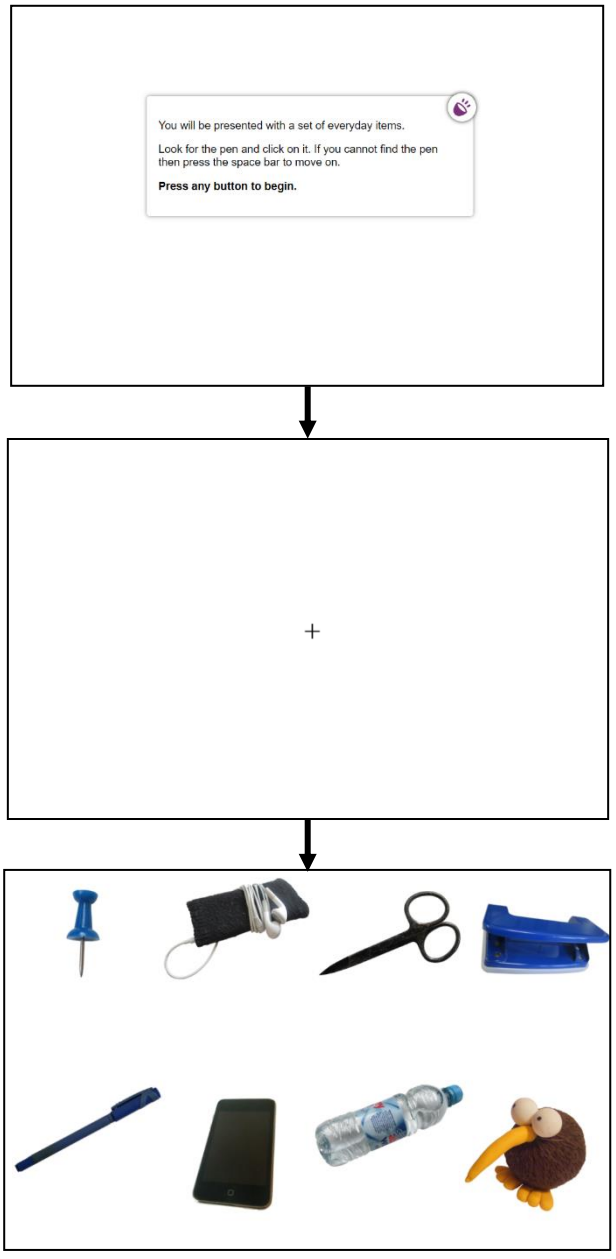


Figure 2.5 Diagram illustrating the step-by-step flow of the DREX pen search task. Not to scale.

2.2.3.4 DREX counting-number search task

The task consisted of randomly distributed numbers from 1 until 20 presented on a white background (see Figure 2.6). Participants were required to look for the numbers in sequence and click (computer-based) or tap (visuomotor) on them. If participants could not find a number, then they had to move to the next number in the sequence. When they had finished the task, they had to click or tap 'I'm finished' (located at the bottom of the screen), so that the time taken to complete the task could be recorded by the DREX system. In each assessment session the distribution of the numbers was changed randomly.

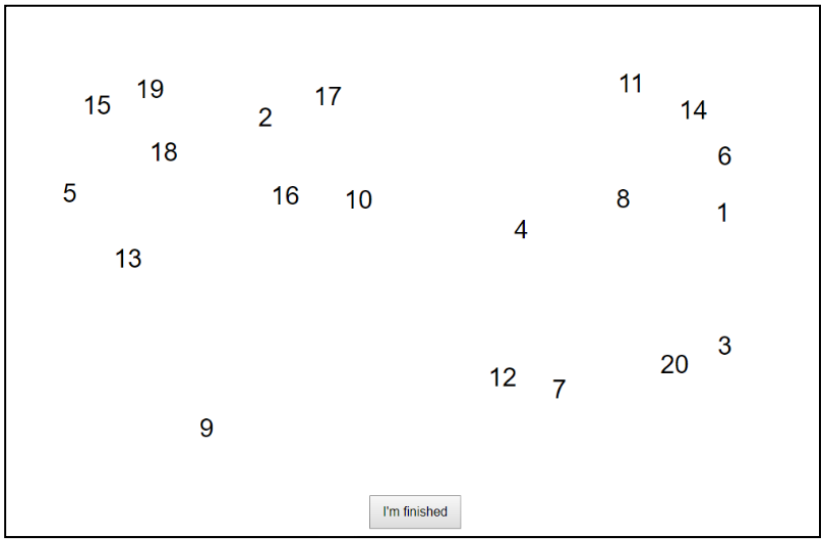


Figure 2.6 An example of DREX counting-number search task. Not to scale.

2.2.3.5 DREX reading task

A short paragraph of text (100 words) was presented to the participants and the time they took to complete the reading was recorded by the DREX system as determined by the participants clicking (computer-based) or tapping (visuomotor) the screen to begin and end. The reading speed in words per minute (wpm) was computed using this formula: words read / time × 60. Then, participants were asked three related multiple-choice questions about what they read to test their comprehension. The participants could spend as

much time as they wanted to answer the questions and only the accuracy of the answers was recorded. The paragraphs were modified from eight Brothers Grimm fairy tales, and in each assessment session a different paragraph was used. Figure 2.7 shows the flow of the assessment procedure.

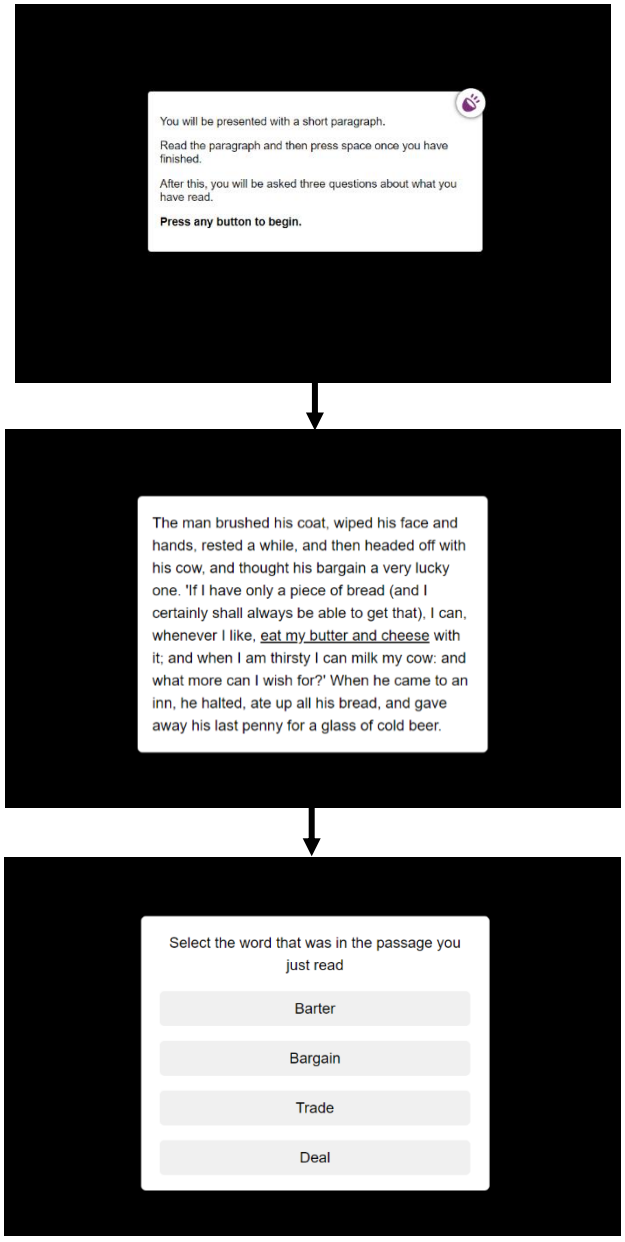


Figure 2.7 Diagram illustrating the step-by-step flow of the DREX reading task. Not to scale.

2.2.3.6 Questionnaires.

2.2.3.6.1 Visual Impairment Questionnaire (VIQ)

Visual disability was measured subjectively with the 10-item Visual Impairment Questionnaire (VIQ). The VIQ had been used in the previous study (Aimola et al., 2014) in a modified version developed by Kerkhoff et al. (1994) to assess the effect of visual impairment on the main daily living skills. The items include: seeing objects, bumping into obstacles, losing way, finding objects on a table, finding objects in a room, finding objects in a supermarket, using public transport, finding way at home, crossing the street and reading. The items are rated on a 5-point Likert scale ranging from 0 (no problem) to 4 (very frequent problem); a higher score is therefore indicative of greater disability (Appendix F).

2.2.3.6.2 Motivation for Traumatic Brain Injury Rehabilitation (MOT-Q)

The MOT-Q has 31 items. It was administered to measure patients' perceptions of their illness and engagement in the rehabilitation process (Boosman, van Heugten, Winkens, Smeets, & Visser-Meily, 2016; Chervinsky et al., 1998; Saltapidas & Ponsford, 2007). The items are rated on a 5-point Likert scale ranging from –2 (strongly disagree) to 2 (strongly agree) with a score of 0 being undecided (Appendix G). Total scores range between –62 and 62, and higher positive scores indicate higher motivation for rehabilitation.

2.2.3.6.3 Beck Depression Inventory II (BDI)

The 21-item BDI II questionnaire was administered to evaluate the impact of training on patients' mood. The BDI is an easy and effective self-assessment questionnaire which is widely accepted by clinicians and has been used in many studies to evaluate depression in medical settings including post-traumatic brain injury (TBI) rehabilitation

(Green, Felmingham, Baguley, Slewa-Younan, & Simpson, 2001; Wang & Gorenstein, 2013). An index score of ≤13 is indicative of minimal depression, a score of 14 to 19 shows mild depressive symptomatology, a score of 20 to 28 indicates moderate depression, and a score of 29 to 63 indicates severe depression (Appendix H).

2.2.3.6.4 Self-efficacy and attitude questionnaire

Participants' hopes, goals, confidence and attitudes were evaluated using the 10-item Self-efficacy and attitude questionnaire. They were designed to include potentially vital issues which had not been asked in the MOT-Q, BDI and VIQ. The questionnaire contains two parts: 1) 5-point Likert scale questions and 2) multiple choice questions. In part one, the questions relate to confidence in using technology (e.g. computer and touchscreen tablet) and computer/mobile app, willingness to pay for the rehabilitation cost, and their opinion about home-based training. The items were rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Participants were considered as having good confidence in using technology if participants rated 3 or more for that particular item. In terms of participants' willingness to pay for the rehabilitation cost, a score of 3 and above was considered as 'cannot afford to pay'. For part two, patients were asked questions about the activities they would like to improve as well as their main goal for the training (Appendix I).

2.2.4 Compensatory training

2.2.4.1 Visual exploration training

The visual exploration training comprised three different visual search tasks: colour, size and shape. For example, in the colour search task participants needed to find a blue 'X' (target) amongst yellow 'X's (distractors) and then click (computer-based group) or tap (visuomotor group) the target. If participants could not find the target they had to

click spacebar (computer-based group) or swipe the screen (visuomotor group) to proceed to the next trial. In every trial a total of 16 items were displayed, including one target if present. The letter 'X' was constantly used as the stimulus items (target-distractor), and the colours varied from a limited selection, although all distractors presented in any given trial were the same colour. The DREX app system dynamically and randomly adjusted the presentation time and location of items displayed in each block of training. One block consisted of 30, 60 or 90 trials, and this was set by participants or the researcher before the start of each block based on participants' preference and other aspects like memory, attention and confidence to perform the task. Participants could change the block setting to increase or reduce the number of trials anytime they wanted. Figure 2.8 below shows an example of colour search task display.

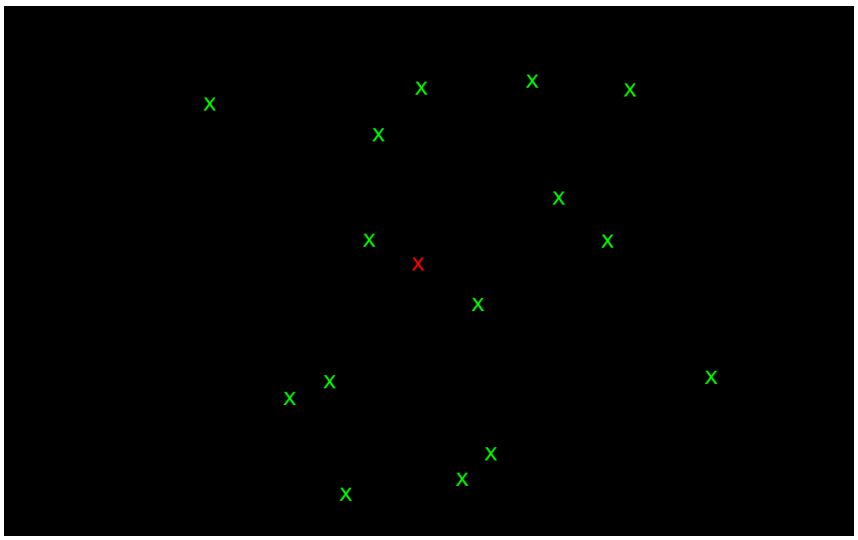


Figure 2.8 A target (red X) was displayed at the centre of the screen amongst distractors (green 'X's) in the colour search task. Not to scale.

As participants progressed through the training, the task was made more difficult by displaying the target further away from the centre, making the target and distractors more similar, and reducing the time available for the visual search. At the easiest level of difficulty, the target appeared mostly near to the centre of the screen and the colours of

target and distractor were significantly different (e.g., blue and red). The presentation time was also longer, approximately 30 seconds, for each trial. When participants' reaction time decreased, and their accuracy was above criterion for more than 90% of the trials, the difficulty of the task then was increased by presenting the target further into the periphery and the distractor colour was made more similar to the target (e.g., pink and red). The time available for visual search was also dynamically reduced by the DREX app system; the fastest presentation time was 1 second. If participants did not respond in time, a message notifying a 'time-out' appeared (see Figure 2.9) and that particular trial was considered as a miss.

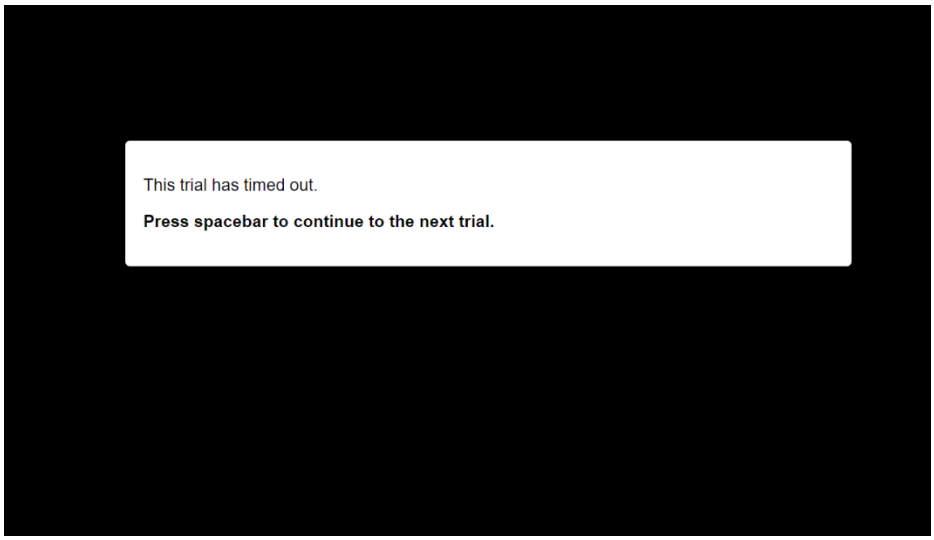


Figure 2.9 A notification stating that the trial has timed out if participant did not respond in time. Not to scale.

On occasion where participants' accuracy reduced again below criterion in more than 75% of trials, the level of difficulty also dropped. The maximum level of difficulty that participants could achieve was 8. The DREX app recorded the accuracy and speed of the search response and performance feedback was provided to the participant for each block of search trials.

The training process and system worked similarly for size and shape search tasks with respect to the adjustment of the task difficulty, the number of items and trials, as well as the way participants should respond to the task. In the size search task, participants were required to find a larger letter (target) amongst the smaller letters (distractors). On any given trial the letter and colour were the same for all items, although these did change from a selection of those available across trials. Specifically, as the difficulty increased, the size difference between the target and the distractors decreased. Finally, in the shape search task, participants had to find a specific target letter (for example a 'V') amongst other distractor letter (for example 'O's). For each trial the colour and size of the items presented was consistent, but these variables did change across the trials. With increasing task difficulty, the letters presented as target and distractors became more visually similar (e.g., if the target was an 'X', in easy tasks the distractors could be 'O's, but in the harder tasks the distractors may be 'K's). Figures 2.10(A) and 2.10(B) below show the examples of size and shape search tasks.

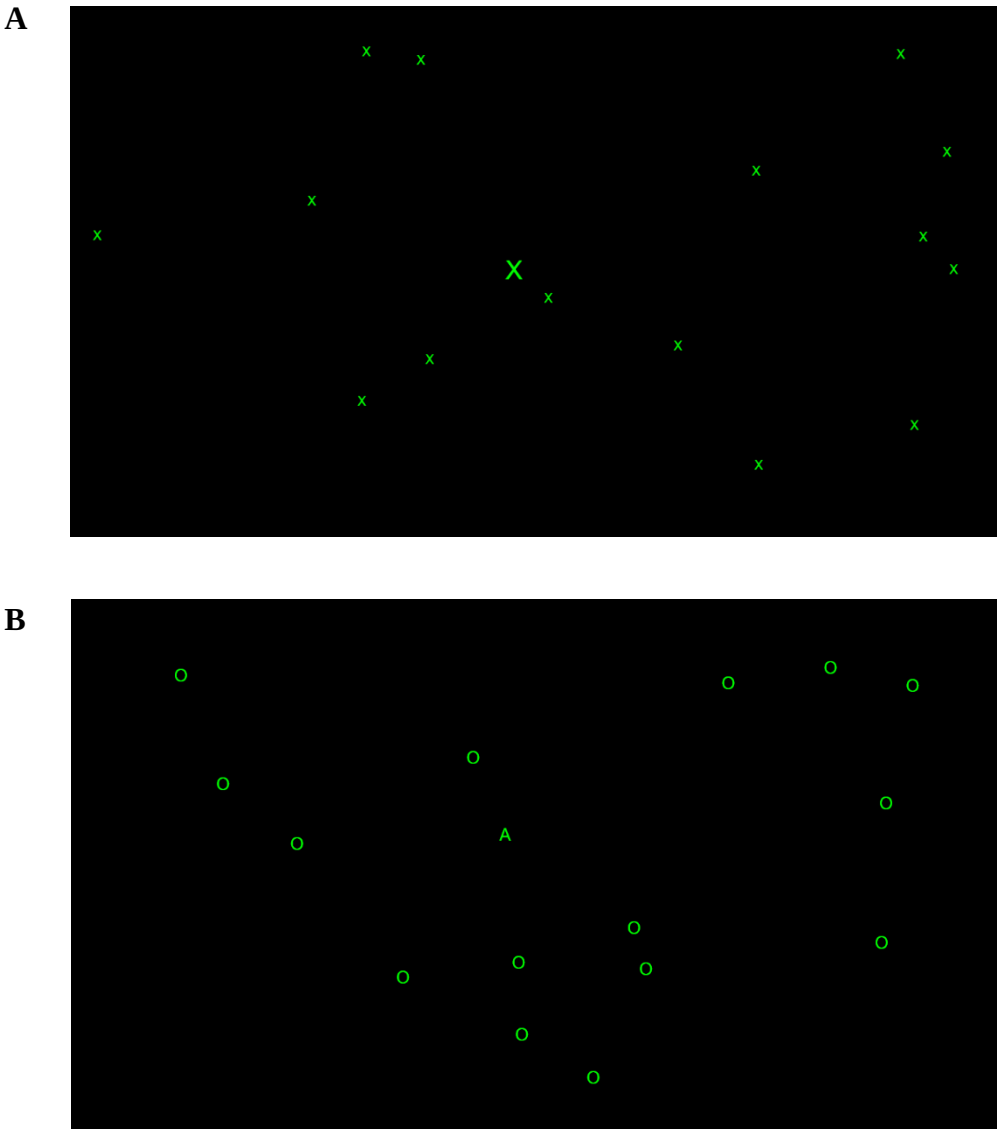


Figure 2.10 **A)** Size search task – a larger X was displayed centrally amongst the identical distractors which were also letter X; **B)** Shape search task – letter A was a target located centrally amongst 'O's. Not to scale.

2.2.4.2 Reading training

The reading training involved participants identifying a non-word from real words which were white in colour and presented on the black background; if they spotted a non-word then they had to click (computer-based group) or tap (visuomotor group) it. However, if all items were real words, they had to click the spacebar (computer-based group) or swipe the screen (visuomotor group) to progress to the next trial. The aim was to improve the small and large voluntary eye movements used when reading to ensure that all letter-strings were explored carefully, and thereby minimising guessing errors. The

automatic adjustment of the task difficulty including the 'time-out' message and personalised change to the total number of trials in each block applied largely the similar procedure as the visual exploration training.

The difficulty of the task was increased by modifying the length of the letter-strings from shorter (2 to 4 letters) to longer (4 to 7 letters), increasing the number of distractor words from 0 to 6 (in the later stages, the distractors were real words and a non-word was the target), and adjusting the presentation time. In the beginning, a single, shorter word or non-word was used and presented in the centre of the screen, and then it was changed to a longer word or non-word as participants progressed. The initial presentation time was set for a maximum of 30 seconds which then reduced progressively as participants' reaction speed increased; the fastest presentation time was also 1 second. In the advanced training stage, more real words increasingly presented in a horizontal line with a non-word (target) appeared randomly at a different location either at the centre or to the left or right of the centre (see Figure 2.11). The progression to more words (longer phrases) indicated a successful training with single word. The length of the words increased if participants' accuracy was above criterion for more than 90% of the trials and could reduce if the accuracy was below criterion in more than 75% of trials. A similar procedure as for the exploration training was also used to provide feedback to the patient. The maximum level of difficulty that a participant could achieve was 26.

A

B

Figure 2.11 Figures illustrating examples of two trials; **A**) 'RUOY' and **B**) 'WORKIGN' are the non-word targets, so participants had to tap or click it in order to progress. Not to scale.

2.2.5 Procedures

Written informed consent was acquired in accordance with the Declaration of Helsinki. The assessment tasks were completed in a pseudo-random order and counterbalanced across the participants. After the A_1 session, participants were randomly assigned into three study groups either visuomotor group, computer-based group or control group. In the intervention groups, participants first completed exploration training followed by reading training using the DREX training app. The only difference was that the visuomotor group completed the training on a touchscreen tablet, while the computer-

based group performed the training using a laptop. If participants had their own computer or tablet then this was used, otherwise a device was loaned to them for the duration of the study. A demonstration and instruction on how to run the training were given prior to the self-training. No compensatory training was given to those in the control group.

2.2.5.1 Intervention groups

After A_1, participants completed 27,000 trials of exploration training (e.g., 300 blocks × 90 trials) followed by 27,000 trials of reading training. If the number of trials for each block was changed to 30 or 60 trials, the number of blocks would be automatically adjusted to 900 or 450 blocks respectively, and this would not alter the total trial number. The average duration required to complete 30 trials/block was approximately 1.5 minutes, 3 minutes for 60 trial/block, and 4.5 minutes for 90 trials/block. Participants were encouraged to complete 900 trials per day. Participants took approximately 6 weeks to complete the exploration training, and similarly 6 weeks for reading training. A post-training assessment, A_3, was conducted after the reading training had finished (see a study flow diagram, Figure 2.1, in the Study Design section for more details).

2.2.5.2 Control group

Participants in the control group repeated the assessment tests 12 weeks later in a post-training assessment session (A_3). The time intervals between assessment sessions did not noticeably differ between the two intervention groups and the control group.

2.2.6 Statistical analysis

The analyses included data only from those who had completed the training (if they were in the intervention groups). The conventional two-sided test procedure [$(1-\alpha)$ x 100%]; 95% confidence interval and 0.05 significant level, was employed. Mixed-model

ANOVAs were applied to the data with the within-subject variable Session (A_1 and A_3), and between subject variable Group (visuomotor, computer-based, and control). When applicable, paired-sample t-tests were used to compare all different combinations of the study groups. As multiple analyses were carried out, Bonferroni corrections were applied where relevant. Questionnaire data were analysed using Wilcoxon signed-ranks for within-subjects and Pearson correlation if required.

2.3 Results

2.3.1 Overall training performance

2.3.1.1 Visuomotor group

The mean accuracy of exploration training was 81.4% (SD = 6.74) and the average level of difficulty that participants achieved was 6.9 out of 8. The mean accuracy of reading training was 88.1% (SD = 5.75) and the average level of difficulty that participants achieved was 21 out of 26.

2.3.1.2 Computer-based group

The mean accuracy of exploration training was 84.8% (SD = 8.92) and the average level of difficulty that participants achieved was 6.6 out of 8. The mean accuracy of reading training was 85.7% (SD = 8.83) and the average level of difficulty that participants achieved was 21.6 out of 26.

One-way ANOVA on the mean accuracy of visual exploration and reading training between visuomotor and computer-based groups revealed non-significant differences, $F_{(1,33)} = 1.55$, $p = 0.222$ and $F_{(1,33)} = 0.86$, $p = 0.360$ respectively, indicating that the performance of participants from both intervention groups in visual exploration and reading training was comparable.

2.3.2 Outcome measures

2.3.2.1 Find-the-number search task

Mean accuracy for all three groups was above 92% in both A_1 and A_3 sessions, and there were no significant main or interaction effects of Session and/or Group [largest $F_{(2,47)} = 2.21$, $p = 0.121$]; the search accuracy remained high. The pre-training RT was not significantly different between the three groups, $F_{(2,49)} = 0.154$, $p = 0.858$, indicating the same visual exploration speed was observed in all participants at baseline.

A 2 (Session: A_1 and A_3) × 3 (Group: visuomotor, computer-based and control) mixed-model ANOVA on mean RT revealed a main effect of Session, $F_{(1,47)} = 15.17$, $p < 0.001$, indicating an enhanced visual exploration performance at A_3 relative to A_1. There was no effect of Group, $F_{(2,47)} = 1.08$, $p = 0.348$, but there was a significant Group by Session interaction, $F_{(2,47)} = 4.11$, $p = 0.023$.

Pairwise comparisons revealed a significance difference between the mean RT of A_1 and A_3 in the visuomotor group, $t_{(16)} = 3.98$, $p = 0.001$ such that participants were faster in their visual exploration after the training. Similarly, participants from the computer-based group were significantly faster in their visual exploration after the training, A_3 compared to their performance before the training, A_1, $t_{(16)} = 2.60$, $p = 0.019$. The difference of the mean RT for control group at A_1 and A_3 was not significant, $t_{(15)} = -0.19$, $p = 0.855$. Figure 2.12 shows the mean RT at A_3 relative to A_1 in all groups.

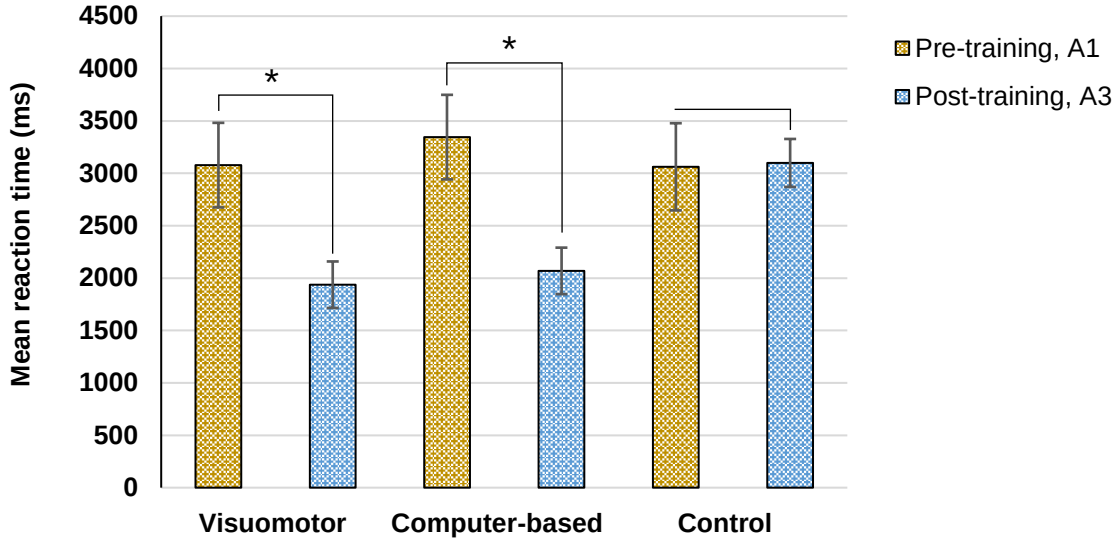


Figure 2.12 Bar chart illustrating the mean RT of visual exploration in visuomotor, computer-based and control groups during the post-training assessment (A_3) relative to pre-training assessment (A_1). The error bars represent the standard error of the mean. Significant difference (*).

To illustrate these differences more clearly, the data was converted into a difference score to show the percentage improvement of visual exploration across groups. The mean improvement was 30.22% (95% confidence interval [CI] = 19.20% to 41.24%) for the visuomotor group, and 28.38% (95% confidence interval [CI] = 17.13% to 39.04%) for the computer-based group. The improvement between both intervention groups was not significantly different (p = 0.717), demonstrating that performance in the find-the-number search among participants trained using touchscreen tablet was comparable to the participants trained using computer. No significant improvement in the visual exploration performance was found in the control sample; this group showed on average a 3.19% (95% confidence interval [CI] = -14.71% to 8.32%) decline in performance.

2.3.2.2 Paper-based reading task

There was no significant difference in the pre-training corrected reading speed of participants with right and left HVFDs, $F_{(48)} = 1.45$, $p = 0.235$ (mean reading speed: right = 90.8 wpm, left = 103.8 wpm). The pre-training reading speed was not significantly different between the three groups, $F_{(2,49)} = 0.076$, $p = 0.927$, indicating the same reading speed was observed in all participants before the training.

A 2 (Session: A_1 and A_3) × 3 (Group: visuomotor, computer-based and control) mixed-model ANOVA on mean corrected reading speed revealed a main effect of Session, $F_{(1,47)} = 34.70$, $p < 0.001$; participants read significantly faster at A_3 relative to A_1, but no effect of Group, $F_{(2,47)} = 0.57$, $p = 0.568$. There was a significant interaction between Group and Session, $F_{(2,47)} = 11.40$, $p < 0.001$.

Pairwise comparisons revealed a significance difference between the mean corrected reading speed of A_1 and A_3 in the visuomotor group, $t(16) = -6.81$, $p = 0.001$ such that participants read faster after the training. Likewise, participants from the computer-based group read significantly faster after the training, A_3 compared to their reading speed before the training, A_1, $t(16) = -3.54$, $p = 0.001$. The difference of the mean corrected reading for control group at A_1 and A_3 was not significant, $t(15) = 0.40$, $p = 0.696$. Figure 2.13 shows the mean corrected reading speed at A_3 relative to A_1 in all groups.

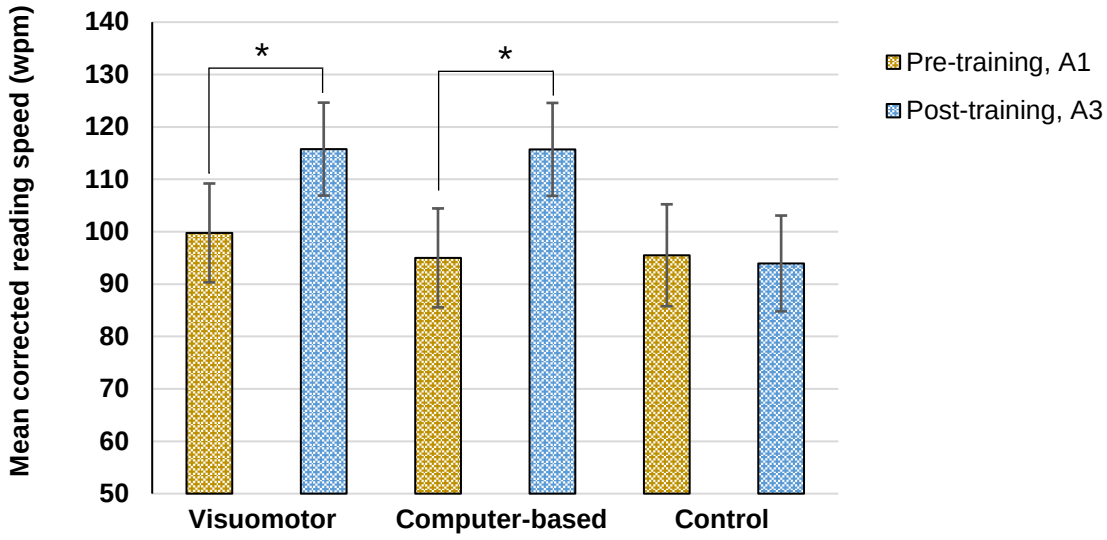


Figure 2.13 Bar chart illustrating the mean corrected reading speed in visuomotor, computer-based and control groups during the post-training assessment (A_3) relative to pre-training assessment (A_1). The error bars represent the standard error of the mean. Significant difference (*).

The data was converted into a difference score to show the percentage improvement of reading across groups. The mean reading speed increased significantly by 20.25% (95% confidence interval [CI] = 11.77% to 28.72%) for the visuomotor group, and 27.59% (95% confidence interval [CI] = 16.38% to 38.79%) for the computer-based group after the training (see Figure 2.13). The improvement between both intervention groups were not significantly different (p = 0.365) demonstrating that the reading performance among participants trained using touchscreen tablet was comparable to the participants trained using computer. The change of reading speed in the controls was not significant; this group improved on average by 1.54% (95% confidence interval [CI] = -7.53% to 10.43%).

2.3.2.3 DREX pen search task

A 2 (Session: A_1 and A_3) × 3 (Group: visuomotor, computer-based and control) mixed-model ANOVA on mean RT revealed a significant effect of Session, $F_{(1,47)} = 20.41$, $p < 0.001$, indicating that participants were significantly faster in the Pen search task at A_3 relative to A_1 (see Table 2.2). No significant effect of Group, $F_{(1,47)} = 0.36$, $p = 0.554$, or Group by Session interaction, $F_{(2,47)} = 1.13$, $p = 0.332$ was indicated. There was no change in the search accuracy as revealed by non-significant main and interaction effects for accuracy ($p \geq 0.089$; minimum search accuracy in all conditions was 95.0%).

Table 2.2

Table illustrating the mean reaction time (RT), in milliseconds, and standard deviation (SD) for the DREX pen search task for all study groups during pre-training assessment, A_1 and post-training assessment, A_3.

Group	**Pre-training Assessment, A_1**		**Post-training Assessment, A_3**	
	Mean RT (ms)	**SD**	**Mean RT (ms)**	**SD**
Visuomotor	3670	2710	2040	720
Computer-based	2910	1350	2120	1080
Control	3940	2130	3000	1350

2.3.2.4 DREX counting-number search task

A 2 (Session: A_1 and A_3) × 3 (Group: visuomotor, computer-based and control) mixed-model ANOVA on the search duration revealed no main effect of Session, $F_{(1,47)} = 3.33$, $p = 0.075$, or Group, $F_{(1,47)} = 0.79$, $p = 0.461$, but a significant Group by Session interaction, $F_{(2,47)} = 4.64$, $p = 0.015$.

Pairwise comparisons revealed a significance difference between the mean search duration of A_1 and A_3 in the visuomotor group, $t(16) = 2.53$, $p = 0.022$ such that the search duration was shorter after the training, indicating faster visual exploration. Similarly, the mean search duration of A_1 and A_3 in the computer-based group was also significantly different, $t(16) = 2.17$, $p = 0.045$; participants took lesser time to complete the task at the

post-training, A_3. The difference of the mean search duration for control group at A_1 and A_3 was not significant, t(15) = -1.43, p = 0.174. Figure 2.14 shows the mean search duration at A_3 relative to A_1 in all groups.

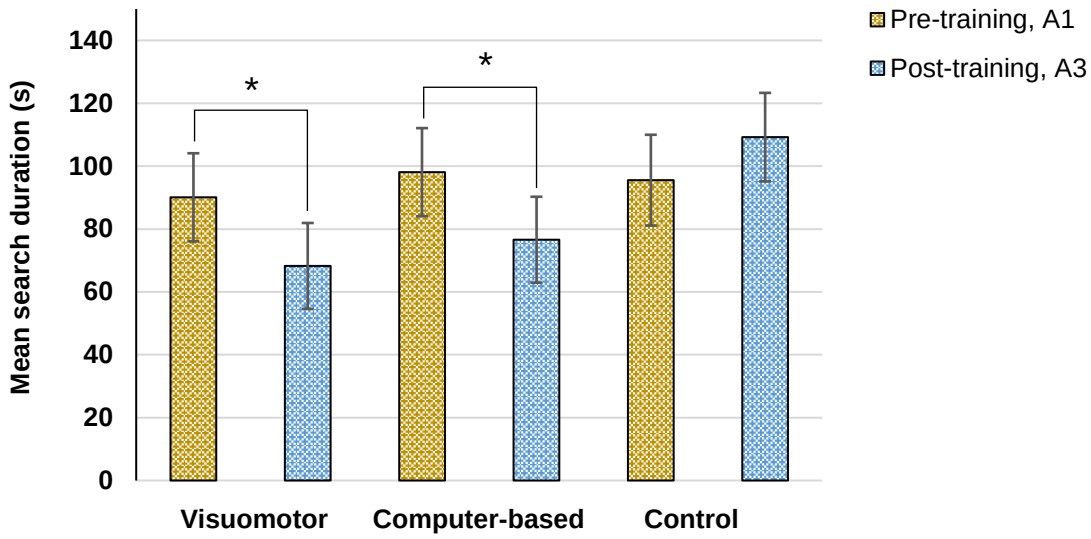


Figure 2.14 Bar chart illustrating the mean search duration in the DREX counting-number search task in visuomotor, computer-based and control groups during the post-training assessment (A_3) relative to the pre-training assessment (A_1). The error bars represent the standard error of the mean. Significant difference (*).

The data was converted into a difference score to demonstrate the percentage improvement of search duration across groups. The mean improvement in search duration for the visuomotor group was 16.87% (95% confidence interval [CI] = 0.76% to 32.98%), and for the computer-based group it was 21.42% (95% confidence interval [CI] = 5.51% to 37.33%). The improvement between both intervention groups was not significantly different (p = 0.660), indicating that the performance in the counting-number search task was comparable among participants trained using a touchscreen tablet or computer. No significant improvement in the visual exploration performance was found for the control group; this group showed on average a decline in search duration of 24.89% (95% confidence interval [CI] = -54.95% to 5.17%). There was no change in the mean search

accuracy, non-significant main or interaction effects: $p \geq 0.302$ (mean search accuracy = 100.0%).

2.3.2.5 DREX reading task

There was no significant difference in the pre-training corrected reading speed of participants with right and left HVFDs, $F_{(48)} = 2.56$, $p = 0.116$ (mean reading speed: right = 103.2 wpm, left = 125.9 wpm). A 2 (Session: A_1 and A_3) × 3 (Group: visuomotor, computer-based and control) mixed-model ANOVA on reading speed revealed no effect of Session, $F_{(1,47)} = 2.27$, $p = 0.139$, or Group, $F_{(1,47)} = 2.10$, $p = 0.134$. There was a significant Group by Session interaction, $F_{(2,47)} = 5.12$, $p = 0.010$

Pairwise comparisons revealed a significance difference between the mean reading speed of A_1 and A_3 in the visuomotor group, $t_{(16)} = -2.98$, $p = 0.009$ such that participants read faster after the training. However, there was no significant difference in the mean reading speed of A_1 and A_3 for computer-based, $t(16) = -0.96$, $p = 0.350$ and control, $t_{(15)} = 1.28$, $p = 0.219$ groups. Figure 2.15 shows the mean reading speed at A_3 relative to A_1 in all groups.

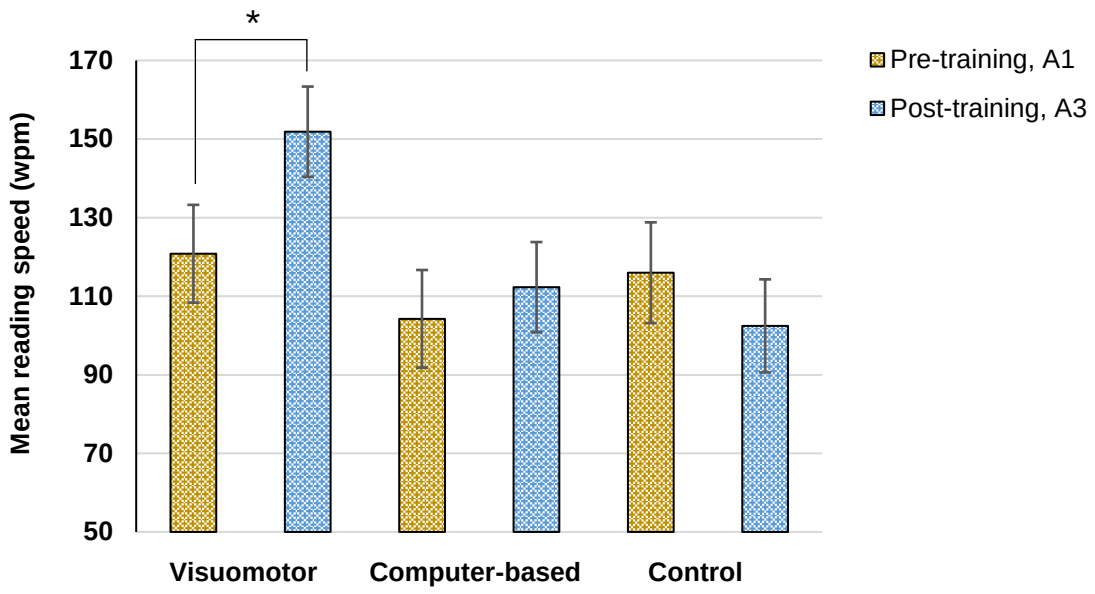


Figure 2.15 Bar chart illustrating the mean reading speed (wpm) measured by reading task from DREX app in visuomotor, computer-based and control groups during the post-training assessment (A_3) relative to pre-training (A_1). The error bars represent the standard error of the mean. Significant difference (*).

In term of the change of mean reading speed across groups, the visuomotor group's reading speed improved significantly by 33.62% (95% confidence interval [CI] = 13.94% to 53.30%; see Figure 2.15). The computer-based group showed improvement in the reading speed by 16.88% (95% confidence interval [CI] = -2.59% to 36.35%), while the controls did not show any improvement (-1.64%; 95% confidence interval [CI] = -20.46% to 17.18%). The improvement between both intervention groups was not significantly different (p = 0.588). Similarly, there was no significant difference in the improvement between computer-based and control groups (p = 0.479).

A 2 (Session: A_1 and A_3) × 3 (Group: visuomotor, computer-based and control) mixed-model ANOVA on the accuracy data relating to reading comprehension revealed a significant main effect of Session, $F_{(1,47)} = 8.27$, p = 0.006; the mean reading comprehension accuracy was significantly higher at A_3 relative to A_1. There was also a significant effect of Group, $F_{(1,47)} = 3.19$, p = 0.050; comprehension accuracy was greater

in the visuomotor group relative to the control group (p = 0.050), whilst for the computer-based group it was comparable with the visuomotor and control groups (p > 0.050). There was also a significant interaction between Session and Group, $F_{(2,47)} = 4.18$, p = 0.021.

Pairwise comparisons revealed a significance difference between the mean comprehension accuracy of A_1 and A_3 in the computer-based group, $t_{(16)} = -3.47$, p = 0.003 such that comprehension accuracy improved greatly after the training. However, there was no significant difference in the mean comprehension accuracy of A_1 and A_3 for visuomotor, t(16) = -1.92, p = 0.072 and control, $t_{(15)} = 0.52$, p = 0.610 groups. Figure 2.16 shows the mean comprehension accuracy at A_3 relative to A_1 in all groups.

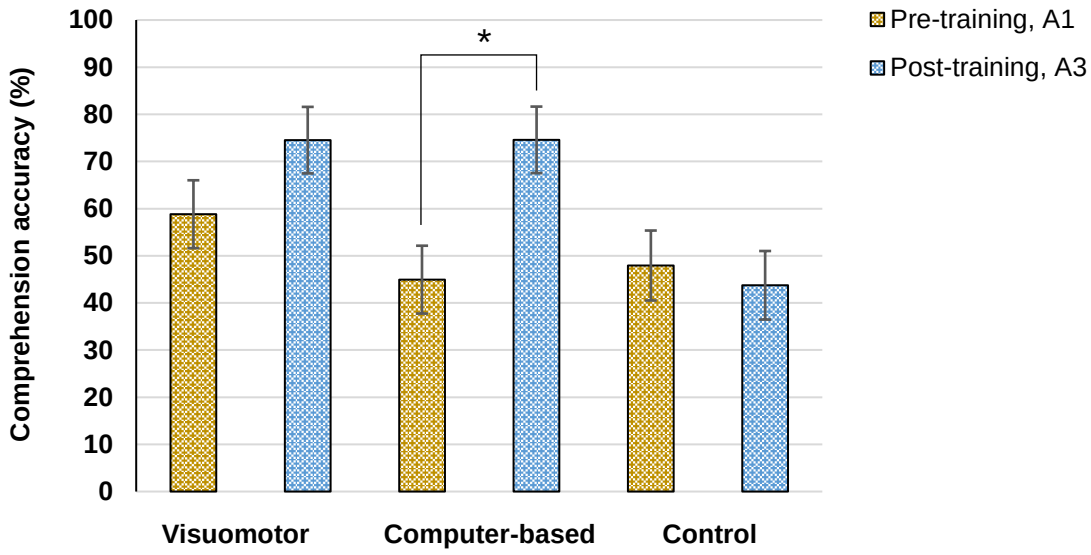


Figure 2.16 Bar chart illustrating the percentage in accuracy for the reading comprehension task in visuomotor, computer-based and control groups during the post-training assessment (A_3) relative to the pre-training assessment (A_1). The error bars represent the standard error of the mean. Significant difference (*).

The mean improvement of comprehension accuracy was calculated to show the change across groups. The mean improvement in the computer-based group was significantly greater than the control group (p = 0.029). The visuomotor group showed an equivalent improvement of mean reading comprehension accuracy with the computer-

based and control groups (smallest $p \geq 0.418$). The mean improvements in the visuomotor and computer-based groups were 39.71% (95% CI = -1.37 % to 80.79%) and 70.85% (95% CI = 30.45% to 111.25%) respectively, and only 0.38% for the control group (95% CI = 15.25% to 60.18%).

2.3.2.6 Questionnaires

2.3.2.6.1 Visual Impairment Questionnaire (VIQ)

Participants from both of the intervention groups reported significant improvement (lower rating) in their capabilities to perform most of the activities of daily living after the DREX training which included the essential skills like seeing objects, reading and navigating around ($p \leq 0.042$; see Table 2.3). The control group actually reported significant declines in performance (higher rating) for the items the ability to find objects on a table, avoiding obstacles, and finding way. None of the groups showed a significant change in the activity 'finding way at home', and this was also the activity for which least impairment was reported at baseline.

Table 2.3

Table illustrating the mean rating (SD) for each item of the Visual Impairments Questionnaire (VIQ) for all study groups during pre-training and post-training assessments. Significant difference (*)

	Visuomotor group (n = 17)		Computer-based group (n = 17)		Control group (n = 16)	
	Pre-training, A_1	Post-training, A_3	Pre-training, A_1	Post-training, A_3	Pre-training, A_1	Post-training, A_3
Seeing objects	2.29 (1.26)	1.41 (1.00)*	2.35 (0.79)	1.53 (0.94)*	1.56 (1.50)	2.13 (1.03)
Bumping into obstacles	2.18 (1.13)	1.53 (1.13)*	2.47 (1.18)	1.06 (0.97)*	1.31 (1.49)	2.19 (1.33)*
Losing way	1.53 (1.46)	0.88 (1.00)	1.59 (1.18)	0.76 (0.75)*	1.00 (1.32)	1.69 (1.25)*
Find objects on a table	1.76 (1.39)	1.00 (1.17)*	2.00 (1.28)	0.94 (0.90)*	1.00 (1.21)	1.88 (1.15)*
Find objects in a room	1.71 (1.36)	0.88(1.05)*	1.76 (0.75)	0.76 (0.83)*	1.06 (1.29)	1.56 (1.21)
Find objects in a supermarket	2.18 (1.38)	1.00 (1.12)*	2.18 (1.02)	0.71 (0.85)*	2.13 (2.78)	1.75 (1.00
Using public transport	2.06 (1.250	0.94 (1.09)*	1.82 (1.24)	0.65 (0.93)*	1.81 (1.60)	1.81 (1.42)
Finding way at home	0.59 (1.00)	0.35 (0.70)	0.29 (0.47)	0.29 (0.47)	0.38 (0.50)	0.56 (0.63)
Crossing the street	2.35 (1.58)	1.12 (1.11)*	1.47 (1.07)	0.41 (0.62)*	1.44 (1.32)	1.50 (1.10)
Reading	2.06 (1.35)	0.76 (0.97)*	1.65 (1.06)	0.65 (0.86)*	2.00 (1.32)	1.94 (1.00)

Note. Lower scores mean less impairment.

2.3.2.6.2 Beck Depression Inventory II (BDI)

At A_1, only two participants were classified as having mild depression; one from the computer-based group and another one from the control group. All remaining participants had a score that was below this cut-off. A Wilcoxon signed-rank test showed that DREX training elicited a statistically significant change in the BDI score in individuals trained in the visuomotor group ($z = -2.707$, $p = 0.007$); the BDI score was slightly higher at A_3 relative to A_1 (see Table 2.4). There was no significant change in the BDI score in individuals from the computer-based group ($z = -0.854$, $p = 0.393$) and the control group ($z = -0.317$, $p = 0.751$) such that the participants' mood remained unchanged at A_3 relative to A_1.

Table 2.4

Table illustrating the mean Beck Depression Inventory II score (BDI) in all study group during pre-training assessment, A_1 and post-training assessment, A_3.

Group	**Mean BDI score[α]**	
	Pre-training Assessment, A_1	**Post-training Assessment, A_3**
Visuomotor	1.24	3.88
Computer-based	3.88	3.76
Control	2.63	2.44

Note. Normal to minimal depression score = 0 to 13
Mild depression score = 14 to 19
Moderate depression score = 20 to 28
Severe depression score = 29 to 63

2.3.2.6.3 Motivation for Traumatic Brain Injury Rehabilitation Questionnaire (MOT-Q).

In the visuomotor group, the mean MOT-Q score was significantly higher at A_3 relative to A_1, $t_{(16)} = -2.224$, $p = 0.041$, demonstrating that participants had greater motivation to engage with the rehabilitation after the training. The mean MOT-Q score among participants in the computer-based and control groups at A_1 and A_3 were not

significantly different, $t_{(16)} = -2.035$, $p = 0.056$ and $t_{(16)} = -0.434$, $p = 0.671$ respectively. Table 2.5 shows the mean MOT-Q scores for visuomotor, computer-based and control groups during A_1 and A_3.

Table 2.5

Table illustrating the mean Motivation for Traumatic Brain Injury Rehabilitation Questionnaire (MOT-Q) score in all study group during pre-training assessment, A_1 and post-training assessment, A_3.

Group	**Pre-training Assessment, A_1**	**Post-training Assessment, A_3**
	Mean score (SD)	**Mean score (SD)**
Visuomotor	29.94 (16.50)	33.35 (14.29)
Computer-based	22.35 (15.27)	28.59 (9.57)
Control	21.63 (13.33)	22.44 (9.91)

There was a significant positive correlation between A_1 MOT-Q score and percentage change in mean RT for visual exploration in both the visuomotor and computer-based groups (see Table 2.6), suggesting that participants trained from either training mode who had higher motivation at the beginning gained greater improvement in their visual exploration. However, the pre-training MOT-Q score did not correlate significantly with the mean change in reading speed for either intervention group despite higher MOT scores being reported by most participants who had larger mean reading speed change. Similarly, a non-significant correlation was found in the control group in all measures.

Table 2.6

Correlations (Pearson's) between the pre-training Motivation for Traumatic Brain Injury Rehabilitation Questionnaire (MOT-Q) score and the changes in the mean reaction time and reading speed.

	Pearson's correlation, r (p-value)		
	Visuomotor	**Computer-based**	**Control**
Baseline MOT-Q vs Mean reaction time change	0.859 ($p < 0.001$)	0.911 ($p < 0.001$)	0.049 ($p = 0.856$)
Baseline MOT-Q vs Mean reading speed change	0.025 ($p = 0.925$)	0.352 ($p = 0.352$)	-0.036 ($p = 0.894$)

2.3.2.6.4 Self-ability and attitude questionnaire

This questionnaire intended to identify participants' main treatment goal, their confidence level in using the technology as a training aid and willingness to pay the rehabilitation costs. At A_1, the majority of participants from the intervention groups identified improving their reading ability (41.2%) or driving again (29.4%) as their primary treatment goal (see Table 2.7). Interestingly, the percentage of those who indicated reading as their main goal reduced to 23.5% at A_3. There was little change in the percentage of participants who wanted to drive again after the training (23.5%). In the control group, reading was the highest reported main goal during A_1 (56.3%) and it remained the highest at A_3 (43.8%).

Table 2.7

Number of participants (percentage) for each main rehabilitation goal for intervention and control groups

	Intervention groups (n = 34)		Control group (n = 16)	
	Pre-training, A_1 n (%)	Post-training, A_3 n (%)	Pre-training, A_1 n (%)	Post-training, A_3 n (%)
Main rehabilitation goal				
Reading	**14 (41.2)**	8 (23.5)	**9 (56.3)**	**7 (43.8)**
Shopping	1 (2.9)	4 (11.8)	0 (0.0)	2 (12.5)
Going out	6 (17.6)	**11 (32.4)**	2 (12.5)	4 (25.0)
Driving	10 (29.4)	8 (23.5)	4 (25.0)	2 (12.5)
Doing sport	1 (2.9)	0 (0.0)	1 (6.3)	0 (0.0)
Visiting people	2 (5.9)	2 (5.9)	0 (0.0)	1 (6.3)
Gardening	0 (0.0)	1 (2.9)	0 (0.0)	0 (0.0)

In terms of participants' willingness to pay the rehabilitation cost, 84.0% of all participants could not afford to pay for the rehabilitation. In addition, the majority of participants, 94.0%, reported that home-based training was very convenient and the most desirable training.

Most participants assigned to the visuomotor group were confident (scored at least 3 out of 5) in using a touch-screen tablet (76.4%) and app (88.2%) based on their confidence level score at A_1. However, their confidence level in using a touchscreen tablet or app was not significantly correlated with the mean visual search RT change or the mean improvement in reading speed (see Table 2.8). The percentage of participants in the computer-based group who were confident in using computers and apps was also high: 64.7% and 70.6%, respectively. But again, no significant correlation was found between their pre-training confidence level with the mean RT change or the mean improvement in reading speed (see Table 9). There was also no significant correlation found in all condition for controls.

Table 2.8

Correlations (Pearson's) between the pre-training confidence level in using touchscreen table, computer or app and the changes in the mean reaction time and reading speed.

	Pearson's correlation, r (p-value)	
	Visuomotor	**Computer-based**
Confidence tablet vs Mean reaction time change	-0.009 (p = 0.973)	-
Confidence tablet vs Mean reading speed change	0.229 (p = 0.376)	-
Confidence computer vs Mean reaction time change	-	-0.222 (p = 0.391)
Confidence computer vs Mean reading speed change	-	-0.040 (p = 0.878)
Confidence app vs Mean reaction time change	-0.328 (p = 0.199)	-0.338 (p = 0.185)
Confidence app vs Mean reading speed change	-0.336 (p = 0.187)	-0.449 (p = 0.070)

The confidence level in using a computer or touchscreen tablet remained unchanged at A_3 relative to A_1 in each group. However, participants from the computer-based group were more confident in using the app after the training (see Table 2.9), while participants from the visuomotor group did not report any significant difference in their confidence level to use the app.

Table 2.9

The difference between the pre-training confidence level score, A_1 and the post-training confidence level score, A_3 in visuomotor and computer-based group.

	Paired t-test, t (p-value)	
	Visuomotor	**Computer-based**
Confidence tablet at A_1 vs Confidence tablet at A_3	1.102 (p = 0.287)	-
Confidence computer at A_1 vs Confidence computer at A_3	-	-0.824 (p = 0.422)
Confidence app at A_1 vs Confidence app at A_3	1.692 (p = 0.110)	-2.704 (p = 0.016)*

Note. * indicates a significant difference.

2.4 Discussion

The current study evaluated the effectiveness of the DREX training app for HVFD rehabilitation using a randomised controlled trial. In the original format, DREX was only available as a computer version which was installed on a patient's computer with a pack of self-explanatory instructions (Aimola et al., 2014). With the advancement of technology and the availability of a cheaper, portable and increasingly available gadget like touchscreen tablets, the new DREX app has been designed to be compatible with both personal computers and tablet devices. In this study, participants completed both visual exploration and reading training in one package and their performance on the outcome measures compared before and after training. The overall results demonstrate that the multiplatform DREX app is an effective tool to aid the rehabilitation of visual search, reading and enhance the quality of life for people with HVFDs. In addition, the effect of DREX training on visual exploration and reading in participants trained using a touchscreen tablet is equivalent to patients trained using a computer, and the benefits extend to their activities of daily living.

It is important to note that at baseline, participants across the three groups were comparable with respect to their reading and visual exploration performance. Therefore, the degree of change in the performance reflects the effect of training unbiased by the pre-training skill level. Of significant note is the fact that in this study no significant difference between the reading speed of participants with right and left HVFDs was found, which was inconsistent with previous findings reported in many studies (Aimola et al., 2014; Leff & Starrfelt, 2014; Schuett et al., 2008b; Zihl, 2010). It is unlikely that this difference reflects the sensitivity of the reading measure for instance, since it is the same as used previously by Aimola et al. (2014), where such differences in reading speed were reported. However, one possible explanation is that this study did not explore further the extent of macular sparing in every participant. It has been mentioned

earlier that the size of macular sparing influences the reading speed such that participants with sufficiently large macular sparing read faster (Trauzettel-Klosinski, 2017; Zihl, 2010). It is possible that some participants with right HVFD in the sample had greater macular sparing which caused their baseline reading speed to be faster and thus more comparable with those with a left HVFD. Alternatively, some patients with right HVFDs may already have developed spontaneous compensatory strategies thereby improving their reading speed to comparable levels.

The present study not only confirms earlier studies examining the therapeutic effect of compensatory training on visual exploration (Kerkhoff, Münßinger, Haaf, Eberle-Strauss, & Stögerer, 1992b; Lane et al., 2010; Mannan et al., 2010; Nelles et al., 2001; Ong et al., 2015; Pambakian et al., 2004; Zihl, 1995b) and reading (Kerkhoff, Münßinger, Eberle-Strauss, & Stögerer, 1992a; Schuett et al., 2012, 2008a; Spitzyna et al., 2007; Woodhead, Ong, & Leff, 2015; Zihl, 1995a), but also the feasibility and utility of compensatory training as an effective home-based treatment (Aimola et al., 2014; Lane et al., 2010; Ong et al., 2012; Ong et al., 2015; Sahraie et al., 2016). Furthemore, the improvement in the visual exploration and reading performance after training using the computer version of DREX was greater than in the original computer-based training reported by Aimola and colleagues (2014; Visual exploration: 28.4% vs. 12.9%; Reading: 27.6% vs. 18.4%), where the visual exploration training was also combined with the reading training.

The DREX training app improves training accessibility; being able to run on both computer and touchscreen tablet gives more flexibility in terms of the training time and location, as well as the access to the training. Participants were not restricted to a specific training time, so they could access and complete the training anytime they wanted within the recommended period of 12 weeks (6 weeks – visual exploration, 6 weeks – reading). The handiness and portability of the touchscreen tablet itself enabled

participants to train at their own convenient location and pace, without any physical or geographical limitations imposed by clinic- or laboratory-based training, and most importantly, they had free access to the training. All of these may reduce the barriers of training and thus enhance efficacy. Additionally, the tablet version can be used successfully for training the elderly patients who are the majority of participants in this study; they were able to operate the device and complete the training despite minimal input from the researcher. This claim is based on the result showing that none of the dropouts stopped their training due to technical errors or problem with the device. Furthermore, all participants from the visuomotor group (tablet version) who chose to stay in the study completed their training until the end. While a study revealed that age does not matter in HVFD rehabilitation (Schuett & Zihl, 2013), it would be interesting to know if performance using different modes of training differs between younger and older patients.

In terms of the performance of visual exploration and reading using the assessment tasks that have been incorporated into the DREX training app, the counting-number search task showed enhanced visual exploration performance of 16.7% in the visuomotor group and 21.4% in the computer-based group. These improvements were modest compared to that observed in the find-the-number search tasks. Possible reasons that the counting-number search task has smaller effects could be that the task is easier and therefore possibly less sensitive to change, or the fact that the assessment was done independently without any supervision which could alter performance. In support of this latter suggestion, Ong et al. (2015) observed that their web-based visual search assessment reported a change that was 50% lower than the original face-to-face assessment. Regarding the pen search task, the task did not capture a significant effect of training on performance; all patients showed an improvement, including those in the control group indicating a strong practice effect. For the reading task, the effect size for

computer-based and visuomotor groups were around 17% and 34% respectively, which were in keeping with the standard, paper-based reading task. Interestingly, the accuracy for the reading comprehension task improved significantly after training, which was greater in the intervention groups by at least 39.7%, demonstrating improved reading comprehension. This provides important additional information about the quality of patients' reading performance after training which has not been considered before as far as we are aware. The finding shows that not only are patients becoming significantly faster at reading, but they appear to be engaging more with the material as well.

As participants' subjective reports indicate, DREX training had a huge effect on their daily activities in terms of decrease of visual disability. Most participants were aware of their difficulties before training; on average they scored at least 2 (occasional problem) out of 4 (very frequent problem) for questions on difficulty with reading, avoiding obstacles, finding objects on a table, and seeing objects at the pre-training assessment. After completing the training, participants reported significant improvements in most of the daily activities except for 'finding way at home'. Most likely, many patients with HVFDs did not struggle with navigation within the very familiar, controlled surroundings like home, as supported by the low score for this item at baseline. Zihl (2010) mentioned that patients are generally able to establish a reliable and quick view over their familiar environments for orientation but may still experience difficulties in more complex situations where the visual search and stimulus processing are more demanding. Nevertheless, DREX training can be considered as an effective means of improving subjective quality of life.

In this study, only two patients (3%) were classified as having even minimal depression, which is at odds with the previous literature on prevalence. This could be due to the nature of participants recruited in this study, who had only HVFDs without major physical or cognitive impairments, which are the common comorbid problems

that could exacerbate the depressive symptoms and reduce their interest and capacity to partake in rehabilitation (Hackett & Anderson, 2005; Nys et al., 2006). Furthermore, participants' self-initiative and optimism can have a positive impact on their mood (Brown, 2011; Symister & Friend, 2003), and it seems likely that when recruiting volunteers to studies such as this, that the sample be biased towards individuals who have more of these qualities. In addition, this study recruited participants who were at least 3-month post-onset. Studies have found that the rate of depression prevalence may already drop after 3 to 6 months (Jorge et al., 2004; Kotila, Numminen, Waltimo, & Kaste, 1999), possibly explaining why most participants in this study had a noticeably steady mood at the point of recruitment. It has been proposed that vision rehabilitation could help in reducing depression among patients (Horowitz, Reinhardt, & Boerner, 2005), but the present study found that the BDI score at the post-training, A_3 for visuomotor group was significantly higher than the BDI score at the pre-training, A_1. (difference between mean score = 2.64). The National Institute for Health and Care Excellence (NICE) proposed a difference of ≥ 3 BDI-II points is a minimum clinically important difference (MCID) for treatment effect (National Collaborating Centre for Mental Health (NCCMH), 2004), and two studies reported BDI of ≥ 5 points after treatment is the MCID to consider a change in the depression status (Dworkin et al., 2008; Hiroe et al., 2005). It is therefore likely that the training did not negatively impact upon mood. Furthermore, the average BDI score at the post-training, A_3 was still within normal to minimal depressive symptom range.

Another factor that might influence rehabilitation outcome is motivation. Interestingly, participants trained from the touchscreen tablet appeared to be significantly more motivated to continue with the rehabilitation after the training relative to the participants who trained from the computer. This could be due to the design of the device itself as well as the effortlessness in responding to the training

using the touchscreen tablet which provide added values to the visuomotor training. This finding is in accordance with the recent studies that proved the usefulness and effectiveness of touchscreen devices for post-stroke rehabilitation (Rand, Kizony, & Zeilig, 2013; Saposnik et al., 2014) and its positive effect on motivation in neuro-rehabilitation (Ameer & Ali, 2017).

A high level of motivation at the beginning of the training had a significant impact on the primary outcome of visual exploration, but not reading. The study found a significant positive correlation between the pre-training motivation and the visual exploration improvement; participants who were more motivated showed greater gains in the reaction time. The same was not observed for reading, and the reason for this remains ambiguous. It might be due to the complexity of the training itself. The reading task is often reported by participants as being more challenging than the simple, pop out visual search tasks used in the exploration training. It is possible therefore that irrespective of motivation, that the reading tasks pushed all patients to engage with this training type more. Finally, participants had either maintained or improved MOT-Q scores post-training, indicating that they were still motivated to engage in the rehabilitation. It is useful to know that even if patients found the training to be challenging, that it was not so difficult as to become demotivating, indicating that the system developed to automatically adjust the difficulty of training was appropriate. Rather it appears that the participants felt the training was working and beneficial to them, and therefore their motivation to engage with the training increased as supported by the positive change in their final goal setting.

The present study identified participants' main rehabilitation goal to investigate if the DREX training could help them to achieve this. The importance of goal setting has been addressed in the rehabilitation of stroke (Burton, 2000; Glazier, Schuman, Keltz, Vally, & Glazier, 2004) and traumatic brain injury (Ylvisaker, Mcpherson,

Kayes, & Pellett, 2008), and reported to optimise the outcome of rehabilitation (Wressle, Eeg-Olofsson, Marcusson, & Henriksson, 2002), facilitate behavioural change (Von Korff, Gruman, Schaefer, Curry, & Wagner, 1997) and improve participation in the rehabilitation (Cott, 2004). In this study being able to read and drive again were the most popular goals prior to the start of the study. This is in keeping with the main impairments typically reported; reading impairments are reported by 80% of patients with HVFDs (Rowe et al., 2009; Zihl, 2010) and most of them, in the UK, are prohibited from driving (Colenbrander & De Laey, 2006). The results showed that DREX training led to improved objective and subjective reading performance. As the result, the percentage of participants in the intervention groups who still wanted to improve their reading at the post-training assessment reduced from 41.2% to 23.5%. The control participants were still struggling with reading until the end of study.

Unfortunately, the training had no impact on the driving-based goal. Although participants had improved visual exploration, which is an important skill in driving, driving requires skills beyond eye movements (Bowers, Mandel, Goldstein, & Peli, 2009; Houston, Peli, Goldstein, & Bowers, 2018; Smith et al., 2015). Studies have shown that the compensatory training (Kooijman et al., 2004) and the use of prisms (Bowers, Tant, & Peli, 2012) could improve patients' fitness to drive and enhance hazard detection. Kooijman et al. (2004) trained HVFD patients using not only compensatory eye movement training in a laboratory, but also using a mobility training in real traffic situations such that patients were instructed to make efficient eye and head movements and scanning while driving. Therefore, compensatory training is useful for driving, but further evaluation in the real driving scene is required (Coeckelbergh, Brouwer, Cornelissen, & Kooijman, 2001; Kasneci & Hardiess, 2017). In the UK, patients must possess at least 120° of intact vision along the horizontal axis to be permitted to drive. Since the training does not aim to restore the lost vision but rather

help patients to compensate, this means that patients do not automatically have their license reinstated and instead have to demonstrate the ability to respond to stimuli as quickly as someone with unimpaired sight in order to regain their licence (DVLA, 2016). This is not routinely tested and only done so on the recommendation of a healthcare professional. Without retesting the patients in this sample, it is not clear if they would be permitted to drive again, and as such this will likely remain their rehabilitation goal. However, it seems likely that whilst the DREX training is effective in improving visual search, it may require additional integrated training that concentrates on specific driving behaviour such as hazard detection and mobility.

Another exciting finding of this study was that most participants showed high confidence to use a touchscreen tablet, computer and apps at baseline, and this was maintained until the end of the training demonstrating their ability to complete it independently without much input from the researcher. Although this study did not find a significant correlation between the level of confidence and participants' performance in visual exploration and reading, the overall results reflect participants' capability to use technology despite being older, thereby answering the issue regarding the practical use of the DREX training app for the increasingly aging population. However, it may also be that the sample was biased towards people with confidence in technology; it is possible that only patients who felt that they would be able to train using such tools agreed to participate in the study. Further work is therefore required to understand if those patients with low confidence initially can still succeed with the training or if additional support is required.

In summary, the results of this study show that the DREX training app is effective for HVFD rehabilitation, and that being home-based and inexpensive is valued by patients. The significant improvements in visual exploration and reading were observed in both visuomotor and computer-based groups relative to the controls, with

no significant difference in the mean improvement gained between the two intervention modes. This is a very important finding as it means that the more accessible technology (touchscreen tablets) can be used for effective rehabilitation of HVFDs. The DREX training not only improved behavioural functions but also enhanced the subjective gains including reading and navigation, which are among the vital instrumental skills in everyday life.

Chapter 3

Study 2 - Transferability between visual exploration and reading.

3.1 Introduction

Studies have demonstrated that compensatory training can lead to significant improvements in eye movements as well as everyday search behaviour (Mannan, Pambakian, & Kennard, 2010; Zihl, 2010). Most compensatory training studies investigated the effect of visual exploration training on visual exploration impairments (Bolognini, Rasi, Coccia, & Làdavas, 2005; Kerkhoff, Münßinger, Haaf, Eberle-Strauss, & Stögerer, 1992b; Lane, Smith, Ellison, & Schenk, 2010; Mannan et al., 2010; Nelles et al., 2001; Ong et al., 2015; Passamonti, Bertini, & Làdavas, 2009; Roth et al., 2009), and several studies evaluated compensatory reading training in the rehabilitation of reading impairments (Ong et al., 2012; Schuett, Heywood, Kentridge, Dauner, & Zihl, 2012; Schuett, Heywood, Kentridge, & Zihl, 2008; Spitzyna et al., 2007; Woodhead, Ong, & Leff, 2015; Zihl, 2010). All these compensatory approaches confirmed the efficacy of compensatory training to alleviate the visual exploration and reading impairments among individuals with HVFDs.

It has been shown that visual search training does not translate to improved reading speed (Lane et al., 2010; Roth et al., 2009; Spitzyna et al., 2007) and vice versa (Schuett et al., 2012, 2008a). Taking either training alone seemed inadequate to ameliorate both skills. While visual exploration training requires the use of large saccades and a spatially organised searching pattern to increase the field of view, improvement of reading needs more practice using small, accurate, systematic and frequent horizontal eye movements such as left-to-right text reading training (Schuett et

al., 2009). However, in the recent trial using the predecessor computer version of DREX, combined visual exploration and reading training resulted in an improvement in both visual exploration and reading performance (Aimola et al., 2014). The same study also demonstrated that the training does not need to be supervised to be effective; patients completed the compensatory training independently at home (~35 hours over ~12 weeks) and significant benefits were observed on ADLs.

Study 1 concluded that the new app version of DREX was effective in the rehabilitation of individuals with HVFDs; positive effects were observed for participants trained via computer and touchscreen tablet with respect to both visual search and reading. Yet, the study did not explicitly evaluate whether visual exploration training could improve reading performance, and if visual exploration performance could be enhanced via reading training. Therefore, this study aims to investigate the transferability of training-related improvement between visual exploration and reading using the DREX training app in both formats. Based on previous research demonstrating training specificity it is expected that the effect of DREX training does generalize to visual exploration and reading irrespective of the training modes.

3.2 Methods

3.2.1 Study design

Participants involved in this study were those who had received DREX training in Study 1 in both visuomotor and computer-based groups. In this study, participants completed visual exploration training followed by reading training in a parallel design. In order to investigate the transferability of training-related improvements between visual exploration and reading, mean RT in the visual search task and corrected reading

speed were compared across three assessment sessions: pre-training (A_1), post-exploration training (A_2) and post-reading training (A_3).

3.2.2 Participants

Thirty-four participants were equally allocated into the visuomotor group and computer-based group. The details of the participants were previously described in Study 1 (see Intervention groups section in Study 1, pp. 46). All participants provided informed consent to participate in the study in accordance with the Declaration of Helsinki (International Committee of Medical Journal Editors, 1991). The study was approved by the psychology department ethics committee at Durham University and from the NHS NRES Committee North East - Newcastle and North Tyneside 1 (REC reference: 15/NE/0351).

3.2.3 Outcome measures

See find-the-number search task and paper-based reading task descriptions in the methods section of Study 1 (pp. 47-48).

3.2.4 Procedures

See compensatory training and procedures descriptions in the methods section of Study 1 (pp. 53-60).

3.2.5 Statistical analysis

The data were analysed using separate mixed model ANOVAs for pre-trainng (A_1), post-exploration training (A_2) and post-reading training (A_3). These were conducted for find-the-number search task (visual exploration performance) and paper-based reading task (reading performance), using pre-/post-visual exploration or reading

training as a within-subject factor (Session) and visuomotor/computer-based groups as a between-subject factor (Group). Post hoc pairwise comparisons between A_1, A_2 and A_3 were performed using two-tailed related samples t-tests if required. Paired t-tests were conducted to compare improvements between reading and visual exploration training. As multiple analyses were carried out, Bonferroni corrections were applied where relevant with a corrected alpha level of 0.025.

3.3 Results

3.3.1 Outcome measures

3.3.1.1 Find-the-number search task

A 3 (Session: A_1, A_2 and A_3) × 2 (Group: visuomotor and computer-based) mixed model ANOVA revealed a significant effect of training on RT (Session; $F_{(2,64)} = 15.84$, $p = 0.001$); participants improved significantly in their visual exploration. No significant effect of Group ($F_{(1,32)} = 0.46$, $p = 0.503$) or Group by Session interaction ($F_{(2,64)} = 0.05$, $p = 0.955$) was indicated. Figure 3.1 shows the mean reaction time at each assessment session for visuomotor and computer-based groups.

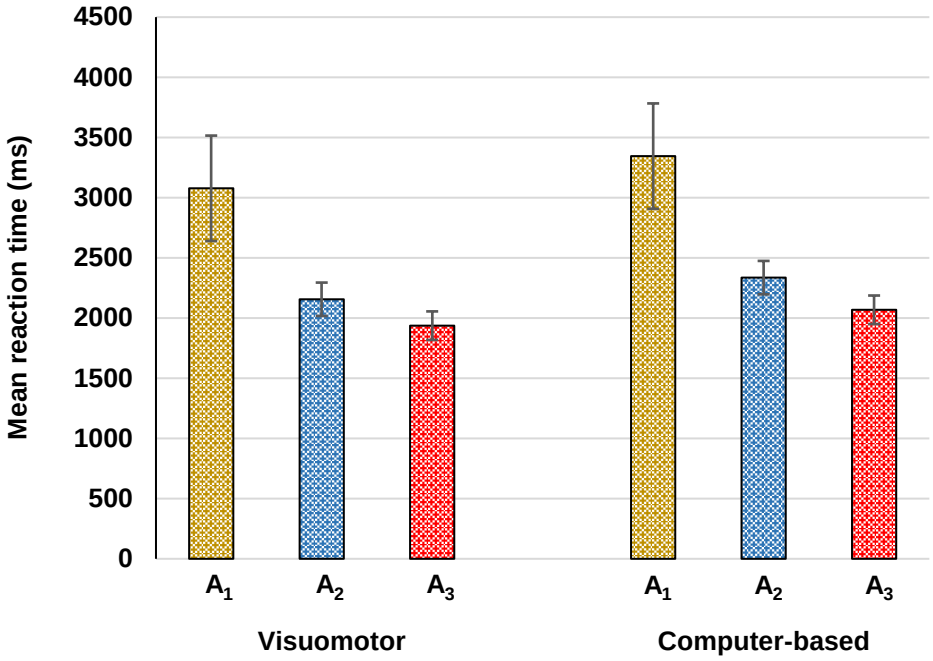


Figure 3.1 Bar chart illustrating the mean RT for the find-the-number task at pre-training, A_1, post-exploration training, A_2 and post-reading training, A_3. The error bars represent the standard error of the mean.

Paired t-tests revealed that the improvement in the mean RT was significantly greater after the exploration training (22.23%; 95% confidence interval [CI] = 15.67% to 28.76%) compared to the RT improvement after the reading training (9.66%; 95% confidence interval [CI] = 5.21% to 14.10%; $t_{(33)} = 3.55$, $p = 0.001$).

3.3.1.2 Paper-based reading task

A 3 (Session: A_1, A_2 and A_3) × 2 (Group: visuomotor and computer) mixed model ANOVA revealed an effect of training on corrected reading speed, (Session: $F_{(2.64)} = 54.70$, $p = 0.001$), indicating that participants' reading speed was faster after the training. No significant effect of Group ($F_{(1,32)} = 0.01$, $p = 0.928$) or Group by Session interaction ($F_{(2,64)} = 1.62$, $p = 0.207$) was indicated.

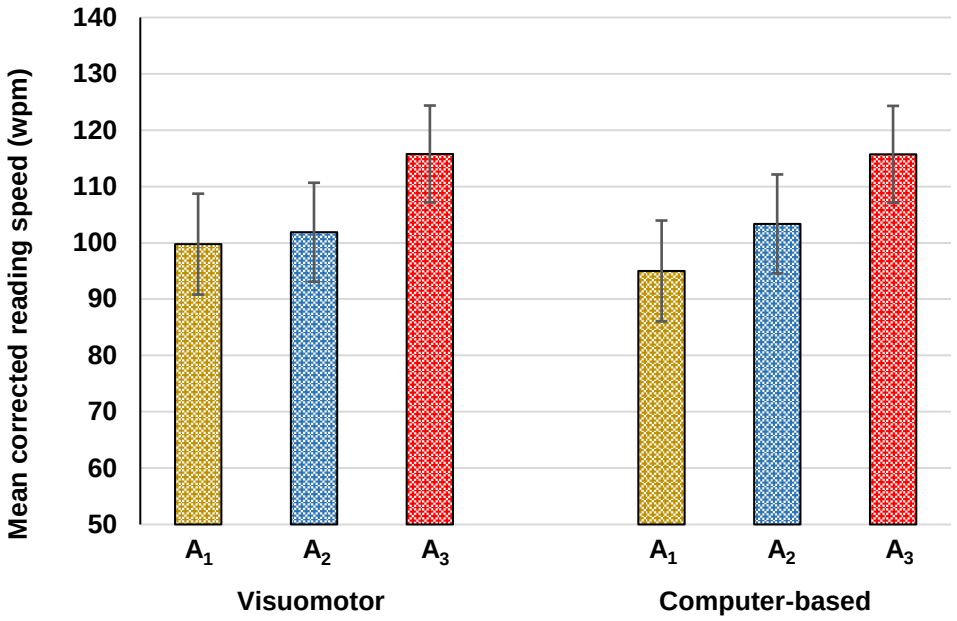


Figure 3.2 Bar chart illustrating the mean corrected reading speed (wpm) at pre-training, A_1, post-exploration training, A_2 and post-reading training, A_3. The error bars represent the standard error of the mean.

Overall the reading training induced a significant increase in reading performance of 15.45% on average [95% confidence interval (CI) = 11.21% to 19.68%], which was significantly greater than the reading improvement induced by exploration training [7.13%; 95% confidence interval (CI) = 3.49% to 10.77%; $t_{(33)}$ = 3.37, p = 0.002; see Figure 3.2

3.4 Discussion

Due to the study design?? Cross over versus parallel, the main findings for the effectiveness of the

mentoring program must be interpreted with caution.

This parallel design study demonstrated a strong therapeutic effect of DREX training on the rehabilitation of HVFDs, with some evidence of transfer between exploration and

reading; there were significant improvements in reading performance after visual exploration training. The study by Aimola et al. (2014) was the first controlled trial that reported improvement in both skills after both had been explicitly trained. However, the results of this study show that specific training was also more impactful in each case; the improvement in visual exploration performance was two times greater than improvement seen in the reading performance after visual exploration training. Similarly, the reading training also led to greater improvement in the reading performance compared to the visual exploration performance. This finding is in keeping with prior works in which task-specific training resulted in the greatest therapeutic effect (Lane et al., 2010; Schuett et al., 2012, 2008a; Spitzyna et al., 2007). Therefore, in order to maximise efficacy of training, the specific training task aiming to improve the impaired skill is more valuable and recommended.

The transfer effects observed in this study could possibly be due to both visual exploration and reading training sharing an element of visual search; in each training type participants must identify a target among distractors: letter of different colour, size or shape in visual exploration training, and a non-word target in reading training. An additional explanation is that the attentional components of the tasks did perhaps allow some degree of transfer between training such that visual exploration and reading are both guided by an overlapping attentional and oculomotor mechanism. Attention and gaze are voluntarily shifted over the spatial scene or words stimulus during the training, and this could improve reorganization of the control of visual information processing and eye movements (Perez & Chokron, 2014; Zihl, 2010) and thus lead to faster eye movements and efficient searching. It is imperative to note that in the present study there were no trade-off effects between the tasks; improvement of visual exploration after visual exploration training did not have a cost on the reading performance, and vice versa. This consequence is important as a study by Behrmann et al. (2005) showed

that the improvement in the trained task (recognizing common objects) led to impaired performance on another task (recognizing faces).

The present study found that participants who trained using computers showed greater reading improvement after reading training than those who trained using the touchscreen tablets, but their search improvements after visual exploration training were comparable on either device. This suggests that computer-based training is better for the rehabilitation of hemianopic dyslexia. The effectiveness of computer-based training has been reported in many studies (for a review see Hanna, Hepworth, & Rowe, 2017; Lane, Smith, & Schenk, 2008). One logical explanation is there might be an underestimation of the effect of reading training in the visuomotor group as a consequence of poor fixation control caused by an unstable training position because of participants holding the device. In the computer-based group the computer or laptop is placed at a fixed distance in front of participants which makes fixating easier. Reading training requires smaller and very precise saccadic eye movements, around 4° of average saccadic amplitude, to give sufficient training effect (Zihl, 1995a). Therefore, any artificial shift of fixation towards the blind hemifield resulting from a more variable training position may enable participants to see the target presented in the blind hemifield without having to move their eyes, leading to the null effect of reading training. This shift is a normal phenomenon in a small percentage of hemianopic patients with macular splitting and is known as eccentric viewing; patients may shift their fixation by 1 to 2° along the vertical midline as a spontaneous adaptive mechanism which expands their perceptual span for reading (Reinhard et al., 2014; Trauzettel-Klosinski, 1997). Since visual exploration training requires larger saccadic eye movements in order to be impactful (Schuett, Heywood, Kentridge, & Zihl, 2008b; Zihl, 1995b), little or slight deviation of fixation control during training would not have such a significant effect, and that could be the reason why the performance of visual exploration in visuomotor and computer-

based group were similar. Although reading training via computer gives greater impact to the reading performance than the touchscreen tablet, participants who opt to use the DREX training app using their touchscreen tablet can still gain benefit and observable improvement in their reading performance in addition to the significant gain in their visual exploration performance.

In summary, the present study showed that the therapeutic effect of the DREX training app's visual exploration component did generalize to reading, and vice versa. However, greater benefits were observed in the task specific situations; visual exploration training led to significantly greater improvements in search than reading training did, and reading training improved reading speed to a greater extent than visual exploration training. Furthermore, computer-based compensatory training is more impactful than visuomotor compensatory training in terms of alleviating the reading impairment, but the two platforms were comparable with respect to visual exploration. In total, both training modes are clinically effective and can be used successfully for HVFD rehabilitation.

Chapter 4

Study 3 - Long-term benefits of DREX training on patients with HVFDs.

4.1 Introduction

Rehabilitation should aim to improve both objective and subjective performance thereby ultimately minimising the disability resulting from the visual impairments (Markowitz, 2006; McCabe, Nason, Demers Turco, Friedman, & Seddon, 2000). The rehabilitation method used should also provide a sustained benefit over a longer period so that patients do not have to resume or spend extra time on the rehabilitation which could be very costly and labour-intensive (Harper, Doorduyn, Reeves, & Slater, 1999; Meads & Hyde, 2003; Russell et al., 2001). In order to achieve this goal, Cicerone et al. (2005) recommended a timely follow up that assesses the functional capacities in terms of ADL to evaluate the generalisation and stability of the treatment effects to everyday functioning.

Increasingly, attention is being given to the fact that medical treatment should extend beyond restoring organ function and should also reflect the quality of life of the person including participation in society (August, 2010; Silva, Nobre, Carvalho, & Montilha, 2014). Improvement of patient's participation should be the end goal of all interventions (Wressle et al., 2002). In general, participation of elderly people after vision loss was reduced compared to their peers, mainly in household activities, recreational activities, employment and voluntary job (Alma et al., 2011; Lamoureux, Hassell, & Keeffe, 2004). This is very worrying because decreased participation and activity loss in the elderly are linked with an increased risk of cognitive (Glei et al., 2005) and functional (Avlund, Lund, Holstein, & Due, 2004) deterioration. They are

also at risk of social separation as well as feelings of loneliness (Newall et al., 2009). According to the International Classification of Functioning, Disability and Health (WHO, 2001) of the World Health Organization (WHO), a person's functioning or disability is a dynamic interaction between health conditions and contextual factors like environmental and personal factors. With the ICF, the WHO emphasizes the significance of participation which was defined as 'a person's involvement in life situations' as an outcome measure of health condition. For example, in the management of homonymous hemianopia due to cerebral disorder like stroke (health condition), rehabilitation should not only concentrate on improving the visual field loss (body function and structure) which could restore reading or visual search ability (activities), but it must also include consequences or impacts of the improved abilities to a wider societal context like participating in social activities, going shopping or even returning to their job (participation). However, a recent review on the treatment effect in patients with HVFDs using the ICF framework revealed that almost no attention has been given to the participation outcome in the compensatory treatment (de Haan et al., 2014). Therefore, information about whether compensatory training has led to sustained and enhanced participation and engagement in their daily activities remains limited.

The evaluation of the transfer and stability of compensatory training effects have received little consideration in previous studies. Even the most recent multicentre, randomised trial comparing the effect of visual exploration training with substitutive therapy did not evaluate explicitly the long-term benefit of training, although the compensatory training was concluded to be very effective in the rehabilitation of HVFDs (Rowe et al., 2017). Several studies had reported the prolonged effects of training for at least one month post-training, mainly with respect to the visual search performance (Kerkhoff, Münßinger, Haaf, Eberle-Strauss, & Stögerer, 1992b; Nelles et al., 2001; Pambakian, Mannan, Hodgson, & Kennard, 2004; Bolognini et al., 2005;

Zihl, 2010). Zihl et al. (2010) assessed patients visual search performance 6 to 8 weeks after the end a period of visual exploration training and found that all patients were efficient in their visual searching, and that this was either similar to or even better than their performance at the end of the visual exploration training. Most patients also reported fewer difficulties in their everyday activities at the follow-up visit including smooth navigation and mobility within a congested place. Patients continued using the scanning strategy acquired during the systematic training which was persistent and potentially able to lead to further improvement.

Study 1 discussed the benefits immediately after training. In Study 3, visual exploration and reading performance of participants who were involved in Study 1 were assessed one more time, 3-months post-training, to evaluate the stability and long-term effects of the DREX training. The subjective report on the ADLs was reassessed to examine the transfer and generalisation of treatment effects on common activities. Additionally, participants' goal setting between post-training and 3-months follow-up were compared to investigate any potential changes in participation. In line with the previous results of Zihl et al. (2010) for instance, it is hypothesized that the improvements in visual exploration, reading, and ADL will be maintained at the follow-up visit.

4.2 Methods

4.2.1 Study design

All participants from the intervention and control groups who had completed the A_3 in Study 1 were included in this study. Participants completed the final follow-up assessment (A_4) at their own home 3-months after the post-training assessment, A_3. The outcome measures of visual exploration and reading, VIQ scores as well as Self-

efficacy and Attitude Questionnaire, were compared between A_3 and A_4 to evaluate the stability of improvements and long-term effects of training on the behavioural change and capability to perform essential daily activities.

4.2.2 Participants

Forty-seven participants (94%) described in Study 1 were successfully followed-up: visuomotor (n = 17), computer-based (n = 16) and control (n = 14). Three participants were not able to attend the follow-up assessment: one participant from the computer-based group (health problem, n = 1), and two participants from the control group (health problems, n = 1 and unknown reason, n = 1).

4.2.2.1 Visuomotor group

See the participants' description in Study 1 (pp. 46).

4.2.2.2 Computer-based group

There were 12 males and 4 females. The mean age of the patients was 61.6 years (range: 46 to 73 years). The main cause of the HVFDs was ischaemic stroke (n = 9), followed by traumatic brain injury (n = 3), haemorrhagic stroke (n = 3), and tumour (n = 1). Nine of the patients (56.3%) had a right-hemifield HVFD and 7 (43.8%) had a left-hemifield HVFD. The mean time since the onset of visual field defect was 24.8 months (range: 3 to 240 months).

4.2.2.3 Control group

The mean age of participants in this study was 68.2 years (range: 39 to 82 years) with 7 males and 7 females. The causes of HVFDs were ischaemic stroke (n = 10), and haemorrhagic stroke (n = 4). Six of the patients (42.9%) had a right-hemifield HVFD

and 8 (57.1%) had a left-hemifield HVFD. The mean time since the onset of visual field defect was 4.5 months (range: 3 to 8 months).

4.2.3 Outcome measures

See find-the-number search task, paper-based reading task, VIQ, and Self-efficacy and attitude questionnaire description in the methods section in Study 1 (pp. 47, 48, 52 and 53)

4.2.4 Procedures

See training and procedures descriptions in the methods section of Study 1 (pp. 53-60). In addition, all participants were invited for the 3-months follow-up, A_4. Participants from the control group were offered the DREX training after the study end. Instruction about its use was provided at A_4.

4.2.5 Statistical analysis

The data were analysed using mixed model ANOVAs, separately for visual exploration and reading performance. Session relates to the post-training (A_3) and follow-up (A_4) assessments, and Group indicates the training mode (visuomotor or computer) and control. Post-hoc pairwise comparisons between A_3 and A_4 were performed using two-tailed related samples t-tests if required. Bonferroni corrections were considered where relevant and an alpha level of .025 for multiple comparisons was applied. The questionnaire was analysed using Friedman test for within-subjects.

4.3 Results

4.3.1 Outcome measures

4.3.1.1 Find-the-number search task

A 2 (Session: A_3 and A_4) × 3 (Group: visuomotor, computer-based and control) mixed-model ANOVA performed on mean RT indicated no main effect of Session, $F_{(1,44)} = 0.95$, $p = 0.334$, indicating that participants performance on visual search remained unchanged 3-months post-training. There was a main effect of Group, $F_{(2,44)} = 9.60$, $p < 0.001$, such that the mean RT in both intervention groups were significantly lower than the control group (see Figure 4.1), but no interaction was found between Session and Group, $F_{(2,44)} = 2.07$, $p = 0.139$. There was no change in the search accuracy as revealed by non-significant Session and interaction effects for accuracy ($p \geq 0.721$; minimum search accuracy in all conditions was 93.7%).

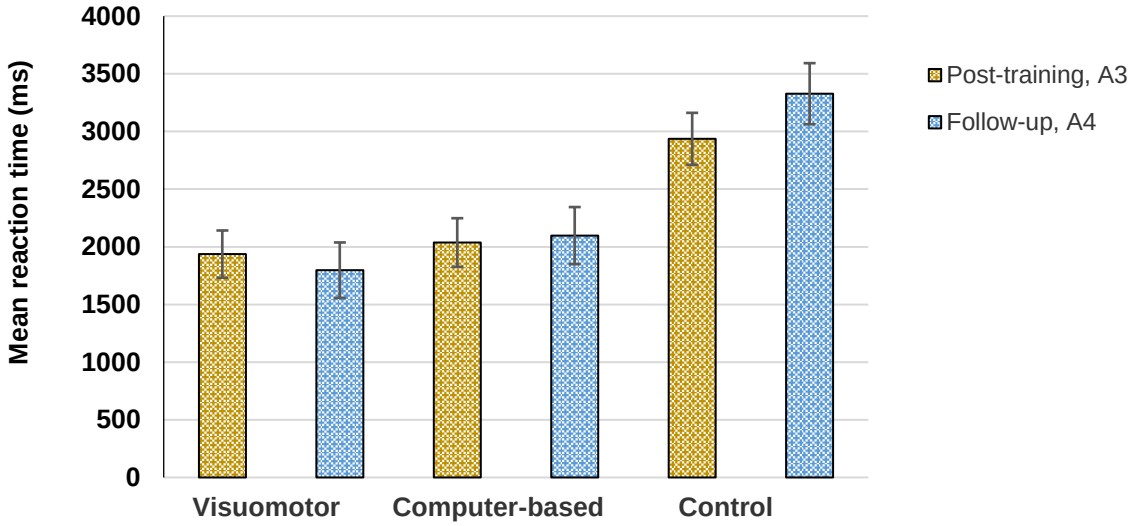


Figure 4.1 Bar chart illustrating the mean reaction time measured by find-the-number search task in visuomotor, computer-based and control groups during the follow-up assessment (A_4) relative to post-training assessment (A_3). The error bars represent the standard error of the mean. Significant difference (*).

4.3.1.2 Paper-based reading task

The mixed-model ANOVA performed on the corrected reading speed indicated no main effect of Session, $F_{(1,44)} = 0.70$, $p = 0.407$, or Group, $F_{(2,44)} = 2.28$, $p = 0.115$. There was also no significant interaction between Session and Group $F_{(2,44)} = 2.60$, $p = 0.086$, indicating that participants' performance on reading had been maintained 3-months post-training (see Figure 4.2).

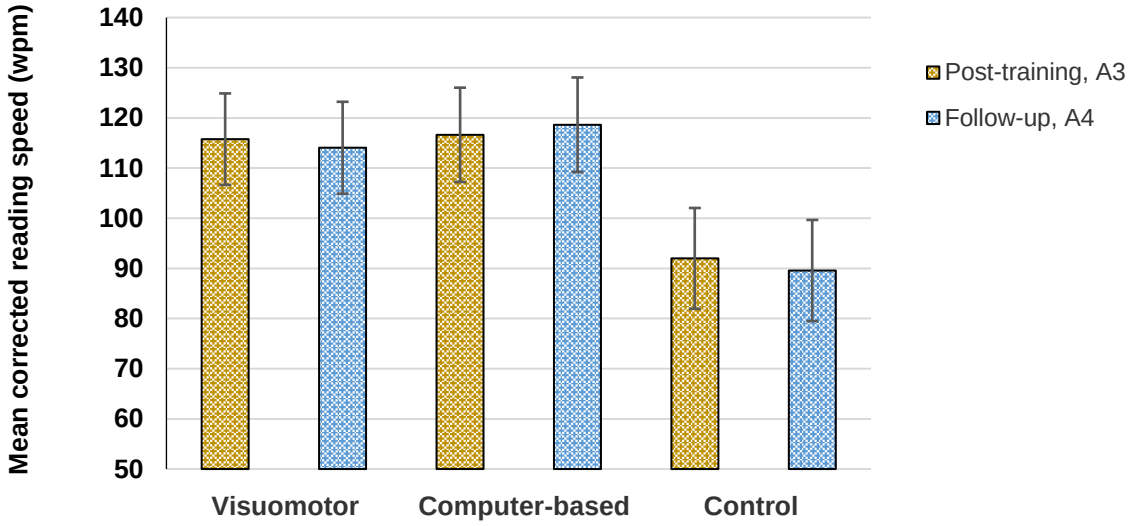


Figure 4.2 Bar chart illustrating the mean corrected reading speed measured by reading task in visuomotor, computer-based and control groups during the follow-up assessment (A_4) relative to post-training assessment (A_3). The error bars represent the standard error of the mean.

4.3.1.3 Visual Impairment Questionnaire (VIQ)

During the follow-up assessment for the visuomotor group, all items were not significantly different relative to the post-training session ($p \geq 0.120$; see table 4.1). Two items were found to be significantly improved in the computer-based group and these were 'seeing objects' ($p = 0.011$) and 'finding way at home' ($p = 0.046$). A non-significant difference was indicated in all items for the control group during the follow-up assessment ($p \geq 0.154$). Therefore, this shows that participants' subjective performance remained stable across the follow-up period.

Table 4.1

Table illustrating the mean rating (SD) for each item of the Visual Impairments Questionnaire (VIQ) for all study groups during post-training and follow-up assessments. Significant difference (*)

	Visuomotor group (n = 17)		Computer-based group (n = 16)		Control group (n = 14)	
	Post-training, A_3	Follow-up, A_4	Post-training, A_3	Follow-up, A_4	Post-training, A_3	Follow-up, A_4
Seeing objects	1.41 (1.00)	1.12 (0.78)	1.44 (0.89)	0.94 (0.68)*	2.29 (0.91)	1.93 (1.27)
Bumping into obstacles	1.53 (1.12)	1.24 (0.83)	0.94 (0.85)	0.88 (0.72)	2.36 (1.28)	2.21 (0.80)
Losing way	0.88 (1.00)	0.76 (0.83)	0.69 (0.70)	0.63 (0.50)	1.79 (1.25)	2.00 (1.11)
Find objects on a table	1.00 (1.17)	0.71 (0.85)	0.88 (0.89)	0.75 (0.58)	1.93 (1.21)	1.71 (0.83)
Find objects in a room	0.88 (1.05)	0.59 (0.62)	0.75 (0.86)	0.56 (0.51)	1.64 (1.28)	1.64 0.84)
Find objects in a supermarket	1.00 (1.12)	0.76 (1.03)	0.69 (0.87)	0.38 (0.50)	1.86 (1.03)	2.14 (0.95)
Using public transport	0.94 (1.10)	0.59 (0.87)	0.56 (0.89)	0.38 (0.50)	2.00 (1.41)	2.14 (0.77)
Finding way at home	0.35 (0.70)	0.24 (0.56)	0.25 (0.45)	0.00 (0.00)*	0.57 (0.65)	0.71 (1.00)
Crossing the street	1.12 (1.11)	0.59 (1.00)	0.38 (0.62)	0.25 (0.45)	1.64 (1.08)	2.14 (0.77)
Reading	0.76 (0.97)	1.06 (0.90)	0.63 (0.89)	0.38 (0.62)	2.07 (1.00)	2.36 (0.63)

Note. Lower scores mean less impairment.

4.3.1.4 Self-efficacy and attitude questionnaire: Rehabilitation goals.

Table 12 shows the change in the rehabilitation goal at the follow-up (A_4) assessment relative to the pre-training (A_1) and post-training (A_3) assessments in all study groups. For the intervention groups, the percentage of participants who indicated improving reading ability as their main rehabilitation goal before the training reduced from 41.2% to 23.4% after the training, and it was further reduced to 9.1% at the follow-up assessment. This indicates that participants felt their reading improved and was no longer the most impaired skill, and that for some patients this occurred during the follow-up period. Resuming driving and going out remained as the most impaired skills that they aimed to improve. For the controls, their reading performance was still poor, and they still indicated improving reading ability as their main rehabilitation goal even at the follow-up assessment (see Table 4.2). Similarly, there was no obvious change in the other activities.

Table 4.2

Number of participants (percentage) for each main rehabilitation goal for intervention and control groups

	Intervention groups			Control group		
	Pre-training, A_1	Post-training, A_3	Follow-up, A_4	Pre-training, A_1	Post-training, A_3	Follow-up, A_4
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Main rehabilitation goal						
Reading	**14 (41.2)**	8 (23.5)	3 (9.1)	**9 (56.3)**	**7 (43.8)**	**7 (50.0)**
Shopping	1 (2.9)	4 (11.8)	2 (6.1)	0 (0.00)	2 (12.5)	1 (7.1)
Going out	6 (17.6)	**11 (32.4)**	10 (30.3)	2 (12.5)	4 (25.0)	2 (14.3)
Driving	10 (29.4)	8 (23.5)	**14 (42.3)**	4 (25.0)	2 (12.5)	4 (28.6)
Doing sport	1 (2.9)	0 (0.0)	2. (6.1)	1 (6.3)	0 (0.0)	0 (0.0)
Visiting people	2 (5.9)	2 (5.9)	0 (0.0)	0 (0.0)	1 (6.3)	0 (0.0)
Others (e.g. gardening, grooming)	0 (0.0)	1 (2.9)	2 (6.1)	0 (0.0)	0 (0.0)	0 (0.0)

Note. Total participants (N) at Pre-training, A_1 and post-training, A_3: Intervention = 34; Control = 16
Total participants (N) at Follow-up visit, A_4: Intervention = 33; Control = 14

4.4 Discussion

The results of the present study showed that the improvements in visual exploration and reading were persistent over the follow-up period of three months for both intervention modes, which is consistent with previous reports on the long-term therapeutic effect of compensatory training (Bolognini et al., 2005; Kerkhoff et al., 1992b; Nelles et al., 2001a; Zihl, 2010). All participants performed at follow-up as efficiently as after the training, indicating that DREX training had a positive long-term effect. On average, the visual search and reading performance for the computer-based group was either similar to, or even better than, performance at the end of the training. There was a slight drop in the reading and visual exploration performance for the visuomotor group, but the change was not significant. This suggests that participants continued using their gained compensatory strategies after the training. It is important to note that this study only assessed performance at a period of 3-month post-training. Whilst this does not fully reflect the stability of the training benefit beyond the follow-up period, this duration is practical from a research perspective. Ideally, in real clinical practice or future research, it would be more meaningful to expand the duration of the follow-up to better understand the maintenance of benefits. Whilst the intervention groups continued to enjoy better visual exploration and reading performance after training, the controls' search and reading performance remained poor and slow, suggesting that impaired reading and visual exploration abilities need to be retrained purposely.

The objective improvements gained by participants from the intervention groups were supported by the subjective gains like faster reading speed and smooth navigation within their surroundings; participants reported an enhanced ability to perform most of the daily activities where efficient eye movements and visual search are necessary. Furthermore, participants' everyday behaviour seems to be normalising as indicated by

the positive change in their rehabilitation goals. An obvious change was seen for reading, such that the number of participants who indicated reading as their main goal has reduced greatly from pre-training (41.2%) to the follow-up visit (9.1%), reflecting their engagement with the reading activity and also satisfaction with the benefit gained from the training. The fact that this change was not observed for some patients immediately after training, but rather was reported only at follow-up, supports the importance of investigating the value of treatment with follow-up measures. It may also be worth extending the range of tasks assessed later on to provide objective data with respect to how patients are employing their newly enhanced saccadic strategies in the real world.

In conclusion, regardless of training mode, the training effects of DREX training were sustained for at least three months in the majority of patients. Furthermore, very few participants reported difficulties in everyday life activities at follow-up and therefore clear recommendations can be made for this treatment. The method of adaptive time limited practice is adequate to alleviate reading and visual exploration impairments in the study population. This method fulfils the crucial requirements of a useful and widely acceptable treatment procedure in the rehabilitation of patients with HVFDs.

Chapter 5

Study 4 - A clinical comparison of visual field testing using self-administered perimetry within the DREX app and standard perimetry tests.

5.1.1 Introduction

Automated visual field assessments are extensively used to identify visual field defects in neurological diseases (Cassidy, Bruce, & Gray, 2001; Fujimoto & Adachi-Usami, 1998). However, to conform with the testing patients must have sufficient mobility and be able to sit upright at the machine, which causes some limitations to the procedure. The confrontation technique of assessing visual fields is an alternative to the 'gold standard' automated perimetry test. However, the method provides only a gross estimation of the visual field loss, and is not a standardised technique (Smith, 2011). Furthermore, it needs a skilled and experienced clinician to perform and evaluate the test and is therefore very laborious. Thus, any attempt at developing alternative screening strategies which are simple, fast, accurate and portable is highly recommended. Lately, the use of smartphone or touchscreen devices in healthcare and research has become very popular (Mosa, Yoo, & Sheets, 2012), including in the assessment of eye problems and low vision rehabilitation (Chhablani, Kaja, & Shah, 2012; Irvine et al., 2014).

The performance of app-based perimetry for screening glaucoma and diabetic retinopathy (Johnson et al., 2017) as well as stroke-related visual impairments (Spofforth et al., 2017) has been recently studied. Researchers found that a visual field testing app could help clinicians to effectively perform a visual field screening among individuals with moderate to severe visual field defects, and that the results were highly

correlated with the conventional automated perimetry like the Humphrey Visual Field Analyser (HVF; Johnson et al., 2017). This method was also preferred by many patients with stroke due to its ease of use and suitability for those with impaired mobility and attention (Spofforth et al., 2017).

A perimetry test is one of the assessments that has been incorporated into the DREX training app. The purpose of the perimetry test was to identify the type of visual field defect of patients prior to them undertaking the training. However, this test has not yet been validated for the screening of visual field defects. Therefore, this study aimed to validate this app-based visual field assessment among individuals with HVFDs and normal subjects.

5.1.2 Methods

5.1.2.1 Study design

This was a prospective cross-sectional study comparing the DREX perimetry test to standard perimetry like Oculus Twinfield perimeter testing (Goldmann standard) and HVF in identifying and diagnosing visual field defects. Participants were classified into one of seven categories of visual field: 1) normal visual field, 2) right homonymous hemianopia, RHH, 3) left homonymous hemianopia, LHH, 4) right homonymous superior quadrantanopia, RSQ, 5) right homonymous inferior quadrantanopia, RIQ, 6) left homonymous superior quadrantanopia, LSQ and 7) left homonymous inferior quadrantanopia, LIQ. The consistency in the classification between perimetry types was compared.

5.1.2.2 Participants

A total of 30 participants, with mean age of 65.6 years (range: 24 – 84), were recruited in this study who had either normal visual field (n = 7) or non-progressive HVFDs [homonymous hemianopia (n = 14: RHH = 9, LHH = 5) or homonymous quadrantnopia (n = 9: RSQ = 1, RIQ = 4, LSQ = 3, LIQ = 1)]. The visual field defects were confirmed from the recent HVF or Goldmann perimetry results which were obtained from their medical notes. Eight participants, including the four participants with a normal visual field, completed the Goldmann perimetry (Oculus Twinfield) at the Durham University laboratory because their perimetry results were not available. Only participants who were able to provide informed consent were included in this study. All participants except those with normal visual fields were already participating in Study 1.

5.1.2.3 Assessment and procedures

5.1.2.3.1 DREX perimetry test

The perimetry test consisted of a static white dot (target stimulus) which was presented on a grey background, and the task was to detect the target as quickly and accurately as possible. The target could appear (or not) randomly in one out of 17 possible locations; either at the centre of the screen or in any of four quadrants within the visual display. The targets or test points spaced approximately 6.5 degrees apart, offset from the vertical and horizontal meridia (single: meridian). In each quadrant, there were four testing locations (Figure 5.1). Each trial started with a white fixation cross presented briefly for one second at the centre of the screen followed by a red square of dots that flickered three times before the target stimulus appeared. If participants saw the stimulus, then they quickly tapped (touchscreen version) or clicked (computer version) the location where it appeared. On the trials where there was no stimulus or participants did not respond to the target, the next trial began automatically

after 10 seconds. There were 2 or 3 trials for each testing location for a total of 40 trials. Participants took approximately 5 minutes to complete the task. Figure 5.2 shows the flow of the perimetry test.

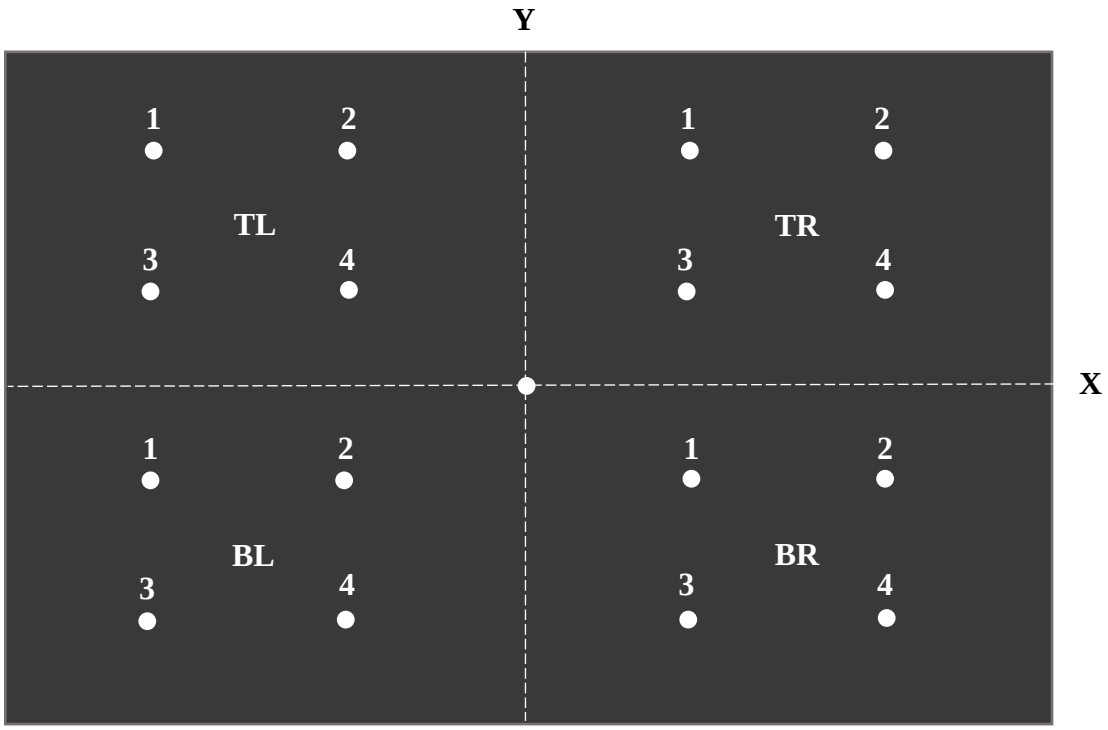


Figure 5.1 A sample of display illustrating the 17 possible locations of the dot stimulus (one at the centre and 16 at the periphery). The locations in each quadrant were arranged in equal distance to each other, and the dashed lines were the X- and Y-axis which were not visible in the actual display. Not to scale. (TL: top left; BL: bottom left; TR: top right; BR: bottom right)

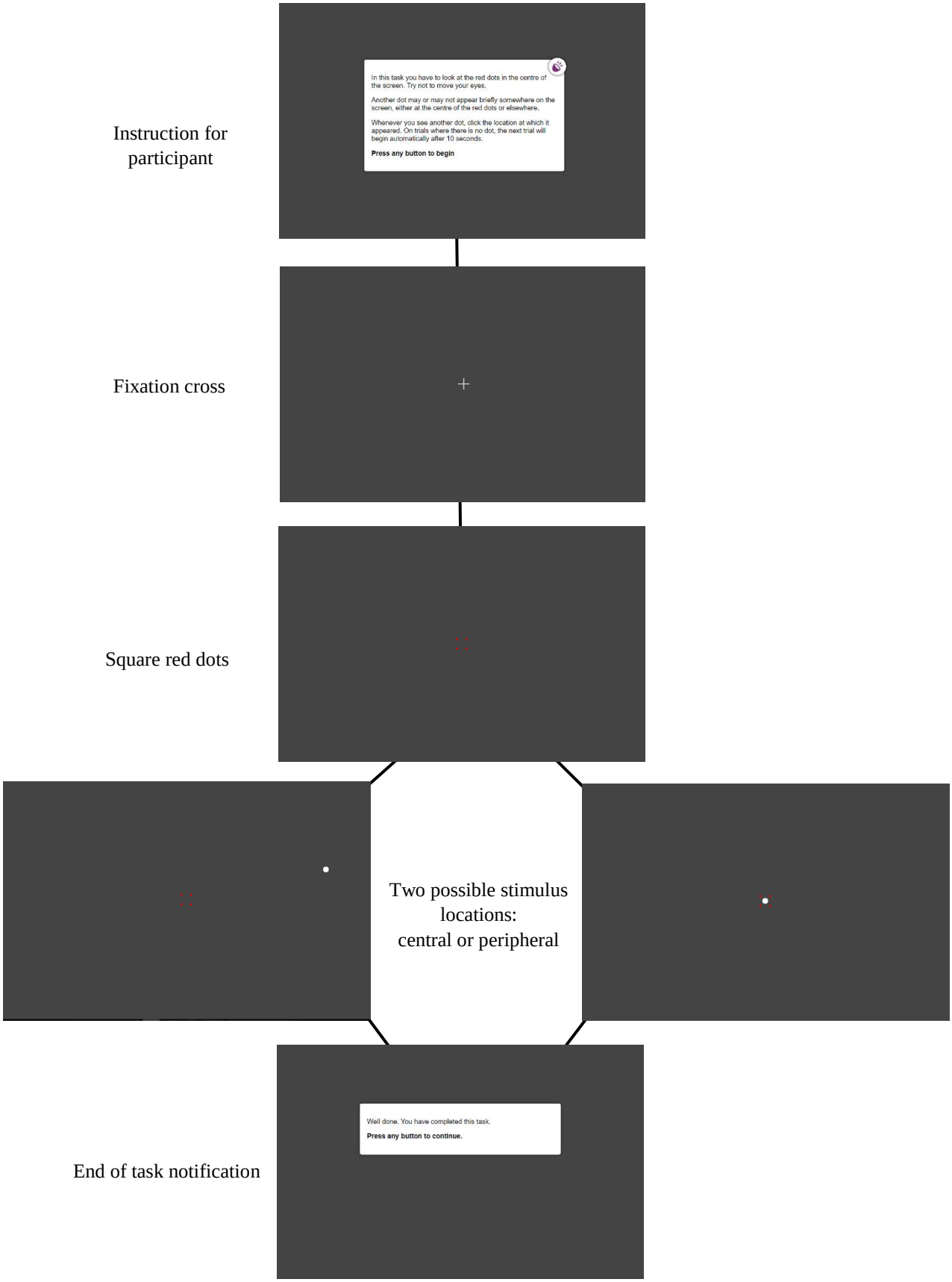


Figure 5.2 Diagram illustrating the step-by-step flow of the DREX perimetry test. Not to scale.

5.1.2.3.2 Determination of the type of visual field defect

The extent of visual field defect was assessed individually in each quadrant. It was determined by totalling the number of unseen points or areas where the target-present stimuli were not correctly responded to. If participants did not respond to the stimulus presented in the tested areas or their response was outside the quadrant where the target-present stimulus was presented, the tested areas were considered as an 'unseen area'. In contrast, a 'seen area' was confirmed if participants correctly clicked or tapped the location of the target-present stimulus. In this study, participants were considered as having homonymous quadrantanopia if two or more unseen areas in the tested quadrant were detected. Similarly, if two adjacent quadrants were involved, e.g. inferior or superior quadrants, such that more unseen areas were indicated, the type of visual field defect was regarded as homonymous hemianopia. For example, if the total number of unseen areas in the right inferior quadrant was three out of four possible areas the participant was therefore considered as having a right homonymous inferior quadrantanopia.

Figure 5.3 below shows one example of direct comparison between the HVF and DREX perimetry test results. Both perimetry tests revealed a right homonymous hemianopia.

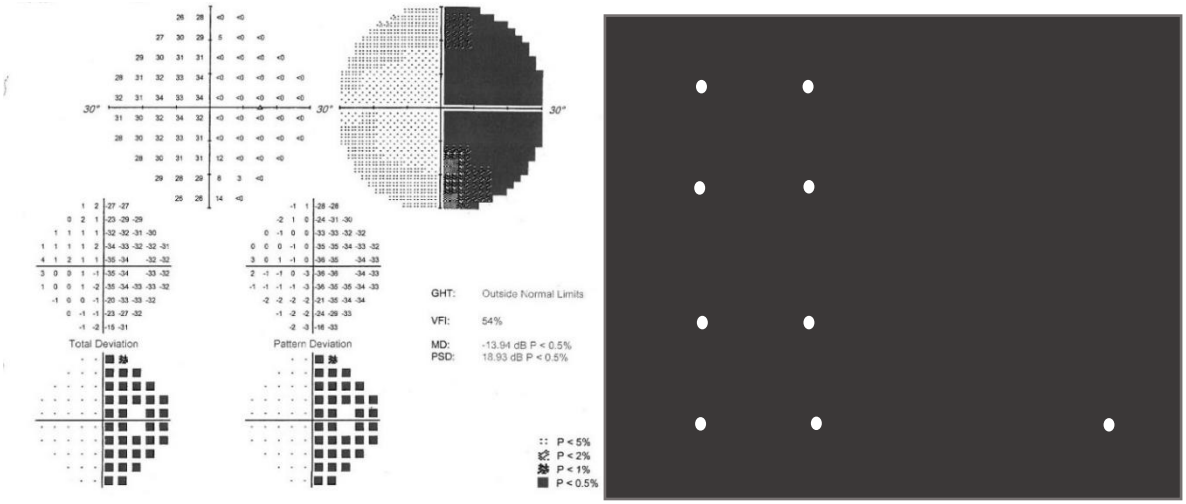


Figure 5.3 **Left.** Visual field performed on a Humphrey Visual Field Analyser (HVF) in a participant with right homonymous hemianopia (Participant 19). **Right.** DREX perimetry test result in the same patient; white dots represent the seen areas. Not to scale.

5.1.3 Results

The distribution of results of the visual field comparisons is demonstrated in Table 5.1. Of the 23 participants with a visual field defect diagnosed by the standard perimetry, 22 of them showed a prominent visual field defect, either hemianopia or quadrantanopia, as detected by the DREX perimetry test. This indicates that the sensitivity of the app-based perimetry was very high (95.7%). All seven participants who had a normal visual field according to standard perimetry showed normal visual field when tested using the DREX perimetry test. Overall, only four out of 30 participants were wrongly diagnosed by the DREX perimetry test, and of those three were still diagnosed as having a defect on the same side of space but the extent was inaccurate (see participants highlighted in bold from Table 5.1).

Table 5.1

Table describing the types of visual field defect from the standard perimetry and DREX perimetry tests.

Par.	Standard Perimetry		DREX perimetry					
	Perimetry	VFD	VFD	Total unseen area (×/4)*				Centre (×/1)
				Top right	Bottom right	Top left	Bottom left	
1	GP	Normal	Normal	0	0	0	0	0
2	GP	RH	RH	4	3	0	0	0
3	HVF	RIQ	RIQ	0	2	0	0	0
4	HVF	RIQ	RIQ	0	4	0	0	0
5	HVF	Normal	Normal	0	0	0	0	0
6	HVF	LH	LH	0	0	4	3	1
7	HVF	RH	RH	3	4	1	0	0
8	**GP**	**RIQ**	**RH**	**2**	**3**	**0**	**0**	**1**
9	HVF	LH	LH	0	0	4	3	1
10	HVF	RH	RH	3	3	0	0	1
11	HVF	RSQ	RSQ	4	0	0	0	0
12	HVF	Normal	Normal	0	0	0	0	0
13	HVF	RH	RH	4	4	0	0	1
14	HVF	RH	RH	4	3	0	0	0
15	HVF	LH	LH	1	0	3	4	0
16	GP	Normal	Normal	0	0	1	0	0
17	HVF	LSQ	LSQ	0	0	4	1	0
18	GP	Normal	Normal	0	0	0	0	0
19	HVF	RH	RH	4	3	0	0	0
20	GP	RH	RH	4	4	0	0	0
21	**HVF**	**RH**	**RSQ**	**4**	**1**	**1**	**0**	**0**
22	HVF	LH	LH	1	0	4	4	1
23	HVF	Normal	Normal	0	0	0	0	0
24	HVF	RIQ	RIQ	1	2	0	0	0
25	GP	LH	LH	0	0	3	4	0
26	HVF	RH	RH	4	4	0	0	0
27	**HVF**	**LSQ**	**Normal**	**0**	**0**	**0**	**0**	**0**
28	GP	Normal	Normal	0	0	0	0	0
29	GP	LSQ	LSQ	0	0	4	1	0
30	**HVF**	**LIQ**	**LH**	**0**	**0**	**3**	**3**	**0**

Note. Abbreviation: Par. = Participant; VFD = Visual field defect; RH = Right homonymous hemianopia; LH = Left homonymous hemianopia; RSQ = Right homonymous superior quadrantanopia; RIQ = Right homonymous inferior quadrantanopia; LSQ = Left homonymous superior quadrantanopia; LIQ = Left homonymous inferior quadrantanopia; HVF = Humphrey Visual Field analyser; GP = Goldmann Perimeter. *Unseen area ≥ 2 is considered as blind or impaired quadrant.

The accuracy of the DREX perimetry test in identifying participants with homonymous hemianopia was very high (92.9%), accounting for 13 out of 14

participants who had been diagnosed with homonymous hemianopia by the standard perimetry. In contrast, the accuracy of the DREX perimetry test in identifying participants with homonymous quadrantanopia was only 66.7%, such that three out of six participants who were confirmed with homonymous quadrantanopia by the standard perimetry were wrongly diagnosed. Only six out of 30 participants were unable to accurately detect the stimulus presented at the centre of the red dots and all of them were diagnosed with homonymous hemianopia.

5.1.4 Discussion

This study finding is of clinical significance in screening for visual field defects compared to the confrontation technique (Kerr, Chew, Eady, Gamble, & Danesh-Meyer, 2010). The sensitivity and specificity of the DREX perimetry test was very high, and greater than findings from the stroke group study which used Visual Field Easy app in screening the visual field loss (sensitivity: 89% and specificity: 76%; Spofforth et al., 2017). Cassidy et al. (2001) found the sensitivity of confrontation technique in detecting visual field defects among stroke patients was 94%, however, it reduced to 56% in following weeks as the visual field improved. Kerr and colleagues (2010) found the highest levels of sensitivity and specificity were 74% and 93% respectively using the confrontation technique but were still lower than our findings. Therefore, the app-based perimetry from the DREX app works better than the typical confrontation technique in screening of visual field defect and is at least comparable to other visual field screening apps.

This study demonstrated that the DREX perimetry test is a promising and reliable screening tool for detection of visual field defects, especially hemianopia, but it is not proposed to replace the standard perimetry. When assessing the extent of a visual

field defect, there is a tendency that patients can still perceive the stimulus presented in the blind visual field due to poor fixation control which can consequently result in inaccurate diagnosis of the visual field defect. This could also be a reason why the DREX perimetry test has poorer ability to detect quadrantanopia, because a slight shift in the fixation during the testing may cause the stimulus presented in the defective quadrant to become visible to the patients. Furthermore, the DREX perimetry test measured the visual field binocularly which could result in variability in the perimetry finding compared to the standard perimetry that was done monocularly. However, we did not observe any large deviation in the final diagnosis between the DREX perimetry and standard perimetry indicating that this was not a significant problem. At present, this is the only study of visual field apps that has explored the usability and accuracy to detect quadrantanopia, while the currently available tests like Visual Field Easy app (Spofforth et al., 2017) and web-based test (Koiava et al., 2012) did not specifically report this.

In terms of the design of the DREX perimetry test, only four locations were tested in each quadrant with the furthest target points presented at 13 degrees from central fixation. Thus, it provides only a gross estimation on the extent of visual field loss that is limited within the testing visual field area. In contrast, the HVF assesses larger visual field area, normally 24 or 30 degrees from the central fixation, giving more accurate evaluation of the visual field loss at the peripheral (Johnson et al., 2017). Although DREX perimetry test employs the use of static stimuli like HVF that gives more precise information about the impaired visual area compared to the perimetry result obtained from the use of kinetic stimuli in the Goldmann perimetry, DREX perimetry test is only sufficient to discriminate between quadrantanopia and hemianopia but does not assess the precise border of the field loss to provide information about the degree of sparing for instance as may be obtained with HVF. However, this perimetry

test is quicker than the conventional perimetry which is an important consideration in testing a visual field loss in stroke patients who are more susceptible to fatigue (Flinn & Stube, 2010; Puchta, 2008; Staub & Bogousslavsky, 2001).

In the future it would be advantageous to test the app with a wider sample of patients, including those with less dense visual fields or scotoma. The participants in this study all had a HVFD that was impacting on their everyday life, and therefore it is likely that their dense visual field loss was more easily detected and discriminated than defects with lesser impact. Furthermore, the nature of participants who agree to take part may be more compliant and more likely to follow the instruction given on the perimetry app diligently, thereby fixating the centre point properly throughout the testing for example. The population as a whole may not be as compliant, although one hopes that if the app was being used as a screening tool in hospitals for instance, that patients would follow instructions for this as well as they would do for standard perimetry.

The DREX perimetry test was quick and easy to administer by patients independently and demonstrated good sensitivity and specificity in detecting the presence of visual field defects when compared to standard perimetry. It can assist a clinician in evaluating their patient's visual field defect prior to the DREX training, and could be used as a supplementary visual field assessment, perhaps as an initial screening tool to replace confrontation perimetry.

Study 5 - The reliability of DREX visual search and reading assessments

5.2.1 Introduction

In the previous trials by Aimola et al. (2014) and Lane et al. (2010), the assessments of visual search and reading performance were done only using a supervised method such that the researcher was present to assist and monitor the testing. In the current study, self-administered tests have been introduced alongside the standard assessments in order to ease the assessment load. Two visual search assessments, pen search and counting-number search tasks, and one reading assessment, have been incorporated into the DREX app. Generally, in the DREX training package itself, patients are prompted to complete the assessments before, mid-way and after the training so that they can know how well they are doing and the benefits they have gained from the training. These assessments are automatically presented when the training system identifies that patients are ready for the next assessment session. Since they are self-assessments, a clear instruction and accessible link to a demonstration video on how to perform the assessments are provided each time. These unique features of the DREX app will guide patients throughout the assessments and enable them to accomplish the tasks independently and sufficiently at their own pace and convenience. However, these novel assessments have not yet been validated in terms of their use and reliability for the assessments of visual search and reading performance, and thus that is the primary aim of this study. If the assessments are validated, it will allow the clinical team, such as doctors, optometrists and occupational therapists, to track patients' progress remotely and will enable suggestions to be made to improve training experience.

5.2.2 Methods

5.2.2.1 Participants

Fifty participants (visuomotor = 17, computer-based = 17 and control = 16) were included in this study. The details of the participants were previously described in Study 1 (see Methods section pp. 46). All participants provided informed consent to participate in the study in accordance with the Declaration of Helsinki (International Committee of Medical Journal Editors, 1991). The study was approved by the psychology department ethics committee at Durham University and the NHS NRES Committee North East - Newcastle and North Tyneside 1 (REC reference: 15/NE/0351).

5.2.2.2 Assessments and procedures

See the descriptions and procedures for find-the-number search task, DREX pen search task, DREX counting-number search task, paper-based reading task and DREX reading task in the methods section of Study 1 (pp. 47-51).

5.2.2.3 Statistical analysis

The analysis was done using the pre-training assessment (A_1) results for DREX pen and find-the-number search tasks as the task performance was not differentially influenced by the effect of training. Initially, a paired t-test was performed to investigate the difference in mean RT (in milliseconds, ms) between the DREX pen and find-the-number search tasks. Then, a Bland-Altman plot was produced with the mean difference against the mean of both tasks. The mean difference and upper and lower limit of agreement (LoA) lines were plotted which included the 95% confidence intervals of each line. A linear regression was conducted to evaluate if there was any proportional bias of the points distribution. The mean of the difference shows an estimate of the average bias between the tasks while the limits of agreement (LoA) estimate the interval

that a given proportion of differences between tasks is probably to lie within. The LoA can be used to determine if the tasks can be used interchangeably, or if the new app-based tasks (DREX pen search task) can replace the find-the-number search task without changing the interpretation of the outcomes. Finally, an intraclass coefficient correlation (ICC) was calculated to confirm the agreement and reliability between DREX pen and find-the-number search tasks. ICC is the most desirable measure of reliability that reflects both degree of correlation and agreement between tasks. In this study, the two-way mixed-effects model and absolute agreement were selected as all participants were tested by the same search tasks and the tasks provided the same result (reaction time) to the same participant. The conventional two-sided test procedure: 95% confidence interval and 0.05 significant level, was employed.

The similar analyses were applied in investigating the reliability of the DREX reading task relative to the paper-based reading task; the reading speed of both tasks was reported in words per minute (wpm). For the DREX counting-number search task, a Bland Altman plot and ICC analysis could not be done because the DREX counting-number search task only measured the search duration (in seconds, s), unlike find-the-number and DREX pen search tasks which measured the average reaction time. Therefore, only Pearson's correlation analysis was done to investigate the relationship between this task with find-the-number and DREX pen search tasks.

5.2.3 Results

5.2.3.1 DREX pen search task

Table 5.2 shows the mean pre-training RT of all participants measured by the DREX pen search task and find-the-number search task. The paired t-test revealed that the mean RT of both tasks was not significantly different ($p = 0.774$), and the mean

difference was nearly zero, thus a good level of agreement was achieved. Next, a Bland Altman plot was plotted with the mean difference between two tasks for each participant against the mean of both tasks (see Figure 5.4). The trend of points distribution between above and below the mean difference line showed no proportional bias ($p = 0.525$) and the coefficient of mean of two tasks (β) was close to zero, supporting the agreement assumption between the two tasks. The data in the plot showed homoscedasticity, such that most of the points lie along the line of the mean difference and there was no obvious relationship between the difference and the mean of the two tasks.

Table 5.2

The mean difference of reaction time, linear regression analysis and intraclass correlation coefficient for evaluating the reliability and agreement of DREX pen search task.

Task	Mean RT (SD)	Mean difference[α] (95% CI; t)	Linear regression analysis[*], β (t)	Intraclass correlation coefficient (95% CI; F)
DREX pen search	3098.20 (1507.70)	-65.64 (391.01, -522.30; 0.289, p = 0.774)	0.109 (0.640, p = 0.525)	0.651 (0.382, 0.802; 2.831, p < 0.001)
Find-the-number	3162.84 (1634.90)			

Note [α]Mean difference = DREX pen search task (A_1) – find-the-number search task (A_1)
[*]Points distribution trend between above and below mean difference line.

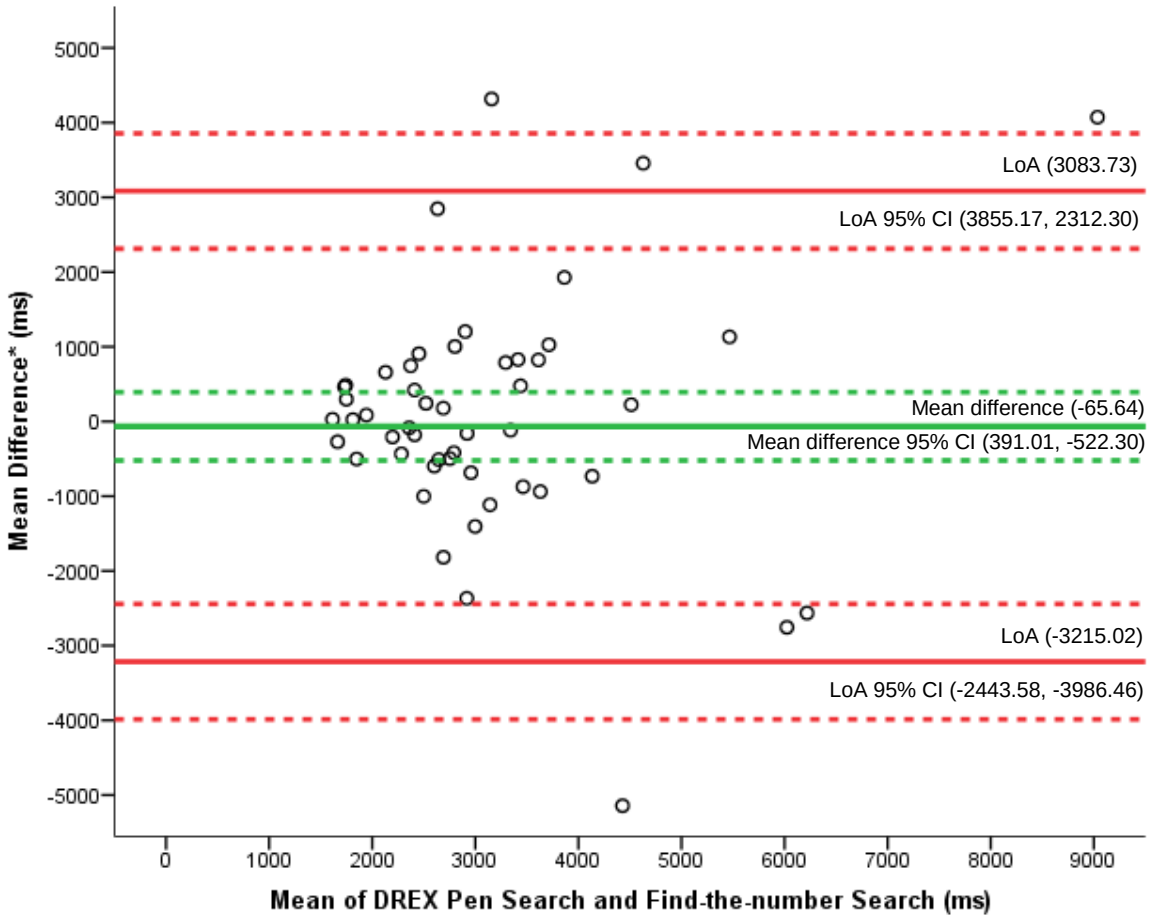


Figure 5.4 The graph shows the Bland Altman plot for the difference of mean reaction time between DREX pen search task and find-the-number search task against the mean of both tasks in 50 participants. The mean difference and upper and lower limit of agreement (LoA; mean ± 1.96 SD) are indicated in the plot (including their 95% confidence intervals). *Mean difference = DREX Pen Search (A_1) - Find-the-number Search (A_1).

The mean difference was 65.64 ms indicating that the mean reaction time for the Pen search task was 65.64 ms faster than for the find-the-number search task. When referring to the Bland Altman plot, only three out of 50 points did not fall within the 95% of confidence intervals for the LoA. Although the range of the interval was slightly wider due to the small sample size and little variation of the differences, most of the points were concentrated largely within or near the 95% confidence interval of the mean difference indicating an acceptable agreement. To further investigate this agreement, the reliability of the two tasks was confirmed by running an Intraclass Correlation Coefficient analysis. A moderate degree of reliability and agreement were found

between the find-the-number and pen search tasks measurements. The average measure ICC was 0.651 with a 95% confidence interval from 0.382 to 0.802, ($p<0.001$).

5.2.3.2 DREX counting-number search task

The DREX counting-number search task significantly and positively correlated with the find-the-number search task ($r = 0.577$, $p < 0.001$) and the DREX pen search task ($r = 0.694$, $p < 0.001$). These show that as the mean RT in the find-the-number search task increases, the mean RT in the pen search task and search duration in the counting-number search task increases.

5.2.3.3 DREX reading task

Table 5.3 shows that the mean of pre-training reading speed measured by the DREX reading task was significantly greater than the paper-based reading task ($p = 0.012$). A Bland Altman plot was plotted to assess reliability and agreement between the two tasks (see Figure 5.5). The trend of points distribution between above and below mean difference line showed proportional bias ($p = 0.025$) but the coefficient of mean of two tasks (β) was close to zero. The data in the plot still showed homoscedasticity as most of the points lie close to the line of the mean difference.

Table 5.3

The mean difference of reaction time, linear regression analysis and intraclass correlation coefficient for evaluating the reliability and agreement of DREX reading task.

Task	Mean reading speed (SD)	Mean difference[α] (95% CI; t)	Linear regression analysis[*], β (t)	Intraclass correlation coefficient (95% CI; F)
DREX reading	113.62 (50.74)	16.84 (29.85, 3.83; 2.602, p = 0.012)	0.374 (2.306, p = 0.025)	0.624 (0.340, 0.786; 2.852, p < 0.001)
Paper-based reading	96.78 (38.18)			

Note [α]Mean difference = DREX reading task (A_1) – paper-based reading task (A_1)
[*]Points distribution trend between above and below mean difference line

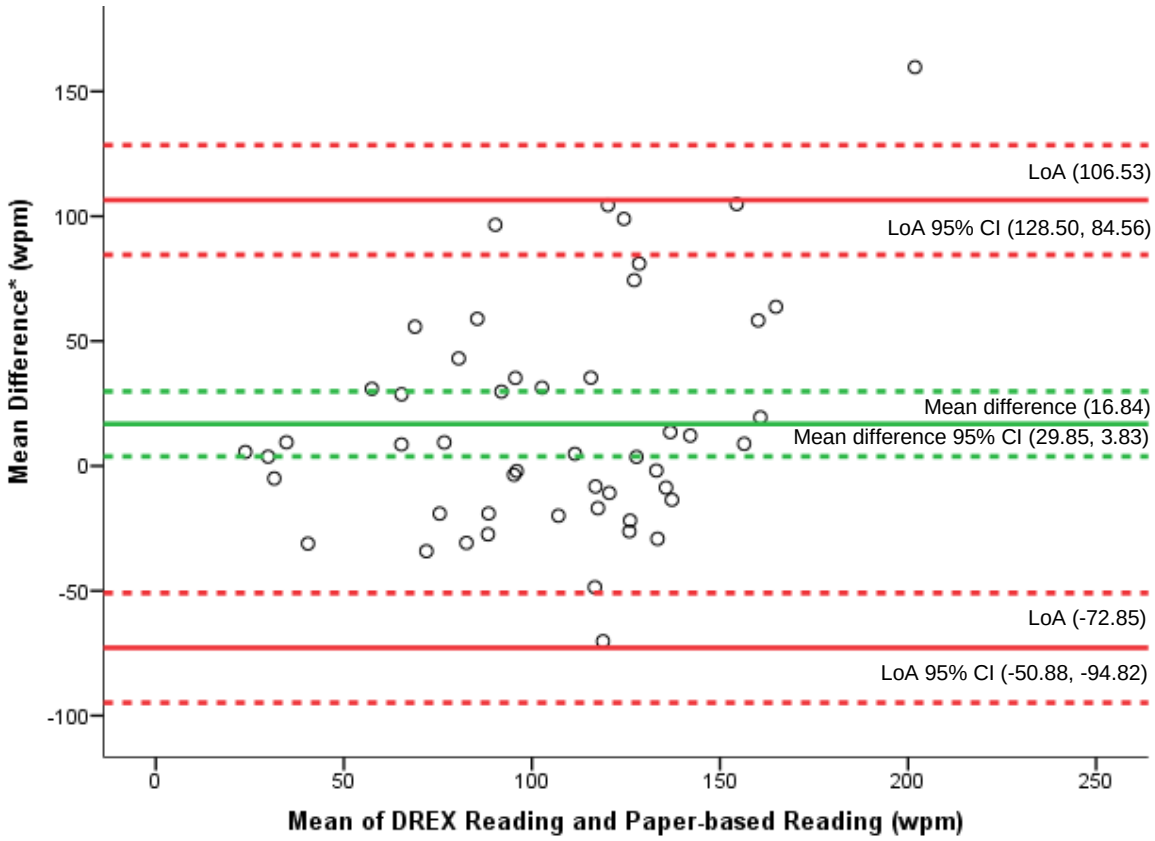


Figure 5.5 The graph shows the Bland Altman plot for the difference of mean reading speed between DREX reading task and paper-based reading task against the mean of both tasks in 50 participants. The mean difference and upper and lower limit of agreement (LoA; mean ± 1.96 SD) are indicated in the plot (including their 95% confidence intervals). *Mean difference = DREX reading (A_1) – paper-based reading (A_1).

The mean difference was 16.84 wpm indicating that the reading speed for the DREX reading task was 16.84 wpm slower than for the paper-based reading task. The Bland Altman plot showed that only one out of 50 points did not fall within the 95% of confidence intervals for the LoA indicating an acceptable agreement. The reliability of the two tasks was confirmed by an Intraclass Correlation Coefficient analysis such that a moderate degree of reliability and agreement were found between the DREX reading and paper-based reading tasks measurements. The average measure ICC was 0.624 with a 95% confidence interval from 0.340 to 0.786, ($p<0.001$). Thus, the DREX reading task is a reliable assessment for evaluation of reading performance.

5.2.4 Discussion

The aim of this study was to evaluate the reliability of the app-based exploration and reading tasks by comparing participants' baseline results (A_1) with the previously used find-the-number search and paper-based reading tasks respectively. In the DREX pen search task, participants were instructed to look for a pen among the distractor objects, therefore it might be very easy to discriminate the target with the pre-attentive attribute provided. Similarly, in the find-the-number search task, the instruction was given such that participants were asked to look for a specific target (a number). Since both tasks used a blank background and guided to a certain character, it was expected that the efficiency of the tasks (mean RT) would be the same (Wolfe, Alvarez, Rosenholtz, Kuzmova, & Sherman, 2011). This finding was corroborated by the fact that most of the points in the Bland Altman plot lay close to the mean difference axis (mostly within the 95% confidence intervals) indicating the difference in the mean RT between the two tasks was near to zero. In addition, the Bland-Altman plot and ICC analyses confirmed that the DREX pen search task is reliable and acceptable for the assessment of visual search performance compared to the find-the-number search task.

The correlational analysis for the DREX counting-number task compared to find-the-number and DREX pen search tasks revealed a positive correlation in all conditions, indicating that an improvement in search speed in one task will result in improvement in the other tasks. From a practical point of view, relying on only the app-based assessment results should be adequate to determine the performance of visual search in the patients after the training. Therefore, it can be concluded that the DREX counting-number search task is also a valid and useful test for visual search assessment alongside the DREX pen search task.

A moderate agreement was revealed between the DREX reading and paper-based reading tasks, such that the DREX reading task is reliable and sufficient for the

evaluation of the effect of DREX training on the reading performance. The task also has the additional advantage of the multiple-choice questions presented after the reading paragraph to assess patients reading comprehension. In Chapter 2, it was revealed that the accuracy of reading comprehension improved significantly after the training. Therefore, the reading task in the DREX training app is not only able to consistently assess patients reading speed, but also their reading comprehension which provides additional information about the quality of their reading performance.

In conclusion, the results of this study have demonstrated the reliability and usefulness of the app-based search and reading tasks in the assessment of outcomes of the training. The assessments could produce a valid result which is very crucial for clinical decision-making and enhancement of training experience. Most importantly, patients can use the assessments independently and can rely on the results of the assessments in order to know how much they have improved after the training. It can also assist the clinician and therapist in monitoring their patients' performance accurately at any time.

5.3.1 Introduction

Self-administered questionnaires are frequently used to measure the subjective aspects of illness such as disability, psychological problems or quality of life (Anderson, Laubscher, & Burns, 1996; Berger, Hense, Rothdach, Weltermann, & Keil, 2000; Niekel, Lindenhovius, Watson, Vranceanu, & Ring, 2009; Nouri & Lincoln, 1987) which offer vital information for clinical decision-making, scientific valuations and clinical studies (Kvien et al., 2005; Lee, Kavanaugh, & Lenert, 2007). Most questionnaires were validated in a paper-based form, but direct entry into a computer is becoming increasingly common. Electronic questionnaires are more efficient and remove the necessity for secondary data entry (Shervin et al., 2011) which makes the evaluation and interpretation of the questionnaire faster and more convenient for both clinician and patient. In the rehabilitation of visual field defects, mainly after stroke, the assessment on the subjective improvements after the therapy is routinely done to know the extent of the training benefits to the daily activities, and most of the time the assessment is conducted using a paper-based questionnaire. Only one study had recently used a web-based questionnaire to evaluate the effect of the hemianopia rehabilitation on the activities of daily living (Ong et al., 2015).

DREX Visual Impairment Questionnaire (VIQ-DREX) is the final assessment that has been incorporated into the DREX training app. The VIQ-DREX is a modified version of the VIQ which was used in the previous trials (Aimola et al., 2014; Lane et al., 2010); six out of ten items were selected for the DREX training app (see the Methods section of this study for the list of the items). The VIQ-DREX is developed as a subjective assessment to evaluate the effects of the training on participants' ability to

perform basic daily activities, allowing participants to know what activities have gained greater improvement and/or activities that require more practice. With a simpler and more user-friendly format, the assessment could be done more efficiently and immediately after the training.

Although the VIQ-DREX version has several advantages over the pen-and-paper version (VIQ-PP), it has not yet been validated and the agreement between both versions is unknown. Therefore, this study aimed to assess the reliability, including agreement of two versions, of VIQ-DREX in assessing the subjective improvements gained after the training relative to the VIQ-PP. It was hypothesized that the VIQ-DREX is reliable and has a substantial agreement with the VIQ-PP.

5.3.2 Methods

5.3.2.1 Participants

Participants were the same individuals who took part in Study 1 (see Methods section of Study 1, pp. 46)

5.3.2.2 Assessments and procedure

5.3.2.2.1 Paper-based Visual Impairment Questionnaire (VIQ-PP)

See VIQ descriptions and procedure in the methods section of Study 1 (pp. 52).

5.3.2.2.2 DREX Visual Impairment Questionnaire (VIQ-DREX)

The VIQ-DREX consisted of six questions; difficulties in seeing objects, avoiding obstacles, finding way, shopping, crossing the street, and reading. For each question, participants were asked to rate how much difficulty they experience with that activity by choosing any point along the scale between the lowest (no difficulty) and

highest (extreme difficulty) points. Participants had to click (computer-based) or tap (visuomotor) the appropriate point. Table 5.4 shows the possible scoring for each scale (severity/frequency) in the VIQ-DREX and VIQ-PP.

Table 5.4

Table illustrating the scoring for each level of severity or frequency for the modified Visual Impairment Questionnaire incorporated in the DREX Training (VIQ-DREX) and the pen-and-paper version of the same questionnaire (VIQ-PP).

VIQ-DREX		**VIQ-PP**	
Severity/Frequency	**Score**	**Severity/Frequency**	**Score**
None	0	No Problem	0
None – Mild	0.5		
Mild	1	Rare Problem	1
Mild – Moderate	1.5		
Moderate	2	Occasional Problem	2
Moderate – Serious	2.5		
Serious	3	Frequent Problem	3
Serious - Extreme	3.5		
Extreme	4	Very Frequent Problem	4

After participants rated their difficulty on that activity, they were prompted to confirm their answer before the next question was presented. At this point, participants could also return to the question and change their rating. The DREX system estimated the score for each question based on participant's final rating. The minimum and maximum scores were 0 and 4 respectively. Figure 5.6 shows the flow of the assessment procedure.

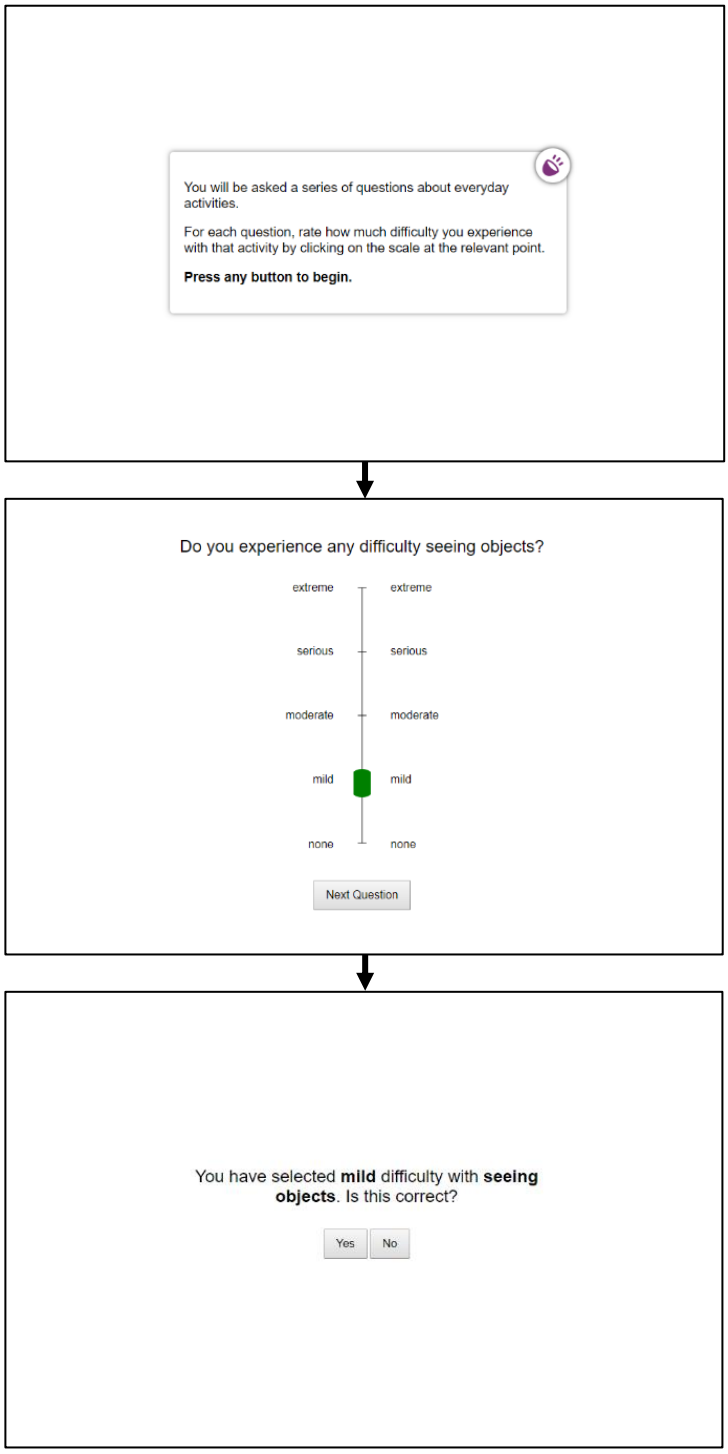


Figure 5.6 Diagram illustrating the step-by-step flow of the DREX Visual Impairment Questionnaire (VIQ-DREX; question 1 only). Not to scale.

5.3.2.3 Statistical analysis

The analysis was done using the baseline assessment results for VIQ-DREX and VIQ-PP only so that the results were not influenced by the effect of training. A paired t-test was conducted to compare the mean score between VIQ-DREX and VIQ-PP. Then,

a Cronbach α to test the internal consistency reliability of VIQ-DREX and VIQ-PP was performed followed by Intraclass Correlation Coefficient the agreement of each item between the two VIQ versions. The conventional two-sided test procedure: 95% confidence interval and 0.05 significant level, was employed.

5.3.3 Results

A total of 29 out of 50 participants completed the VIQ-DREX via touchscreen tablet. The paired t-test on the mean score on each item between VIQ-DREX and VIQ-PP revealed a non-significant difference for the item 'losing way', which was nearing significance ($p = .055$). For all of the other items there was a significant difference ($p < 0.001$); participants scored significantly lower (less difficulty to execute the activities) in the VIQ-DREX than the VIQ-PP (see Table 5.5). For the internal consistency reliability of VIQ-DREX and VIQ-PP, the Cronbach α were nearly identical, 0.845 and 0.874 respectively. This indicated a good internal consistency of both versions.

Table 5.5

Table illustrating the mean score (SD) for each item of the Visual Impairments Questionnaire completed via DREX training app (VIQ-DREX) and pen-and-paper (VIQ-PP), the paired t-test of mean score between both versions as well as the Intra-class Correlation Coefficient of each item. Significant difference (*)

	Mean (SD)		**Paired t-test**		**Intra-class Correlation Coefficient, ICC**	
	VIQ-DREX	**VIQ-PP**	**t**	***p***	**ICC (95% CI)**	***p***
Seeing objects	1.65 (1.02)	2.08 (1.24)	4.022	<0.001*	0.876 (0.781, 0.930)	<0.001*
Avoiding obstacles	1.55 (1.11)	2.00 (1.34)	3.930	<0.001*	0.878 (0.786, 0.931)	<0.001*
Losing way	1.17 (1.06)	1.38 (1.32)	1.963	0.055	0.889 (0.805, 0.937)	<0.001*
Shopping	1.44 (1.08)	1.96 (1.31)	4.204	<0.001*	0.847 (0.730, 0.913)	<0.001*
Crossing the street	1.54 (1.20)	1.76 (1.38)	2.267	0.028*	0.924 (0.867, 0.957)	<0.001*
Reading	1.67 (1.08)	1.23 (0.17)	2.929	0.005*	0.939 (0.893, 0.966)	<0.001*

Table 2 provides ICCs for agreement between VIQ-DREX and VIQ-PP. The ICC ranged between 0.847 to 0.939 for all six items ($p < 0.001$). An excellent agreement was indicated for ‘crossing the street’ and ‘reading’ items while the remaining items showed good agreement.

5.3.4 Discussion

Treatment benefits for patients with HVFDs using DREX training were well reflected by self-reported outcome questionnaires (see Results section in Chapter 2). The present study evaluated the reliability of the app-based version of the visual impairment questionnaire (VIQ-DREX) compared to its standard pen-and-paper version (VIQ-PP). The results showed that data acquisition for the visual impairment questionnaire (VIQ) using the app-based version is efficient and feasible in patients with HVFDs despite substantially lower rating (less difficulty) for most activities

obtained via the VIQ-DREX. This was possibly due to the wider rating scales offered in the VIQ-DREX version, such that participants could choose a more precise score for each question. For example, rather than simply choosing either no difficulty or mild difficulty option, participants with 'little difficulty' in that particular activity may opt for none-mild difficulty by clicking/tapping the scale between none to mild. As a result, the average score for VIQ-DREX becomes somewhat lower than the VIQ-PP. One notable difference between VIQ-DREX and VIQ-PP is the rating scales for VIQ-DREX was set in scrolling vertical line while the rating scales for VIQ-PP was horizontally arranged. It could possibly make administrating the VIQ-DREX is much easier compared to the VIQ-PP if patients have hemifield loss; looking up and down along vertical line when attempting the VIQ-DREX seems effortless. Patients may see all information (e.g. rating scales) clearly without needing to do eye scanning to their blind hemifield.

The VIQ-DREX is reliable and valid for the assessment of self-reported improvements after the vision training with higher internal consistency and excellent agreement with the standard pen-and-paper method, VIQ-PP. Therefore, the VIQ-DREX can be used interchangeably with the VIQ-PP for the assessment of subjective benefits after the DREX training. This is an important finding as the data obtained via VIQ-DREX could now be used for a clinical decision-making and consultation, especially where a face-to-face meeting or visit is not possible at that time. It will enable a quick and fast decision to be made remotely to enhance patients' experience with the DREX training, and indirectly improve the quality of care and contribute to patients' self-empowerment. In conclusion, this study added some insights into the benefits of using technology for the assessment of quality of life after vision rehabilitation, specifically for visual field defect patients.

5.4 Conclusion

In summary, all of the assessments in the DREX training app appear to be reliable and valid, and can be used to accurately evaluate the extent of patients' visual field loss as well as measure their performance in the visual exploration, reading and common daily activities. This means that clinicians and therapists can rely on the findings from the assessments in making decision about the treatment with confidence and monitor their patients' progression at the same time without needing any additional testing. Furthermore, the assessments are integrated within the training which could absolutely save more time and enable a comprehensive evaluation to be made quickly as possible. Finally, anyone even a novice user can assess himself independently without requiring an intensive training because the assessments are very simple and easy to be operated.

Chapter 6

Study 7 - The efficacy of DREX training for other partial visual field defects: a case series

6.1 Introduction

Visual field changes not only affect individuals' ability to perceive objects within their environment, but may also interfere with the functioning of the visual system in executing efficient eye movements, which are important for better performance in daily activities (Cornelissen, Bruin, & Kooijman, 2005), and affect socio-emotional well-being (Augustin et al., 2007; Rovner & Casten, 2002). Researchers studied the visual behaviour in many age groups (Humphrey & Kramer, 1997) and in different visual field defects like HVFDs (Tant, Cornelissen, Kooijman, & Brouwer, 2002; Zihl & Von Cramon, 1985), central visual field loss (Van der Stigchel et al., 2013; Whittaker, Cummings, & Swieson, 1991; Cheung & Legge, 2005; Cornelissen et al., 2005), tunnel vision (Luo, Satgunam, & Peli, 2012; Smith, Glen, & Crabb, 2012; Smith, Glen, Mönter, & Crabb, 2014; Lowe & Drasdo, 1992) and bitemporal visual field loss (Lohmann, Köhler, & Ullirich, 2000), a type of visual field loss that received little attention but is very prevalent among patients with a pituitary adenoma (Becker et al., 2010). Previous chapters have discussed the benefits of DREX training for rehabilitating the visual search and reading impairments associated with HVFDs, and the present study will focus on the effectiveness of this training for other types of partial visual field defects that are frequently caused by chronic eye diseases like age-related macular degeneration (AMD) and retinitis pigmentosa, highly

debilitating ocular disorders globally (Flaxman et al., 2017) that require a reliable and effective treatment.

6.1.1 Partial visual field defects

6.1.1.1 Tunnel vision

Tunnel vision is a restricting concentric visual field loss in the periphery, a disorder frequently caused by advanced retinopathy of prematurity (ROP) and retinitis pigmentosa. ROP is a leading blinding disease in children in the developed country despite currently available treatment. There are two stages of ROP progression: the first stage starts with delayed retinal vascular growth after birth and incomplete regression of existing blood vessels, while the second stage involves hypoxia-induced pathological vessel growth (Chen & Smith, 2007). The changes in the visual field, mainly constriction of the peripheral visual field, were reported due to the chorioretinal scar as a consequence of cryotherapy, the common treatment given to second stage ROP (Wheatley, Dickinson, Mackey, Craig, & Sale, 2002). However, Quinn et al. (1996) reported the extent of peripheral visual field loss to be only 10° in each meridian tested on average.

Retinitis pigmentosa is a progressive retinal dystrophy classically characterised by night blindness, bone spicule-like pigmentary retinal changes (see Figure 6.1), and progressive loss of peripheral visual fields that were identified to impair visual performance (Sumi, Matsumoto, Okajima, & Shirato, 2000; Szlyk, Alexander, Severing, & Fishman, 1992). Retinal damage related to retinitis pigmentosa usually starts in the periphery and gradually ends at the fovea, and its symptom is highly variable between patients. Some patients experience symptomatic visual loss in childhood while others continue asymptomatic until young adulthood; many patients start experiencing difficulties with dark adaptation and night blindness as well as the

loss of mid-peripheral visual field during their young adulthood (Nemshick, McCay, & Ludman, 1986). In the severely advanced cases, the loss of peripheral vision becomes very prominent such that patients eventually develop tunnel vision and loss of central vision, typically by age 60 years (Hartong, Berson, & Dryja, 2006).

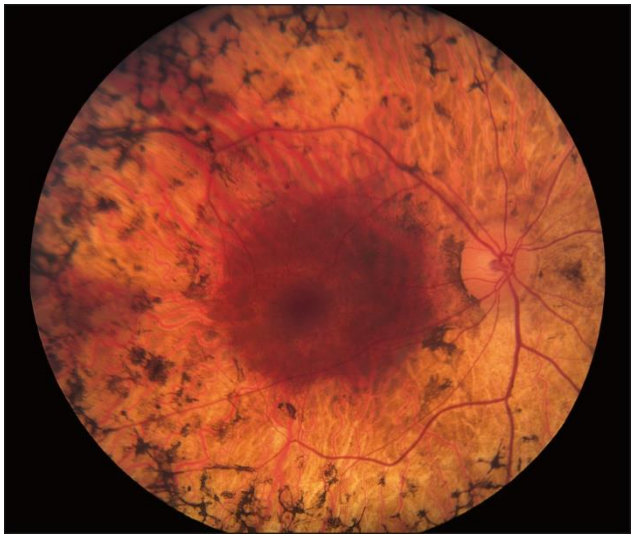


Figure 6.1 Fundus photograph of a patient with retinitis pigmentosa, demonstrating bone spicule-like pigmentation at the peripheral retinal (Fingert et al., 2008).

Generally, the consequence of gradual constriction of the visual field could result in a loss of central vision which often remains relatively intact at the early stage. However, less than 0.5% of patients experience total vision loss in both eyes (Grover et al., 1996). Most patients aged 45 years or above, more than half of the population, are able to see 6/12 letters or better in at least one eye (Grover et al., 1999) and even patients with moderate and severe impairment may still have normal or nearly normal visual acuity (Hyvarinen, Romvamo, Laurinen, & Peltoma, 1981), indicating that a good level of visual acuity could be expected although the retinitis pigmentosa is progressing. Despite having functionally and noticeably clear central vision, many patients are still struggling to execute most of the basic daily activities because the progression of retinitis pigmentosa not only affects the visual acuity but also the

contrast sensitivity especially the higher frequencies (Lindberg, Fishman, Anderson, & Vasquez, 1981; Szlyk et al., 2001). The loss of contrast sensitivity is frequently described as dullness of images, for example, loss of features of faces or letters. Thus, patients may take a long time to recognise the specific characteristics of visual items presented within their seeing field (Alexander, Derlacki, & Fishman, 1995).

6.1.1.2 Central visual field loss

Central visual field loss is a typical visual manifestation of AMD, an atrophy of photoreceptor cells in the macula, which is an undesirable consequence of aging resulting in a breakdown of cells in the centre of the retina (Cheung & Legge, 2005; Nilsson, Frennesson, & Nilsson, 2003). Generally, AMD can be classified into two main forms: dry AMD and wet AMD (Chopdar, Chakravarthy, & Verma, 2003; O'Neill, Jamison, McCulloch, & Smith, 2001). Dry AMD normally results from the accumulation of drusen (yellow deposit from lipids; see Figure 6.2) beneath the light-sensitive retinal pigment epithelium (RPE) layer in the macula region. As the drusen gradually increases, the RPE function progressively deteriorates causing significant central vision loss in the affected eye. Although dry AMD does not commonly cause total loss of central vision, it could potentially lead to a more profound wet AMD (Smiddy & Fine, 2017).

Figure 6.2 Fundus photograph of dry AMD with large drusen at macula and its surrounding area (Age-Related Eye Disease Study Research Group, AREDS, 2005)

Wet AMD is caused by choroidal neovascularization (CNV) generally at the sub-foveal location. The new, fragile blood vessels from CNV can invade the RPE layer and then rupture, resulting in blood and lipid leakage. Consequently, a severe disciform scar will form and damage the visual function. With either dry or wet AMD a central scotoma due to the retinal damage can manifest as a relative scotoma (presence of residual light sensitivity) or an absolute scotoma (total loss of light sensitivity), and could affect one eye or both eyes simultaneously (plural: scotomata). It has been estimated that 90% of individuals with wet AMD experience severe vision loss as compared to the dry AMD (Ferris, 1983).

A population-based study showed that 42% of eyes with AMD had visual acuity of 6/60 or worse, and in most cases reduced contrast sensitivity was present and persistent throughout patients' life (Sunness et al., 1997). Although patients, at the early stage, may present with good visual acuity of 6/15 or better, there was a high tendency that the vision could deteriorate up to 8% annually until no useful vision is left (Schatz and McDonald, 1989). On average, the loss of visual acuity could increase from 31% at the 2-year of examination to 53% by the 4-year examination (Sunness et al., 1999),

reflecting the adverse and progressive effect of AMD to the quality of vision in the later stage.

6.1.1.3 Bitemporal visual field loss

Bitemporal visual field loss like bitemporal hemianopia is caused by chiasmatic compression (Graham & Wakefield, 1973; Lohmann et al., 2000; McIlwaine, Carrim, Lueck, & Chrisp, 2005; Poon, McNeill, Harper, & O'Day, 1995), which is a result of a pituitary adenoma (Kosmorsky, Dupps, & Drake, 2008). Pituitary adenoma is a benign tumour of the pituitary gland which is the most common cause of chiasmal compression in an adult (Kerrison et al., 2000), accounting for approximately 10% - 15% of all intracranial neoplasms (Glisson, 2014; Ogra et al., 2014). The bitemporal hemianopia may also be caused by pressure, arachnoiditis or demyelinating disease (Graham & Wakefield, 1973; McFadzean, Doyle, Rampling, Teasdale, & Teasdale, 1991). The visual field defect may be complete which involves the whole hemifield (bitemporal hemianopia) or partial, usually starting superiorly (bitemporal quadrantanopia) and progressing inferiorly, depending on the severity of nerve lesion or compression (Ogra et al., 2014). Normally, bitemporal superior quadrantanopia could be the early stage of bitemporal hemianopia (Law & Law, 1998).

The visual field loss may be accompanied by reduced visual acuity (McFadzean et al., 1991), however some patients present with excellent visual acuity despite the prominent visual field loss; about 52% of patients with bitemporal defects had a visual acuity better than 6/7.5 in both eyes (Ogra et al., 2014). Similarly, Klauber and coworkers (1978) in their earlier study also reported that 41% of patients with pituitary adenoma presented with visual acuity of 6/6. Typically, the visual field loss in patients with a pituitary tumour may go unnoticed because visual acuity is only affected when the central vision or visual field becomes severely impaired. Findlay et al. (1983)

studied the recovery of vision following pituitary gland treatment in 34 patients and reported that patients who had visual field loss less than 50% did not show an obvious decrease in visual acuity, while those who had a severe decrease in acuity also had a manifest visual field loss.

6.1.2 Impairment of eye movement and behavioural functions

The changes in visual search behaviour have been widely studied among patients with glaucoma (Luo et al., 2012; Smith et al., 2012, 2014), AMD (Van der Stigchel et al., 2013; Whittaker, Cummings, & Swieson, 1991) and retinitis pigmentosa (Lowe & Drasdo, 1992), such that most patients generally executed a slow and unorganised visual search mainly on the side of their visual field loss, either at central or peripheral visual field. Typically, the impaired visual search caused by peripheral visual field loss like in retinitis pigmentosa impacts patients' ability to identify an object located at the peripheral field. In contrast, the impaired visual search in patients with central visual field loss like AMD affects mostly the near tasks such as reading and recognising faces.

Reading is the most common functional disability and clinical complaint reported by patients with central visual field loss (Stelmack, Rosenbloom, Brenneman, & Stelmack, 2003), and reading speed has a direct impact on patients' capability to accomplish everyday activities independently (Bullimore & Bailey, 1995; Chopdar et al., 2003; Rubin & Feely, 2009). Studies on eye movement patterns in AMD revealed that a reduced reading rate was linked with a reduced number of forward saccades and increased backwards refixations (Bullimore & Bailey, 1995; Crossland et al., 2004; Rubin & Feely, 2009), affecting 71% of the cases (Rubin & Feely, 2009). In addition, Rovner and Casten (2002) reported slightly higher percentage such that 87.5% of 51 AMD patients suffered from reading problems, but among mainly patients with an

absolute scotoma. In terms of patients reading performance, Legge et al. (1985) found that the highest reading speed among AMD patients was 70 words per min (wpm) when reading 12 degrees to 24 degrees print size, and the reading speed decreased as the size of central scotoma increased (Ergun et al., 2003; Sunness, Applegate, Haselwood, & Rubin, 1996). The factors that lead to reduced reading speed are larger size of the central scotoma, impaired saccadic control (more information about eye movement in AMD in the next section), reduced visual span size which is defined as the number of letters that can be recognized accurately in a line of text without making eye movements (see Legge et al., 2007), and poor fixation stability (Crossland, Culham, & Rubin, 2004; Ergun et al., 2003; McMahon, Hansen, & Viana, 1991).

The reading performance of most patients with retinitis pigmentosa is only moderately impaired (Virgili et al., 2004; Sandberg & Gaudio, 2006; Szlyk et al., 2001) as the disease did not primarily involve the macular area except in the advanced stage of the disease. However, the impact of peripheral vision loss due to retinitis pigmentosa leads to greater difficulty with general visual searching (Latham, Baranian, Timmis, Fisher, & Pardhan, 2017; Lowe & Drasdo, 1992) as well as orientation and mobility (Black et al., 1997; Geruschat, Turano, & Stahl, 1998; Haymes, Guest, Heyes, & Johnston, 1996; Szlyk et al., 1997; Leat & Lovie-Kitchin, 2006; Turano, Geruschat, Baker, Stahl, & Shapiro, 2001). The mobility impairment had also been studied among patients with glaucoma and AMD (Haymes, Guest, Heyes, & Johnston, 1996; Jacko et al., 2000; Turano et al., 2004). In a recent study, the visual search behaviour of persons with retinitis pigmentosa while walking or avoiding obstacles was described as very inconsistent due to the restricted peripheral visual field (Timmis et al., 2017). Another study by Turano et al. (2001) found that while walking a simple route, persons with retinitis pigmentosa fixate over a larger area of the scene than do individuals with normal vision. On average, the retinitis pigmentosa subjects directed their gaze over an

area that was three times larger than the size of the area over which the normally sighted individuals directed their fixation (Turano et al., 2001). Fuhr et al. (2007) studied the relationship between visual search and mobility in severe visual impairment and found that visually impaired subjects took a longer time to navigate through the mobility course, especially in a low light condition, and bumped into obstacles more often than the normal subjects. In addition, Kuyk and colleagues (2010) described the importance of the effective visual search for safe mobility among patients with advanced retinitis pigmentosa. They found that the travel time and the number of collisions made while navigating could be predicted from the number of items that a person with vision impairment could find in a black and white photo of a street view in 10 seconds. The results of this study demonstrated that individuals with advanced vision impairment due retinitis pigmentosa inspect their environment in a way different (e.g. slow and unsystematic visual search) from individuals with normal vision during mobility.

6.1.3 Compensatory eye movement training as a treatment option.

Some patients with partial visual field loss might spontaneously compensate for their visual field loss by making an alternative gaze on the locations surrounding the intended target in order to perceive it (Smith et al., 2012). However, AMD patients may longer time to establish this adaptation (White & Bedell, 1990). After a certain time, AMD patients may also develop an preferred retinal locus (PRL; Timberlake, Peli, Essock, & Augliere, 1987), known as pseudo-fovea, that permits them to re-establish reading ability with appropriate low vision devices. However, it has been found that many patients with central vision loss may still have a decreased reading speed despite the best low vision devices and the use of PRL (Legge et al., 1985).

Researchers have proposed several treatment options for the rehabilitation of reading and visual exploration impairments in patients with central or peripheral visual

field loss including optical aids, environmental modifications and perceptual training (Chopdar et al., 2003; Herse, 2005; Parmeggiani et al., 2011; Plank et al., 2014). The recent rehabilitation approach using visual compensatory training that focuses on the re-establishment of an efficient eye movement strategy has also been proposed (Ivanov et al., 2016; Liu et al., 2007; Plank et al., 2014); patients rehabilitate themselves by encouraging the development of more organised and effective eye movements using a simple visual compensatory training programme which can be completed either in a clinic or at their home. This type of behavioural training has long been recognized as beneficial for AMD patients (Pijnacker, Verstraten, van Damme, Vandermeulen, & Steenbergen, 2011). Seiple and colleagues (2011) compared the effectiveness of eccentric viewing training, eye movement training and perceptual learning using rapid serial visual presentation (RSVP), and they concluded that eye movement training led to the greatest enhancement in reading speed. Interestingly, an fMRI study revealed structural changes in the cerebellum (increased grey and white matter density) following eye movement training which directly correlated with an improved reading speed and fixation stability (Rosengarth et al., 2013).

A study on the effects of visual compensatory training on retinitis pigmentosa patients was recently conducted in a controlled trial by Ivanov and co-workers (2016). They reported a promising therapeutic impact of exploratory saccade training among a group of 14 patients with retinitis pigmentosa; participants demonstrated faster visual search and improved mobility, benefits which were persistent up to 6 weeks post-training. Unfortunately, the reading impairment was not trained using the same compensatory approach. Yoshida and colleagues (2014) did train reading impairment among retinitis pigmentosa subjects and found that reading performance can be improved using eye movement training. The training that was conducted at home for a duration of 8 to 10 months, 5 minutes per day using horizontally written print, resulting

in a reduction in the saccade frequency and enhancement in the fixation of the target letter, indicating faster reading speed. Brain activations recorded via fMRI in this study reported increased activity in the frontal eye fields (FEFs) and parietal eye fields (PEFs), which are responsible in regulating working memory, attention and eye movements, supporting the positive effect of eye movement training on reading performance and the neural substrates involved in the behavioural improvement. To the best of our knowledge, visual compensatory training has never been employed to address the retinopathy of prematurity patients with a manifested tunnel vision. Since retinopathy of prematurity is a retinal disease that causes the tunnel vision, we assumed that the visual difficulties experienced by retinopathy of prematurity patients may be the same as retinitis pigmentosa patients. Therefore, this is the first study to report the benefit of such training on their reading and visual exploration impairments.

6.1.4 The aim of the present study

It has been clearly stated that visual search and reading are greatly impaired in patients with partial visual field defects regardless of the location of the field loss. The impairment of these skills was directly associated with the defective eye movements in most cases, and therefore compensatory training has been suggested in several studies to ameliorate the impairments. However, the evidence about its effectiveness is still lacking and the training is not widely accessible and available for use.

The DREX programme has been demonstrated as an effective treatment for rehabilitation of reading and visual search impairments among patients with HVFDs in the previous clinical trials (Aimola et al., 2014; Lane et al., 2010) and also in the recent study (see Chapter 2). At present, we do not know if the DREX training programme can also benefit those who suffer from other types of partial visual field loss like central visual field loss or tunnel vision. Therefore, as a proof of principle study, this case

series explored the efficacy of DREX in the rehabilitation of visual exploration and reading impairments of patients from three different groups of partial visual field loss: tunnel vision, central visual field loss and bitemporal visual field loss resulting from ocular and non-ocular disorders like retinitis pigmentosa, retinopathy of prematurity, age-related macular degeneration (AMD), and pituitary gland tumour. If successful, DREX can be one of the alternatives for the rehabilitation of the common eye diseases which can cause inevitable visual disabilities.

Co-morbid visual acuity and contrast sensitivity impairments are among the factors that could influence the outcomes of vision rehabilitation of the chronic eye diseases including AMD (Jacko, Barreto, Marmet, et al., 2000; Mackenzie et al., 2002). Frequently, visual field loss, which is the main visual characteristic of AMD (Nilsson et al., 2003; O'Neill et al., 2001), may be accompanied by reduced visual acuity (McFadzean et al., 1991; Rowe et al., 2009) and is highly associated with reduced contrast sensitivity (De Luca, Spinelli, & Zoccolotti, 1996; Ross, Bron, & Clarke, 1984). Therefore, knowledge of these specific co-morbid conditions is important for therapists or clinicians whose patients consist mainly of older adults, as decision-making concerning treatment and its outcome may be affected (Wolff, Starfield, & Anderson, 2002). Since participants recruited for this case series differed in their types of visual field defects, their visual acuity and contrast sensitivity level are likely to vary as well, therefore these factors have been addressed and investigated in the present study.

6.2 Methods

6.2.1 Study design

In this case series, five participants with partial visual field loss were trained using the DREX programme. Participants were allocated into one of three case

categories, according to the types of visual field defect that participants had; tunnel vision, central scotoma, and bitemporal visual field defect. The characteristics of each participant, such as the size of residual visual field and cause of visual field defect, were summarised and compared within the case categories. The effects of DREX training on visual exploration, reading, and activities of daily living, and the factors that may influence the training outcomes were also reported.

All assessments and training procedures included in this case-series were also used in Study 1 (chapter 2) and followed the guidelines and protocols that were approved by the NHS NRES Committee North East - Newcastle and North Tyneside 1 (REC reference: 15/NE/0351). Ethical approval for the case-series was also obtained from the departmental ethics committee at Durham University. Written consent was acquired during the baseline assessment visit before conducting any assessments or training tasks, and participants were briefed about the study procedures and possible impacts of the training.

6.2.2 Participants

Four participants were referred by optometrist or rehabilitation worker from Sight Services[1] after their medical and ocular conditions had stabilised, and one participant self-referred. Participants were classified based on their type of visual field loss: tunnel vision, (n = 2); central visual field loss (n = 2); bitemporal visual field loss (n = 1), which was confirmed by their medical records and the result of perimetry conducted during the baseline assessment. Participants provided medical documentation regarding their diagnosis of visual field defect, recent eye care received, and detailed optometric evaluation, if any, such as refractive assessment, ocular health assessment

[1] Sight Service is a local charity based in the North East of England, which support visually impaired people living in Gateshead, South Tyneside and surrounding areas.

and any low vision aids prescription. The details of participants' characteristics are reported in the results section.

6.2.3 Assessments

The assessment of the primary outcome measures: visual exploration and reading performance, and the subjective perception on participants' ability to perform basic activities of daily living using the Visual Impairment Questionnaire (VIQ), were measured during the baseline assessment (A_1), and then repeated during post-exploration training (Assessment 2, A_2), and post-reading training assessments (Assessment 3, A_3). The additional optometric tests (description below) were conducted only during A_1. All assessments were conducted at Sight Services, except one participant with AMD who preferred to complete the assessments at their home. The assessments took approximately one hour in total, and breaks were offered as necessary between tasks to minimise fatigue.

There were three main types of assessments included in this case-series. The assessment tasks were completed in a pseudo-random order and counterbalanced across the participants.

6.2.3.1 Primary assessments.

6.2.3.1.1 Find-the-number search task

See the details of the assessment in Study 1 (pp. 47)

6.2.3.1.2 Paper-based reading task

See the description of the assessment in Study 1 (pp. 48)

6.2.3.1.3 Visual Impairment Questionnaire (VIQ)

See the description of the assessment in Study 1 (pp. 52)

6.2.3.2 Additional optometric tests

6.2.3.2.1 Presenting visual acuity (VA)

The presenting VA for distance and near were tested using a 4-metre logMAR chart and an ETDRS 2000 series chart, which were tested monocularly and then converted into a 6-metre Snellen notation. The near presenting VA was tested at 40 cm, and was measured with whatever refractive correction the individual is using if any (Dandona & Dandona, 2006). The distance presenting VA was not done for one AMD participant (Participant 3) as she was not able to attend the testing at Sight Services where the 4-metre logMAR chart was set up. Thus, the distance VA was taken from her best-corrected visual acuity (BCVA) testing result in the medical records. The near presenting VA for that participant was tested at her home using the portable near ETDRS 2000 series chart. Only accurate near presenting VA was crucial for this study as all of the assessment tasks and training were done at near distance. BCVA was regarded as the VA obtained with the best probable refractive correction (Dandona & Dandona, 2006). In this case series, the presenting VA was preferable over the BCVA as participants can rehabilitate themselves using their habitual vision, either with spectacles or not, that they use to perform all daily activities. All participants required spectacles during the vision testing, therefore they were asked to use their spectacles during both assessments and training.

6.2.3.2.2 Contrast sensitivity test

Contrast sensitivity is a vital aspect of vision that provides useful information with regards to visual function which may not be revealed by standard VA measurement

(Hirvela, Koskela, & Laatikainen, 1995; Oomachi et al., 1986; Rubin et al., 1997), and it also gives insight into quality of life and disability (Owsley, 2003). In this case series, the contrast sensitivity testing was done using the MARS Letter Contrast Sensitivity chart which has several advantages over the standard Pelli Robson Contrast Sensitivity chart, such as a portable and smaller testing chart (Dougherty, Flom, & Bullimore, 2005). Therefore, it is more convenient to be used for home testing. Furthermore, the MARS Letter Contrast Sensitivity chart also has excellent agreement with, and good validity compared to, the Pelli Robson Contrast Sensitivity test (Dougherty et al., 2005; Haymes et al., 2006).

The Mars Letter Contrast Sensitivity test measures approximately 23 × 36 cm and is printed on resin-coated paper. It entails of 48 letters, 1.75 cm high, arranged in eight rows of six Sloan letters each which declines in contrast across and down the chart by a constant factor of 0.04 log units; the contrast varies from 91% (0.04 log units) to 1.2% (1.92 log units). A lower percentage of contrast sensitivity indicates better contrast sensitivity level. Each letter subtends 2° at the test distance of 50m (Arditi, 2005). The test was performed with participants' presenting VA, therefore spectacles were worn if participants habitually used them for accomplishing their routine near tasks.

6.2.3.2.3 Visual field test

The extent of visual field loss in participants (except Participant 3) was measured using a manual Goldmann kinetic perimetry. The Goldmann kinetic perimetry test was not done on Participant 3 because she was tested at home. Therefore, the changes of the visual field at the centre/macular area were assessed using an Amsler grid test, which is portable. Only Participant 3 and 4 were required to perform the Amsler grid test because they had central visual field loss (AMD).

The Amsler chart provides meaningful information about the quality of central vision, mainly the 20 degrees of visual field surrounding central fixation (Crossland & Rubin, 2007). While Goldmann kinetic perimetry reported the actual size of the remaining visual field, the Amsler grid described the subjective characteristics of the visual field defect at the macular region including fuzzy or distorted vision and dark areas (scotomata) at the centre. The Amsler chart consists of a 10 × 10 cm square with a grid containing 400 single squares. The segmenting vertical and horizontal lines are 0.5 cm apart in which each square indicates an angle of 1°. During the testing, participants were asked to fixate a central spot which is located in the centre of the grid (Figure 6.3; Amsler, 1953). When the participants fixated on the central dot at a distance of 30 cm, they were asked to report any abnormalities on the grid which included distortions, blurriness, or missing lines.

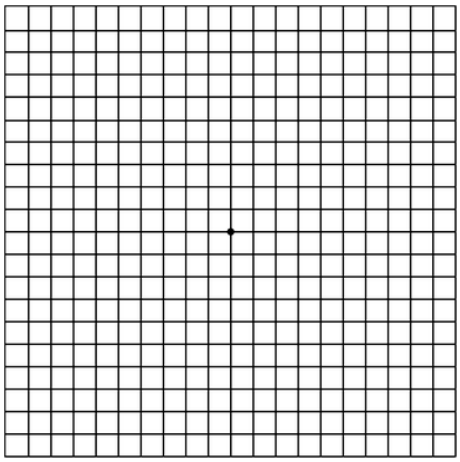


Figure 6.3 The example of Amsler grid (Schwartz & Loewenstein, 2015). Not to scale.

The Goldmann kinetic perimetry was used to measure the full extent of the visual field in participants with tunnel vision, bitemporal visual field defects, and estimation of scotoma size for Participant 4. With a background illuminance of 10cd/m^2, a target of III4e was projected on to the inside of the illuminated bowl. No filter was used as the brightness of the target used was sufficiently good to be detected

by the participants. Participants with spectacles were asked to remove them during the testing to assist the evaluation of peripheral visual field more accurately. The advantage of using a manual perimeter was the examiner can interact with patients during the testing to improve their concentration and can monitor their fixation during the testing especially if patients are partially sighted (Dersu, Wiggins, Luther, Harper, & Chacko, 2006).

6.2.4 Training procedures

After the baseline assessment, A_1, participants received the visual exploration training followed by reading training. Participants received a demonstration on how to perform the training and then they completed it independently. Personalised modifications such as the number of trials in each block, brightness of the display, and sensitivity of the touchscreen devices were done during the initial visit according to each participant's visual status and preference. The details of the training were described previously in Study 1 (pp. 53-59). The duration of the training was approximately 12 weeks (6 weeks for each training type). All participants completed the training using a touchscreen tablet at their home.

6.3 Results

6.3.1 Participant 1

6.3.1.1 Individual characteristics

Participant 1 suffered from retinopathy of prematurity since childhood and described her visual field as 'normal' despite a marked tunnel vision observed from the Goldmann perimetry testing (see Figure 6.4). She reported being able to read comfortably and accurately but only for a short time. She found that her spectacles were

still helpful for aiding most of the near tasks such as reading and carrying out her daily routines. The chief problems that she experienced were difficulty with independent navigation in a crowded space and crossing the busy road. She also was not able to identify and avoid the obstacles very well. Her personal systemic health was otherwise unremarkable. The individual characteristics of Participant 1 are reported in Table 6.1.

Table 6.1

The characteristics of the participant that include their visual field defects and vital visual functions.

	Participant 1
Demographic information	37 years old; female; right handed
Type of VFD	Tunnel vision
Cause of VFD	Retinopathy of Prematurity (ROP) – stage 3
Duration of VFD (years)	37
Size of remaining VF in the best eye (°)[a]	35
Type of refractive error[b]	High myopia
Presenting VA in the best eye[c]	
Distance	6/7.5
Near	6/6 (bifocal spectacle)
Contrast sensitivity	MARS 2.5%; normal contrast sensitivity
Training	Reading and visual exploration training
Mode	Touchscreen tablet
Adjustment on the device[*]	None

Note Abbreviation: VFD = visual field defect; VF = visual field; VA = visual acuity

[a]The size of visual field was measured as the distance between the central of visual field and the furthest point which the target was first detected along the horizontal axis either on the right- or left-hemifield.

[b]Participant 1: Right eye refraction = -7.25DS/-1.00DC × 35° (ADD = +2.00DS); Left eye refraction = -8.25DS/-0.75DC × 60° (ADD = +2.00DS).

The type of refractive error was determined based on spherical equivalence estimation of the best eye.

[c]Presenting VA was measured using patients' current spectacles, if any, during the assessment session.

Best eye was determined based on the best monocular VA - Best eye for Participant 1 was left eye

[*]Personalised adjustment on the device was done if the clarity and visibility of the items displayed was poor. The adjustments include modifying display brightness and contrast.

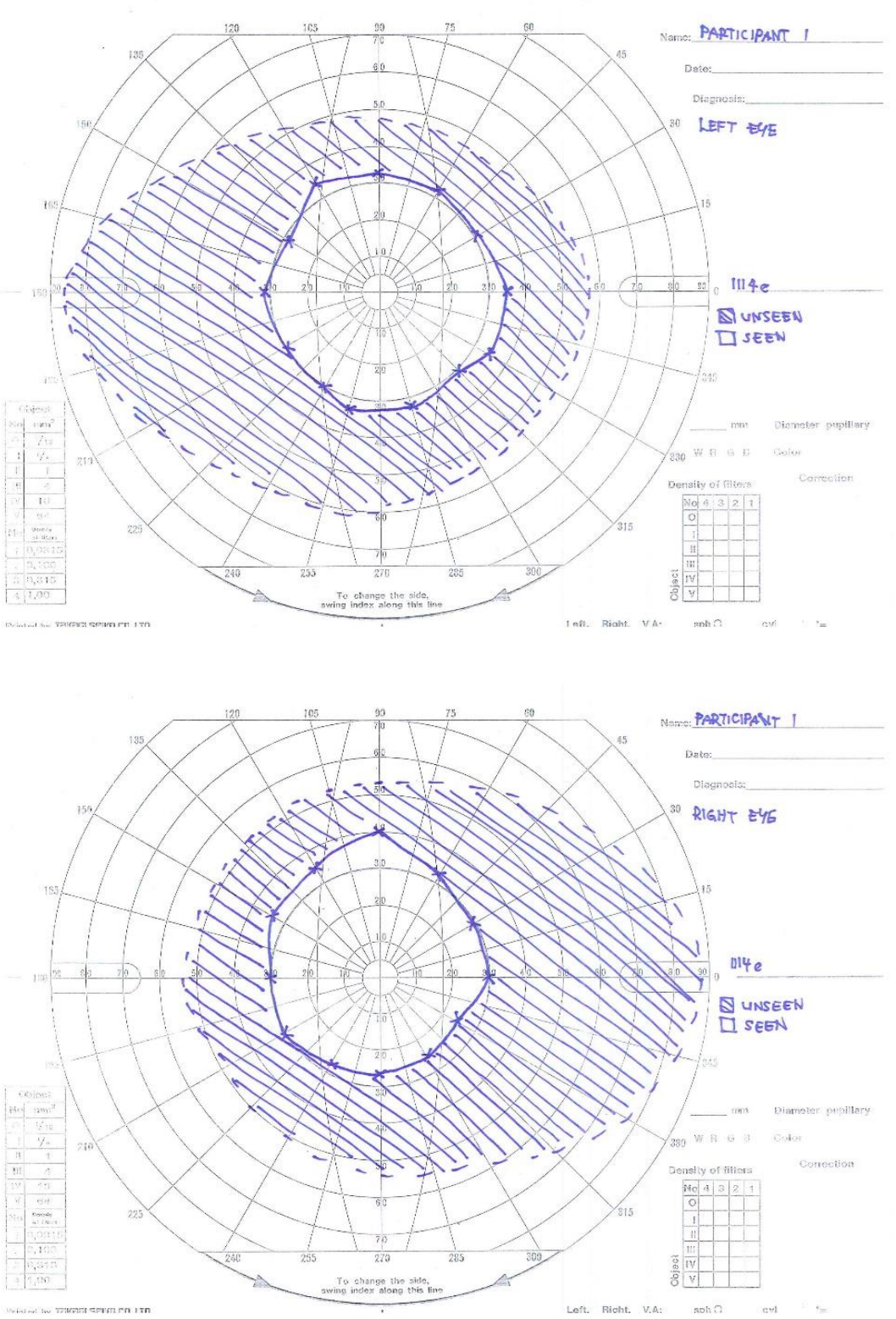


Figure 6.4 Goldmann perimetry results for Participant 1 (upper - left eye and lower – right eye). Not to scale.

6.3.1.2 Outcome measures

6.3.1.2.1 Visual exploration

In the find-the-number search task, a large improvement in search speed was observed after exploration training: Participant 1 was 33.5% faster in her visual exploration performance after the exploration training (see Table 18). However, little improvement in the search speed was revealed after the reading training; the mean reaction before and after reading training showed only 0.3% change (see Table 6.2).

Table 6.2

The mean result for each of the assessment tasks for Participant 1

	Assessment[a]	Find-the-number search		Reading
		RT (ms)[$]	Accuracy (%)	(wpm)[α]
Participant 1	A_1	2454.53	100	78
	A_2	1632.26	100	81
	A_3	1627.52	100	95

Note. Abbreviation: RT = mean reaction time; ms = millisecond; s = second; wpm = words per minute
[a]A_1 = pre-training; A_2 = post-visual exploration training; A_3 = post-reading training
[$]Lower RT means faster visual exploration speed
[α]Higher wpm means faster reading speed

6.3.1.2.2 Reading

Reading performance improved after the DREX training (faster reading speed), with greater increment in the corrected reading speed observed during the post-reading training (17.3%) relative to the post-visual exploration training (3.8%; see Table 6.2).

6.3.1.2.3 Visual Impairment Questionnaire (VIQ)

The participant reported subjective improvement in five out of ten activities asked in the VIQ after the DREX training had finished: Seeing objects, reading, finding object in the room, finding object on the table, and avoiding obstacles. The remaining five items/activities like finding the way at home and crossing the road were generally

unchanged. In terms of individual item scores, seeing objects and finding objects on the table were ranked as highly improved items (see Table 6.3).

Table 6.3

Table illustrating the scoring for each item of the Visual Impairments Questionnaire (VIQ) for Participant 1 baseline, A_1 and post-training, A_3 assessments.

	Participant 1	
	Baseline, A_1	Post-training, A_3*
Seeing objects	**4**	**1**
Bumping into obstacles	**3**	**2**
Losing way	3	3
Find objects on a table	**3**	**0**
Find objects in a room	**2**	**1**
Find objects in a supermarket	2	2
Using public transport	2	2
Finding way at home	1	1
Crossing the street	2	1
Reading	**3**	**1**

Note. Lower scores mean less impairment (maximum score = 4; minimum score = 0).

6.3.2 Participant 2

6.3.2.1 Individual characteristics

Participant 2 was not a good reader due to a very small amount of remaining central vision and blurred vision at near distance that she had due to progressive retinitis pigmentosa. She did not use spectacles very often because she claimed that it was not sufficient to aid her vision, but she occasionally used a handheld magnifier for reading a normal print size such as a newspaper. The main concern that she had was her reading speed was very slow and she frequently omitted words while reading long text. In terms of navigating around, she relied mostly on her guide dog or a walking cane to assist her mobility. Consequently, she reported that she did not have much problem avoiding obstacles or finding a specific object within her familiar surroundings. The individual

characteristics of Participant 2 are reported in Table 6.4, and Figure 6.5 shows the result of the Goldmann perimetry tests.

Table 6.4

The characteristics of the participant that include their visual field defects and vital visual functions.

	Participant 2
Demographic information	55 years old; female; right handed
Type of VFD	Tunnel vision
Cause of VFD	Retinitis Pigmentosa (RP)
Duration of VFD (years)	36
Size of remaining VF in the best eye (°)[a]	10
Type of refractive error[b]	Low myopia
Presenting VA in the best eye[c]	
Distance	6/38
Near	6/30 (reading spectacle)
Contrast sensitivity	MARS 4.4%; noticeable contrast sensitivity loss
Training	Reading and visual exploration training
Mode	Touchscreen tablet
Adjustment on the device[*]	Increase display brightness and contrast

Note Abbreviation: VFD = visual field defect; VF = visual field; VA = visual acuity

[a]The size of visual field was measured as the distance between the central of visual field and the furthest point which the target was first detected along the horizontal axis either on the right- or left-hemifield.

[b]Participant 2: Right eye refraction = -1.00DS (ADD = +2.50DS); Left eye refraction = -1.50DS (ADD = +2.50DS)

The type of refractive error was determined based on spherical equivalence estimation of the best eye.

[c]Presenting VA was measured using patients' current spectacles, if any, during the assessment session.

Best eye was determined based on the best monocular VA - Best eye for Participant 2 was right eye.

[*]Personalised adjustment on the device was done if the clarity and visibility of the items displayed was poor. The adjustments include modifying display brightness and contrast.

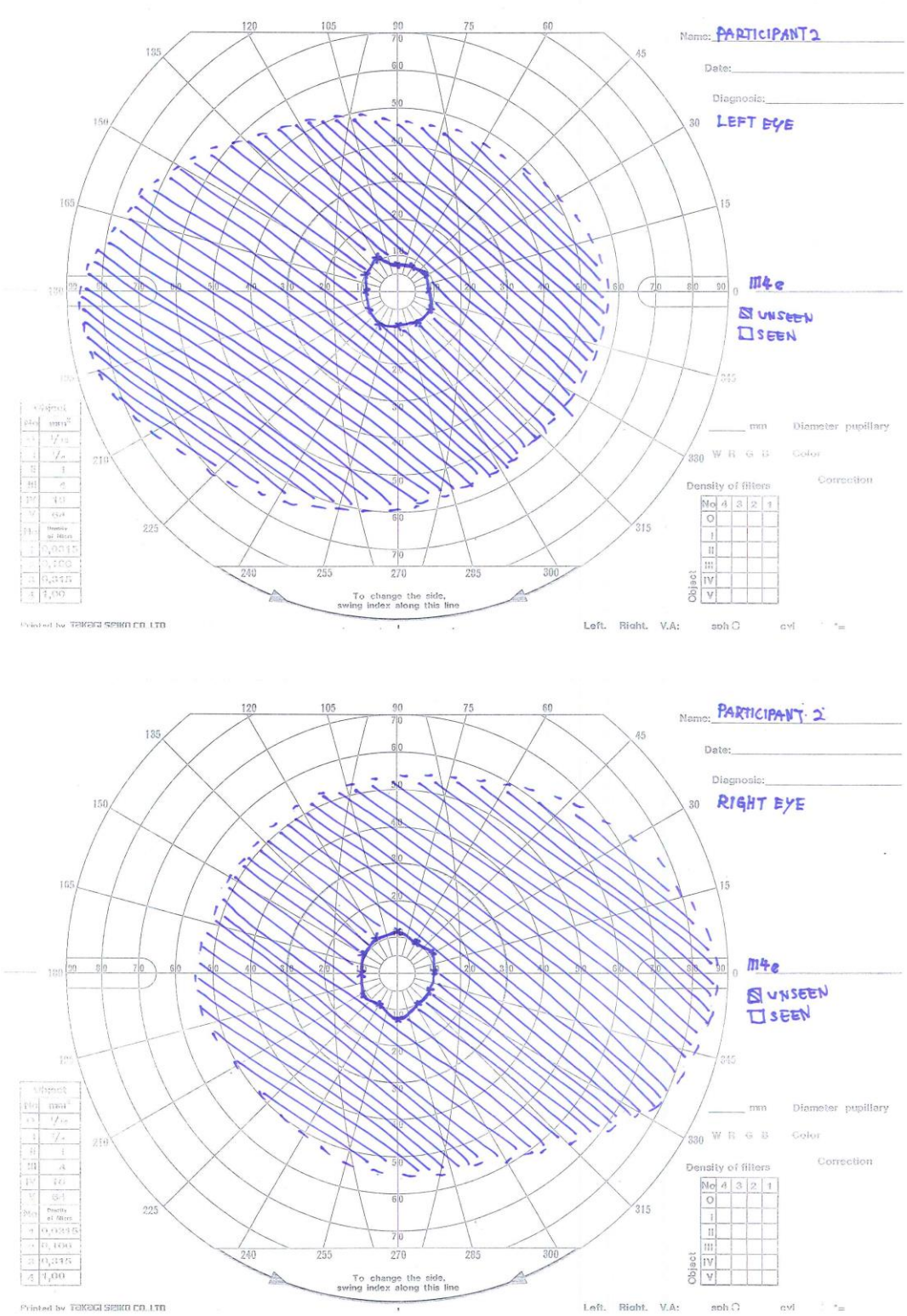


Figure 6.5 Goldmann perimetry results for Participant 2 (upper - left eye and lower – right eye). Not to scale

6.3.2.2 Outcome measures

6.3.2.2.1 Visual exploration

Participant 2 started with noticeably slow search performance in the find-the-number search task (mean RT was 4827.05 ms at A_1; see Table 6.5). Her search performance improved firstly after exploration training, and also after reading training, indicating a positive effect of both types of training on visual exploration. The improvement in visual search speed was greater after the visual exploration training compared to the visual search speed after the reading training; the mean RT decreased by 36.6% and 11.7% respectively.

Table 6.5

The mean result for each of the assessment tasks for Participant 2.

	Assessment[a]	Find-the-number search		Reading
		RT (ms)[$]	Accuracy (%)	(wpm)[α]
Participant 2	A_1	4827.05	98	41
	A_2	3058.07	98	45
	A_3	2701.80	95	60

Note. Abbreviation: RT = mean reaction time; ms = millisecond; s = second; wpm = words per minute
[a]A_1 = pre-training; A_2 = post-visual exploration training; A_3 = post-reading training
[$]Lower RT means faster visual exploration speed
[α]Higher wpm means faster reading speed

6.3.2.2.2 Reading

The reading performance improved after the DREX training which was markedly faster after the reading training than the visual exploration training; the changes in the corrected reading speed after visual exploration and reading training were 9.8% and 33.3% correspondingly (see Table 6.5).

6.3.2.2.3 Visual Impairment Questionnaire (VIQ)

The participant reported subjective improvement in three out of ten items asked in the VIQ after the DREX training had finished: Seeing objects, reading, and finding objects on a table (see Table 6.6). All other items/activities were rated as the same as before training, except for finding object in a supermarket which declined slightly.

Table 6.6

Table illustrating the scoring for each item of the Visual Impairments Questionnaire (VIQ) for Participant 2 baseline, A_1 and post-training, A_3 assessments.

	Participant 2	
	Baseline, A_1	Post-training, A_3*
Seeing objects	**2**	**1**
Bumping into obstacles	3	3
Losing way	2	2
Find objects on a table	**3**	**2**
Find objects in a room	3	3
Find objects in a supermarket	2	3
Using public transport	4	4
Finding way at home	2	2
Crossing the street	3	3
Reading	**4**	**2**

Note. Lower scores mean less impairment (maximum score = 4; minimum score = 0).

6.3.3 Participant 3

6.3.3.1 Individual characteristics

Participant 3 noticed a distorted and blurred vision, worse in the right eye, for about 3 months before the baseline assessment visit. She was diagnosed with bilateral wet AMD which was more severe in the right eye and was bilaterally pseudophakic (decentred intraocular lens in the right eye was reported but did not affect vision). She had no problem with mobility and other basic activities, but recently gave up reading

due to constant blurring and distorted vision which was confirmed by the Amsler chart test result. The individual characteristics of Participant 3 are reported in Table 6.7.

Table 6.7

The characteristics of the participant that include their visual field defects and vital visual functions.

	Participant 3
Demographic information	72 years old; female; right handed
Type of VFD	-
Cause of VFD	Wet AMD
Duration of VFD (years)	0.25
Size of scotoma in the best eye (°)[a]	-
Type of refractive error[b]	Low myopia
Presenting VA in the best eye[c]	
Distance	6/7.5
Near	6/6 (reading spectacle)
Contrast sensitivity	MARS 4.8% (noticeable contrast sensitivity loss)
Training	Reading and visual exploration training
Mode	Touchscreen tablet
Adjustment on the device[*]	None

Note Abbreviation: VFD = visual field defect; VF = visual field; VA = visual acuity

[a]The size of scotoma was measured as the diameter of scotoma along the horizontal axis using the Amsler grid estimation. Participant 1 did not perceive any scotoma within the 20° of Amsler grid.

[b]Participant 3: Right eye refraction = -0.25DS/-1.50DC × 95° (ADD = +1.50DS); Left eye refraction = -0.25DS/-1.50DC × 90° (ADD = +1.50DS)

The type of refractive error was determined based on spherical equivalence estimation of the best eye.

[c]Presenting VA was measured using patients' current spectacle, if any, during the assessment session. Distance VA for Participant 3 was reported based on her BCVA. Best eye was determined based on the best monocular VA - Best eye for Participant 3 was left eye.

[*]Personalised adjustment on the device was done if the clarity and visibility of the items displayed was poor. The adjustments include modifying display brightness and contrast.

6.3.3.2 Outcome measures

6.3.3.2.1 Visual exploration

There was no substantial change in the visual exploration performance after visual exploration or reading training revealed by the find-the-number search task (see Table 6.8). The search accuracy remained high in all assessment sessions.

Table 6.8

The mean result for each of the assessment tasks for Participant 3.

	Assessment[a]	Find-the-number search		Reading
		RT (ms)[$]	Accuracy (%)	(wpm)[α]
Participant 3	A_1	2207.80	100	98
	A_2	2334.20	96	103
	A_3	2253.85	100	115

Note. Abbreviation: RT = mean reaction time; ms = millisecond; s = second; wpm = words per minute
[a]A_1 = pre-training; A_2 = post-visual exploration training; A_3 = post-reading training
[$]Lower RT means faster visual exploration speed
[α]Higher wpm means faster reading speed

6.3.3.2.2 Reading

Reading speed improved after the DREX training. Participant 3 read faster after training, improving by 5.1% after visual exploration training and then 11.7% after reading training (see Table 6.8).

6.3.3.2.3 Visual Impairment Questionnaire (VIQ)

The participant reported improvement in only two out of ten items asked in the VIQ: finding objects on a table and reading (see Table 6.9). All other items/activities were rated as the same as before training.

Table 6.9

Table illustrating the scoring for each item of the Visual Impairments Questionnaire (VIQ) for Participant 3 baseline, A_1 and post-training, A_3 assessments.

	Participant 3	
	Baseline, A_1	Post-training, A_3*
Seeing objects	2	2
Bumping into obstacles	2	2
Losing way	2	2
Find objects on a table	**3**	**1**
Find objects in a room	1	1
Find objects in a supermarket	2	2
Using public transport	0	0
Finding way at home	1	1
Crossing the street	2	2
Reading	**2**	**0**

Note. Lower scores mean less impairment (maximum score = 4; minimum score = 0).

6.3.4 Participant 4

6.3.4.1 Individual characteristics

Participant 4 suffered from bilateral wet AMD for more than 10 years. The Amsler chart test revealed a prominent, dense central scotoma of approximately 10-degree size, measured horizontally, in each eye. Figure 6.6 shows the location and size of the scotoma in right and left eyes. The participant reported being able to navigate fairly well in familiar surroundings, only occasionally bumping into items or obstacles. He had major difficulty with reading which was described as slow and inefficient; missing words was very common. He was prescribed with a self-illuminated handheld magnifier, but he rarely used it because it did not produce a comfortable reading, small field of view and did not improve his reading as much as he expected from an optical aid. The individual characteristics of Participant 4 are reported in Table 6.10.

Table 6.10

The characteristics of the participant that include their visual field defects and vital visual functions.

	Participant 4
Demographic information	71 years old; male; right handed
Type of VFD	Bilateral central scotoma
Cause of VFD	Wet AMD
Duration of VFD (years)	10
Size of scotoma in the best eye (°)[a]	10
Type of refractive error[b]	Low hyperopia
Presenting VA in the best eye[c]	
Distance	6/15
Near	6/38 (multifocal spectacle)
Contrast sensitivity	MARS 12.0% (contrast enhancement)
Training	Reading and visual exploration training
Mode	Touchscreen tablet
Adjustment on the device[*]	None

Note Abbreviation: VFD = visual field defect; VF = visual field; VA = visual acuity

[a]The size of scotoma was measured as the diameter of scotoma along the horizontal axis using the Amsler grid estimation. Participant 1 did not perceive any scotoma within the 20° of Amsler grid.

[b]Participant 4: Right eye refraction = +.175DS/-0.50DC × 15° (ADD = +3.50DS); Left eye refraction = +2.00DS/-1.00DC × 125° (ADD = +3.50DS)

The type of refractive error was determined based on spherical equivalence estimation of the best eye.

[c]Presenting VA was measured using patients' current spectacle, if any, during the assessment session.

Best eye was determined based on the best monocular VA - Best eye for Participant 4 was left eye. [*]Personalised adjustment on the device was done if the clarity and visibility of the items displayed was poor. The adjustments include modifying display brightness and contrast.

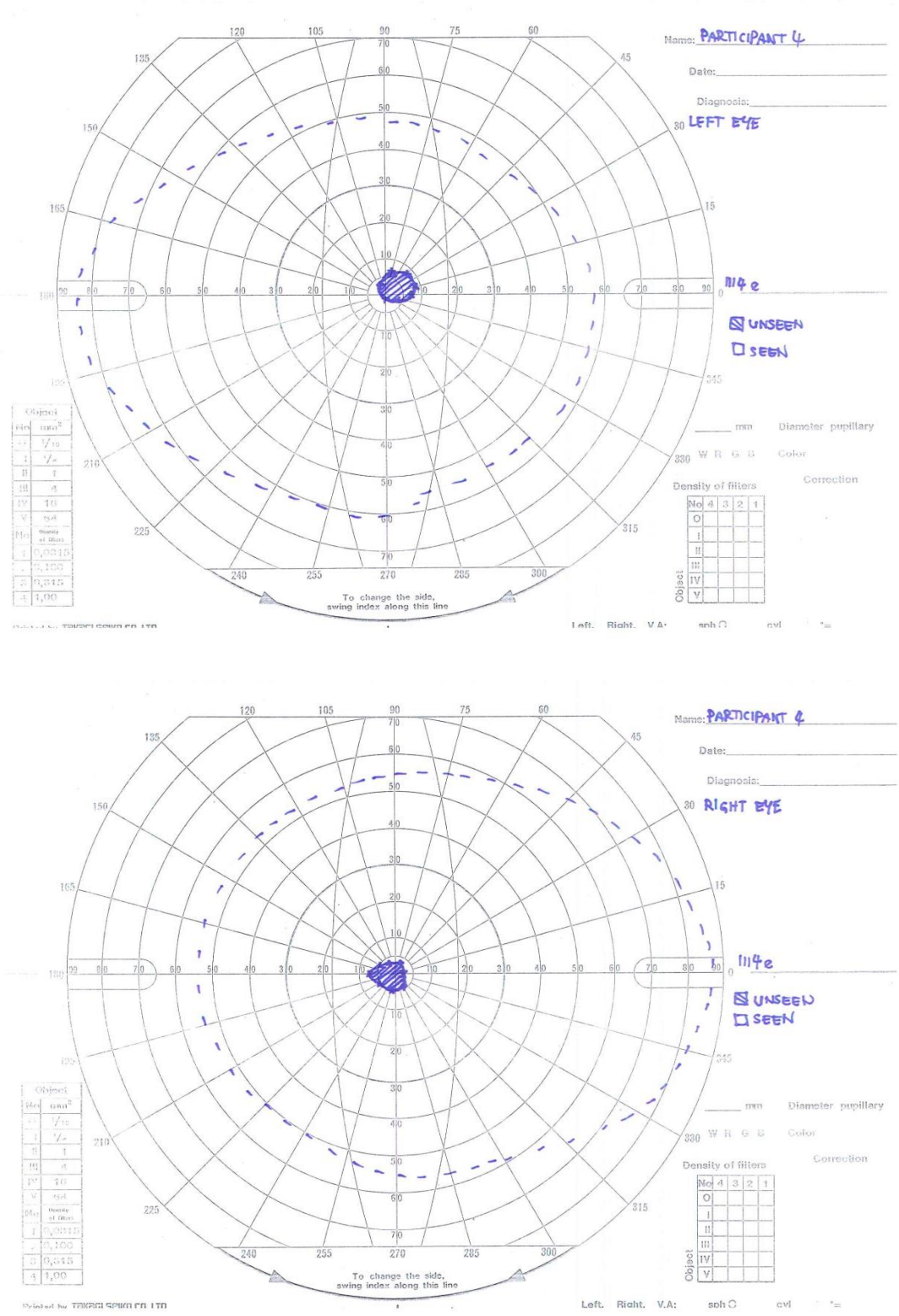


Figure 6.6 Goldmann perimetry results for Participant 4 (upper = left eye; lower = right eye). Not to scale.

6.3.4.2 Outcome measures

6.3.4.2.1 Visual Exploration

The DREX training led to improved visual exploration performance (see Table 6.11). In the find-the-number search task, the improvement in the mean RT gained after visual exploration and reading training was 12.1% and 17.2% respectively. The accuracy of the task was constantly high throughout the study.

Table 6.11

The mean result for each of the assessment tasks for Participant 4.

	Assessment[a]	Find-the-number search		Reading
		RT (ms)[$]	Accuracy (%)	(wpm)[α]
Participant 4	A_1	4394.15	97	71
	A_2	3862.50	100	76
	A_3	3195.80	98	87

Note. Abbreviation: RT = mean reaction time; ms = millisecond; s = second; wpm = words per minute
[a]A_1 = pre-training; A_2 = post-visual exploration training; A_3 = post-reading training
[$]Lower RT means faster visual exploration speed
[α]Higher wpm means faster reading speed

6.3.4.2.2 Reading

Reading performance also improved after the DREX training, with greater improvement observed after reading training (14.5%) relative to after visual exploration training (7.0%; see Table 6.11).

6.3.4.2.3 Visual Impairment Questionnaire (VIQ)

Only one item in the VIQ improved after the DREX training which was 'reading' (see Table 6.12). The score on other items remained unaffected, except for 'crossing the street' which showed a slight decline.

Table 6.12

Table illustrating the scoring for each item of the Visual Impairments Questionnaire (VIQ) for Participant 4 baseline, A_1 and post-training, A_3 assessments.

	Participant 4	
	Baseline, A_1	Post-training, A_3*
Seeing objects	3	3
Bumping into obstacles	2	2
Losing way	3	3
Find objects on a table	3	3
Find objects in a room	3	3
Find objects in a supermarket	4	4
Using public transport	2	2
Finding way at home	1	1
Crossing the street	2	3
Reading	**4**	**2**

Note. Lower scores mean less impairment (maximum score = 4; minimum score = 0).

6.3.5 Participant 5

6.3.5.1 Individual characteristics

Participant 5 was diagnosed with bitemporal visual field loss, affecting superior portions of her visual field, due to a pituitary gland tumour (see Figure 6.7). She reported that the visual field loss did improve a few days after the surgery but did not notice any further improvement in her visual field loss. The chief complaints were difficulties with navigation and finding objects in a crowded place. In general, she did not have any big issue with reading, except slightly reduced reading speed compared to before she had the visual field loss. She was generally healthy and did not have any other ocular problems. The individual characteristics of Participant 5 are reported in Table 6.13.

Table 6.13

The characteristics of the participant that include their visual field defects and vital visual functions.

	Participant 5
Demographic information	71 years old; female; right handed
Type of VFD	Bitemporal quadrantanopia
Cause of VFD	Pituitary gland tumour
Duration of VFD (years)	4.5
Visual field sparing (°)[a]	30
Type of refractive error[b]	Moderate myopia
Presenting VA in the best eye[c]	
Distance	6/9.5
Near	6/6 (reading spectacle)
Contrast sensitivity	MARS 2.1%; normal contrast sensitivity
Training	Reading and visual exploration training
Mode	Touchscreen tablet
Adjustment on the device[*]	None

Note Abbreviation: VFD = visual field defect; VF = visual field; VA = visual acuity

[a]Visual field sparing was measured as the distance between the central of visual field and the furthest point which the target was first detected along the horizontal axis either on the right- or left-hemifield in the best eye.

[b]Participant 5: Right eye refraction = -2.50DS/-0.75DC × 100° (ADD = +2.50DS); Left eye refraction = -2.25DS/-0.50DC × 50° (ADD = +2.00DS).

The type of refractive error was determined based on spherical equivalence estimation of the best eye.

[c]Presenting VA was measured using patients' current spectacle, if any, during the assessment session. Best eye was determined based on the best monocular VA - Best eye for Participant 5 was right eye.

[*]Personalised adjustment on the device was done if the clarity and visibility of the items displayed was poor. The adjustments include modifying display brightness and contrast.

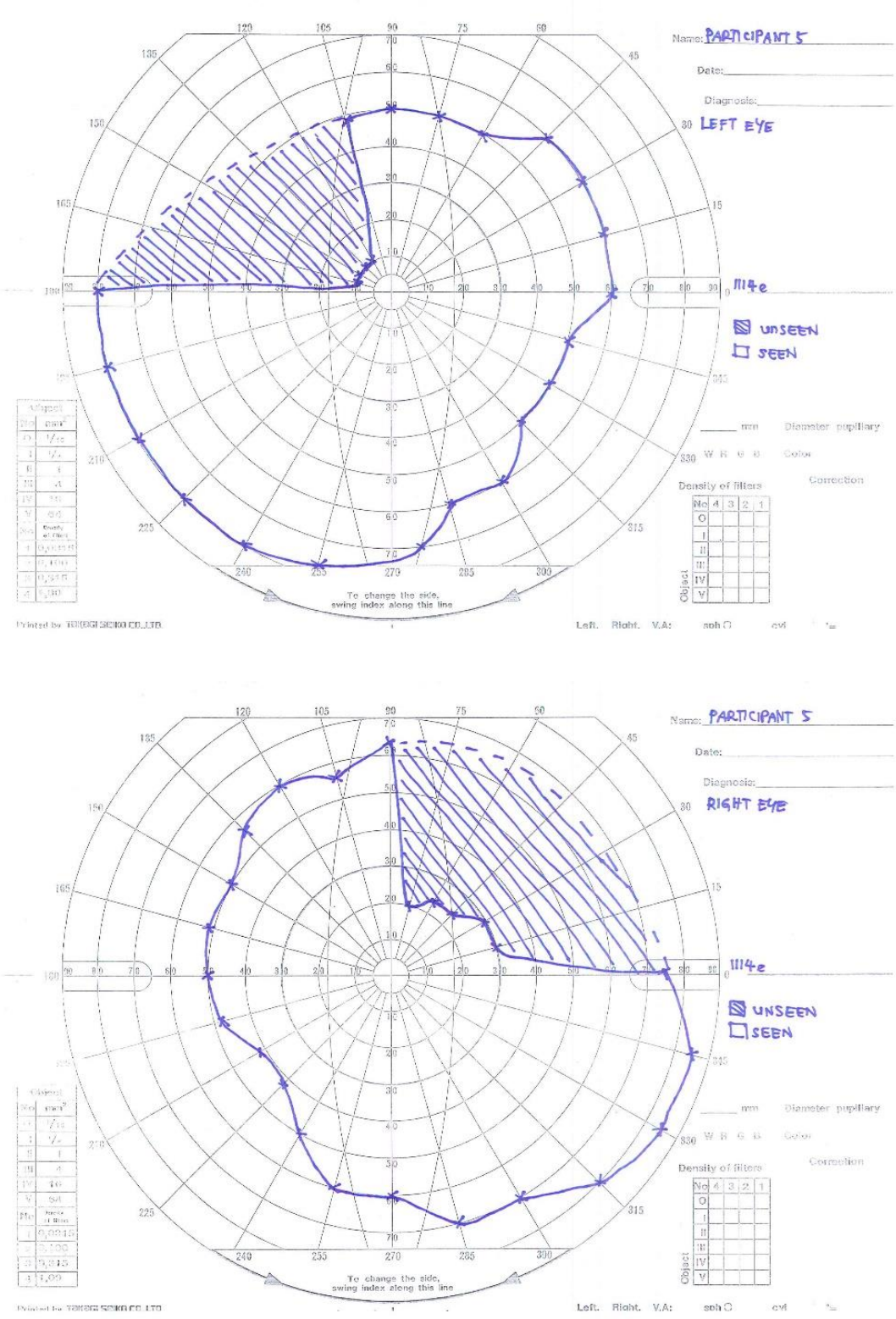


Figure 6.7 Goldmann perimetry results for Participant 5 (upper = left eye; lower = right eye). Not to scale.

6.3.5.2 Outcome measures

6.3.5.2.1 Visual exploration

Participant 5 gained improvement in visual exploration after training. The decrease in the mean RT after the visual exploration training (12.3%) was greater than the decrease observed after the reading training (8.0%; Table 6.14). The accuracy the task was constantly high throughout the study.

Table 6.14

The mean result for each of the assessment tasks for Participant 5.

	Assessment[a]	Find-the-number search		Reading
		RT (ms)[$]	Accuracy (%)	(wpm)[α]
Participant 5	A_1	2905.62	100	97
	A_2	2547.10	100	102
	A_3	2342.63	100	112

Note. Abbreviation: RT = mean reaction time; ms = millisecond; s = second; wpm = words per minute
[a]A_1 = pre-training; A_2 = post-visual exploration training; A_3 = post-reading training
[$]Lower RT means faster visual exploration speed
[α]Higher wpm means faster reading speed

6.3.5.2.2 Reading

The reading performance improved after the visual exploration and reading training, with greater change in the corrected reading speed revealed after the reading training (9.8%) compared to the change in the corrected reading speed after the visual exploration training (5.2%; Table 6.14).

6.3.5.2.3 Visual Impairment Questionnaire (VIQ)

Participant 5 reported subjective improvement in three out of ten items in the VIQ: seeing objects, losing way, and bumping into the obstacles (see Table 6.15), while the scores for the rest of the items were unchanged.

Table 6.15

Table illustrating the scoring for each item of the Visual Impairments Questionnaire (VIQ) for Participant 5 baseline, A_1 and post-training, A_3 assessments.

	Participant 5	
	Baseline, A_1	Post-training, A_3*
Seeing objects	**3**	**1**
Bumping into obstacles	**4**	**2**
Losing way	**2**	**0**
Find objects on a table	1	1
Find objects in a room	1	1
Find objects in a supermarket	2	2
Using public transport	0	0
Finding way at home	1	1
Crossing the street	2	2
Reading	2	2

Note. Lower scores mean less impairment (maximum score = 4; minimum score = 0).

6.4 Discussion

6.4.1 Tunnel vision

Two participants with tunnel vision were included in this case series: retinopathy of prematurity (Participant 1) and retinitis pigmentosa (Participant 2). Overall, these participants benefited from the DREX training, with faster and more accurate visual exploration and reading. This is in accordance with previous studies that demonstrated that saccadic training can lead to such improvements for patients with retinitis pigmentosa (Ivanov et al., 2016; Yoshida et al., 2014). The degree of improvement (percentage change in mean RT) in exploration after training did not vary largely between both participants, even though the visual impairment was greater in Participant 2, who is classified as having moderate visual impairment according to the International Classification of Disease (WHO, 2001; Vashist, Senjam, Gupta, Gupta, & Kumar, 2017). The mean RT for visual search decreased by an average of 35% after the

exploration training, which can be considered a huge improvement in the searching speed for individuals with an advanced tunnel vision. Most importantly, the improved visual exploration performance was coupled with reported enhanced ability to avoid obstacles (Participant 1) and to find objects (Participant 2), activities that require good visual exploration skill and represent meaningful changes in everyday functioning. In terms of reading performance after the reading training, Participant 2, who had more severe visual impairments, gained a greater improvement than Participant 1. This may be because Participant 1 presented with a good reading performance at baseline, and therefore she had only small room for improvement. In contrast, Participant 2 had higher chance to gain more improvement in reading as she started with very poor reading performance. The subjective improvement in the reading performance that was reported by Participant 2 was in accordance with the objective gain observed. Although only a few items in the VIQ showed improvement, the training was able to ameliorate the disability, mainly reading and visual exploration impairments, resulting from the retinopathy of prematurity and retinitis pigmentosa.

In these two cases, it was found that modifying the training setting (e.g. working or training distance) and device (e.g. display brightness) according to the patients' own preference, and the quality of associated visual functions like visual acuity and contrast sensitivity, are very important and practically useful to enhance the outcomes of the tunnel vision rehabilitation. This is especially the case when the visual field loss has progressed and severely affecting their vision. For example, Participant 2 who had 6/30 near vision could perform the training more comfortably with a higher contrast and brighter display which increased the saliency of the items. Thus, she was able to increase her focus in completing the training that eventually led to a larger training effect. Liu et al. (2007) found the similar training results when subjects with profound

visual impairment completed the visual search training after the modifications on the training were made to accommodate the poor vision.

6.4.2 Central visual field loss

Reading impairment is the most frequent problem reported by patients with AMD (Coco-Martín et al., 2017; Timberlake et al., 1987), and this is supported by the AMD participants recruited in this case series (Participants 3 and 4) who claimed that their reading performance was markedly reduced. The present study found that improvement of reading performance was observed after participants had completed the reading training from the DREX programme. The average improvement of reading speed for both participants was about 13.1% (12 wpm). Hall and Ciuffreda (2001) found that reading speed increased by 21% after auditory feedback was provided to the reading eye movement training, and other authors reported an average of 17% (Solan, Feldman, & Tujak, 1995) and 27.5% (Seiple, Szlyk, McMahon, Pulido, & Fishman, 2005) increase in reading speed after training eye movement control. Other than improvement of the reading speed, both participants also reported subjective improvement in reading post-training, indicating a benefit with respect to patient quality of life. Even relatively small improvements in reading performance, say 10 – 15 wpm increase, could be of value and impact on daily life functioning.

No improvement in the visual exploration performance was observed after DREX training in Participant 3. This participant was not severely affected by the AMD as there was no central scotoma reported by the participant, and which was confirmed by the Amsler grid test. The only complaint was distorted and reduced vision in both eyes. Therefore, it is possible that the training did not provide many benefits on her visual search because the central vision was still good (the near presenting VA was 6/6), with an intact overall visual field, to execute normal visual searching. Since Participant

3 reported a slight improvement in her ability to search for objects on the table after the training, it is possible that the training led to a general improvement of visual awareness, especially in familiar surroundings like their own home. In contrast, Participant 4's exploration did improve after training. They presented with bilateral central scotoma that could reduce the efficiency of visual search as was observed, and therefore they had greater potential to benefit in this aspect of functioning. A recent study demonstrated that the difficulty of visual search in patients with central scotoma is aggravated by the regular lack of awareness of the scotoma (Fletcher, Schuchard, & Renninger, 2012), and it is possible that the training had an effect by improving the participant's awareness. Furthermore, patients with central scotoma normally make disorganised eye movements that are of smaller amplitude relative to healthy adults (Renninger, Dang, Verghese, & Fletcher, 2008; Van der Stigchel et al., 2013). Most probably, the eye movements made were more frequent and stable after the visual exploration training, leading to enhanced visual exploration which was also observed in subjects studied by Janssen and co-worker (2016). This would be worthy of further investigation in the future to better understand the mechanism by which the training works.

It is interesting to note that the visual exploration training in the DREX training programme did not aim to enhance awareness at the central field but rather concentrating more on peripheral field awareness, but improvements were still found. Most of the eye movement training for AMD focuses in awareness of scotoma or affected central visual field (Janssen & Verghese, 2016; Nguyen, Stockum, Hahn, & Trauzettel-Klosinski, 2011; Seiple et al., 2005). Since the unique design of the training itself (at the easiest level, the target appears mostly at the centre surrounding the fovea), the participant with central visual field loss can still gain improvement in visual searching.

6.4.3 Bitemporal visual field loss

Participant 5 complained of diminished ability to navigate effectively within her environment or avoid the obstacles while walking, which resulted from bitemporal superior visual field loss. After visual exploration training, visual search performance improved, and this was greater than the improvement seen after reading training. Participant 5 not only showed a substantial increase in visual exploration speed, but also a considerable subjective improvement in her daily activities like seeing objects and navigating around. The study found that there was a slight improvement in reading speed after reading training, but this did not result in any obvious change in her reading ability that she then reported. It seems likely that the visual field sparing of 30 degrees in the best eye did not cause a huge impact on her reading performance, and indeed at baseline she did only a moderate difficulty with this task. Studies among HVFDs have addressed the advantage of having large macular sparing for better reading performance (McFadzean, Brosnahan, Hadley, & Mutlukan, 1994; Schuett, 2009; Zihl, 2010). Furthermore, the inferior visual field areas which were crucial for reading were also intact, reserving a large portion that is useful for reading.

6.4.4 General discussion and conclusion

Impaired contrast sensitivity and visual acuity may lead to reduced visual exploration and reading performance in patients with partial visual field loss. Participants 1 and 2 both have tunnel vision; however the baseline visual exploration and corrected reading speed of Participant 1 were faster than Participant 2, which could reflect the apparently more defective contrast sensitivity and visual acuity that Participant 2 suffered. This finding confirmed the earlier studies that a poor visual acuity and contrast sensitivity had a strong correlation with difficulty in reading (Sumi et al., 2000; Szlyk et al., 1997; Virgili et al., 2004) and visual exploration (Senger et al.,

2017) in retinitis pigmentosa. Similarly, the baseline assessments of two AMD cases revealed that Participant 4 was more affected by his central visual field loss than Participant 3; they had poorer performance in visual exploration and reading tasks. This may be also due to reduced near vision and contrast sensitivity level rather than just the size of scotoma itself. Although, Ergun and co-workers (2003) found that the absolute scotoma size correlated significantly with reading ability and reading speed, the impaired contrast sensitivity and near visual acuity, at certain extent, had greater influence in the reading performance (Hirvela et al., 1995; Lennerstrand & Ahlström, 1989; Loshin & White, 1984).

Knowing the effect of co-morbid visual acuity and contrast sensitivity impairment in visual field loss rehabilitation, the DREX training was conducted with participants' recent refractive correction to ensure that the image of the items displayed was clear and visible so as to not affect the training outcomes. Senger et al. (2017) stated that the accuracy of visual searching and recognising rely on the clarity of the image displayed, the sensitivity of intact visual field and integrity of the visual pathways. If the refractive correction alone was not able to produce sufficiently good image clarity and visibility, personalised modifications on the participant's tablet settings, like display brightness and contrast, were made; Participant 2 required greater display brightness and contrast in this case. Participant 2 was also advised to view the screen at a shorter viewing distance, approximately 15 cm shorter than her normal viewing distance of 30 to 40 cm, to increase the image size. In low vision practice, as an alternative to an optical magnifier, getting the object (or tablet in this case) closer to the eyes could potentially increase the retinal image size; this technique is known as relative-distance magnification (Lovie-Kitchen & Whittaker, 1998). The advantage of relative-distance magnification over relative-size magnification (optical magnifier) is that the field of view could be optimised and maintained without any interference by the

magnifier frame. This magnification strategy was not only helpful in aiding the training in retinitis pigmentosa, but also those with AMD (Wolffsohn & Eperjesi, 2005). Thus, personalised training modification is an important point. Since every patient may present with different visual characteristics and needs, the training should entail modifiable settings, mainly for the size of the display items and their contrast level, so that patients can adjust the training setting accordingly to enhance their training experience. This aspect of training will also increase the access of the training to a wider population. In addition, factors such as contrast sensitivity and visual acuity levels must be taken into consideration and assessed when training patients with visual field loss in order to minimize the unfavourable impact of these factors to the training outcomes.

This study found that mobility-related activities such as avoiding obstacles are one of the major issues encountered by participants, and compensatory eye movement training seems potentially beneficial at improving their ability to walk without bumping into things based on the promising report from the participants. Participants 1 and 5, who had tunnel vision and bitemporal visual field loss respectively, reported an improvement in their ability to avoid obstacles after the training. It is important to note that Participant 5 had a more preserved visual field at the centre and inferior regions. It is most likely that identification of obstacles at the ground became much better and easier because the visual field regions that are advantageous for mobility are still intact and larger. Earlier studies reported that mobility performance and number of bumps are correlated with the region of the affected visual field (Haymes et al., 1996; Lovie-Kitchin, Mainstone, Robinson, & Brown, 1990; Turano et al., 2004). Turano et al. (2004) found that the visual field loss involving the central and lower peripheral regions can severely affect mobility and increase the number of collisions. For Participant 1, despite a constricted overall peripheral visual field, she still gained improvement in avoiding obstacles showing that encouraging patients to gain awareness about their

visual field loss using a systematic exploration training could be very beneficial for aiding safe travel.

Among all three categories of partial visual field loss trained in this case series, the impact of DREX training seems greater in patients with tunnel vision compared to those with central or bitemporal field loss. This result indicates that having particularly good central visual acuity as well as an intact central visual field are beneficial for a successful compensatory eye movement training. In tunnel vision, patients can train their eye movement effortlessly and gain full functional benefit from the training because the items presented on the display can be seen with the remaining central visual field. However, when there is a damage in the central visual field and vision, patients might miss the target, make numerous inaccurate responses or produce longer reaction times causing the training to become less efficient. The visual search improvement gained after the training still provided remarkable benefit on participants' ability to perform other basic daily activities like seeing, searching for objects, and reading, indicating a positive impact in quality of life for users irrespective of the cause of their field loss.

The analysis of this study was done on individual patients without comparing to the normal controls. It could be more meaningful to explore empirically if there is any difference in the visual exploration and reading performance of individuals with tunnel vision relative to the controls. Furthermore, since tunnel vision patients in this study have nearly similar presentation of peripheral visual field loss as those with hemianopia or quadrantanopia in Study 1, it is likely that their performance on the outcome measures of visual exploration and reading are comparable. Due to the limited number of patients recruited in this case series, it is recommended that further evaluation is warranted in larger samples between tunnel vision and hemianopic patients.

In conclusion, there is provisional evidence that the DREX training is effective in helping to ameliorate the impairments of visual exploration and reading among

patients with tunnel vision, central and bilateral visual field loss. Most importantly, all patients can be trained using the touchscreen tablet indicating the benefit of mobile training, and it could potentially improve quality of life for many sufferers. Some modifications are recommended for the existing DREX training app, such as providing more options for the size and colour of the stimuli as well as the background contrast in order to make it a more comprehensive and user-friendly compensatory eye movement training. Future work seems warranted to investigate if such modifications are workable and beneficial to optimize the training effect in a larger samples and wider visual field pathologies.

Chapter 7

The effects of blurred vision on the visual exploration performance (Study 8) and the outcomes of visual exploration training (Study 9).

7.1 Introduction

Blurring of vision is a common impaired visual function primarily due to aging (Holden, 2008; Weale, 2003) and eye diseases like cataracts, glaucoma, age-related macular degeneration (AMD) and diabetic retinopathy (Naidoo, Govender, & Holden, 2015). Although some eye diseases like cataracts are easily treated which could restore normal visual functioning, other diseases like AMD and diabetic retinopathy are not fully treatable and could cause permanent blurring of vision (Klein & Klein, 2013; Oduntan, 2005; Pascolini & Mariotti, 2012). Sometimes, these patients are left with blur that cannot be helped even with the best optical corrections, which could greatly affect their visual search performance (Senger et al., 2017). Studies on the association between visual search and visual acuity[2] (VA) have been conducted in children aged 4 and 9 years old (Huurneman & Boonstra, 2014; Huurneman, Cox, Vlaskamp, & Boonstra, 2014; Tadin, Nyquist, Lusk, Corn, & Lappin, 2012), 9 to 18 years old (Tadin et al., 2012) and in adults aged 18 to 80 years old (Dougherty et al., 2009; Fuhr et al., 2007; Kuyk et al., 2005; Liu et al., 2007; Satgunam et al., 2012) with VA from 6/6 to 6/240[3] who suffered from various eye disorders including retinal diseases and amblyopia.

[2] Visual acuity refers to the clarity or sharpness of a person's vision. Ideally, visual acuity 6/6 indicates perfectly clear vision. When visual acuity drops (e.g. visual acuity 6/24 or 6/36), it indicates the loss of sharpness of vision, causing objects to appear out of focus and hazy. Thus, the term 'blurred vision' is interchangeable with 'reduced visual acuity'.

[3] Visual acuity of 6/240 is considered as Category 3 blindness according to the World Health Organization, International Classification of Disease (ICD)-10 revision (Vashist et al., 2017).

Patients showed prolonged search time and increased amplitude of eye movements which were directly proportional to their VA, reflecting VA as a pivotal factor that could contribute to an effective visual search process.

It has been shown that impaired visual search among visually impaired patients can be improved with training (Liu et al., 2007; Pambakian et al., 2004). Patients learn to distribute their attention more effectively over the test display, ignore irrelevant information and respond as quickly as possible to the tasks (Schuster, Rivera, Sellers, Fiore, & Jentsch, 2013; Sireteanu & Rettenbach, 2000). This adoption will enable patients to reduce the number of saccadic eye movements and eventually develop new, systematic eye movement strategies during the visual search (Kerkhoff, Münßinger, Haaf, et al., 1992b; Mannan et al., 2010; Scialfa & Joffe, 1998). Liu et al. (2007) studied the effect of visual search training on subjects with severe to profound vision loss due to retinal diseases like AMD and retinitis pigmentosa (<6/60 best corrected visual acuity, and/or <20 degrees visual field) and compared the change in the visual search speed with normal controls. The study demonstrated that training could improve visual search speed in severely visually impaired subjects by approximately 20%, which was persistent for at least 1 month after training ended. Crucially, they reported visual search training to be equally efficient in subjects with severe and profound vision loss as for those with normal vision, showing that patients with blurred vision can regain normal visual search speed if trained. However, the study did not include patients with minimal or moderate vision loss and thus the effect cannot be generalized into a wider population. On a practical note, patients who require visual search training may present with various visual characteristics and severity of vision loss, so a good training should not limit to only a certain group of patients. Therefore, knowledge about the effect of minimal to moderate blurring is important too.

Study 7 demonstrated the detrimental effect of co-morbid blurred vision on the visual search performance in patients with common eye diseases like AMD; patients with poorer VA demonstrated slower search speed. This finding however requires further investigation and a systematic quantification as to how different levels of blurred vision affect visual search performance. At present, no clear recommendation has been published about the minimum level of VA (or tolerable level of blurred vision) that could still allow the execution of efficient visual search either in normal subjects or visually impaired patients. Therefore, the first study in this chapter (Study 8) will investigate the effect of different levels of blurred vision on visual search performance. This information is not only theoretically interesting but may also have profound practical value in predicting the outcomes of visual search impairment assessment and rehabilitation via DREX training. The next study (Study 9) concentrates on the preliminary finding of Study 7 that showed a positive therapeutic effect of DREX training on patients with common eye diseases even in the presence of blur. Study 9 will investigate the effect of perceptual training under different blurring conditions on the visual search performance to quantify the conditions under which DREX can have a positive effect, at least with respect to visual search. Therefore, the finding of this study may enable a suggestion to be made about whether individuals with impaired visual search and untreatable blurred vision could benefit from the DREX training.

7.2 Study 8

7.2.1 Methods

7.2.1.1 Study design

In this mixed design study, participants completed a single session of three different visual search tasks under optically induced blurred vision. The primary

outcome measures were the mean reaction time and mean accuracy recorded for each task. Ethics approval was obtained from the Psychology department ethics committee at Durham University. All participants provided informed consent to participate in the study in accordance with the Declaration of Helsinki. Figure 7.1 below shows the overall study flow.

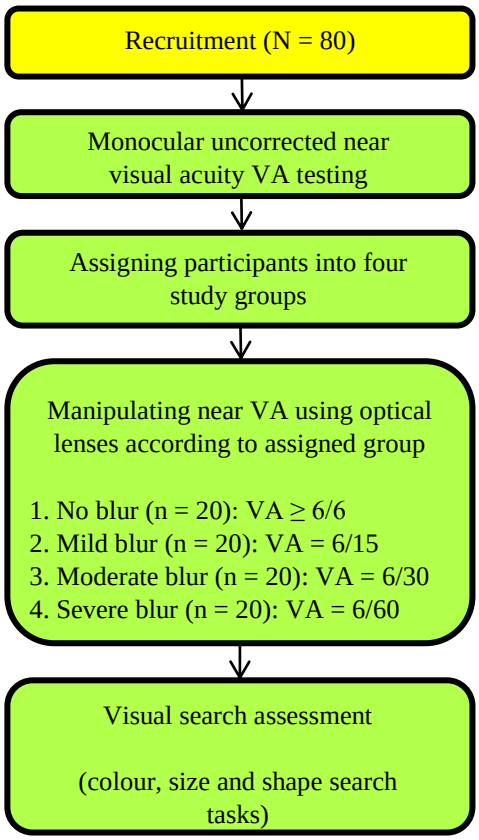


Figure 7.1 Flowchart illustrating overall study flow. VA is the abbreviation for visual acuity.

7.2.1.2 Participants

A total of 80 volunteers (16 males, 64 females) aged between 18 and 52 years (mean age = 21.35 years; SD = 4.84) were recruited from Durham University. Psychology undergraduates who participated in the study received course credit in accordance with the experiment duration. All participants were either emmetropes (presenting vision of 6/6) or had corrected-to-normal vision (6/6 or better when tested).

None of the participants reported having any history of progressive systemic or ocular pathology, or any cognitive dysfunction. Participants were asked about their knowledge about their current spectacle prescription and/or visual acuity if applicable. Overall, 40 participants did not wear any refractive correction whilst 40 participants wore spectacles, contact lenses or both.

7.2.1.3 Near vision testing and manipulations

VA for near distance was measured using a near ETDRS 2000 series chart at 40 cm. Uncorrected vision testing (e.g., without glasses or contact lenses) was completed monocularly by all participants irrespective of their current refractive statuses such as emmetropia or ametropia (e.g. myopia or hyperopia). The near VA was recorded as 6-meter Snellen equivalent. In this study, participants were randomly allocated to one of four experimental blur groups differing in best VA (see Figure 7.1): no blur group (VA = 6/6; controls), mild blur group (VA = 6/15), moderate blur group (VA = 6/30), or severe blur group (VA = 6/60).

The experimental groups were determined by manipulating participants near VA using optical lenses to obtain the desired VA according to their assigned group. In all instances, participants started with their uncorrected vision and wore a trial frame in which optical lenses were then placed. In cases where participants had emmetropia, a high diopter power of plus lens was used during the initial manipulation of near VA (blurring up to 6/60), which was used to avoid participants from memorising the near chart letters in the subsequent acuity lines. The diopter power was then reduced using an estimated method until the desired VA level was achieved. The eye was blurred monocularly so that both eyes had the same level of induced VA. In cases with participants with ametropia (unaided < 6/6), if the unaided VA was the same as their assigned group then no visual acuity manipulation was done and blank lenses inserted

into the frame. If required, their unaided VA was further blurred or partially corrected using plus or minus lenses until the desired VA was achieved for the group to which they were allocated.

7.2.1.4 Assessments

7.2.1.4.1 Colour, size and shape search tasks

E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA) was used to create the visual search test. The arrays were displayed on a 16-inch colour monitor with a refresh rate of 85 hertz and 800 × 600 resolution. A chin rest was placed 57.5 cm from the computer screen such that the display subtended 32.5° horizontally and 24.5° vertically. Responses were collected using a standard computer keyboard. The test comprised three visual search tasks, where the target item was defined by only colour, size or shape (see Table 7.1 for the specific combinations of items for each task).

Table 7.1

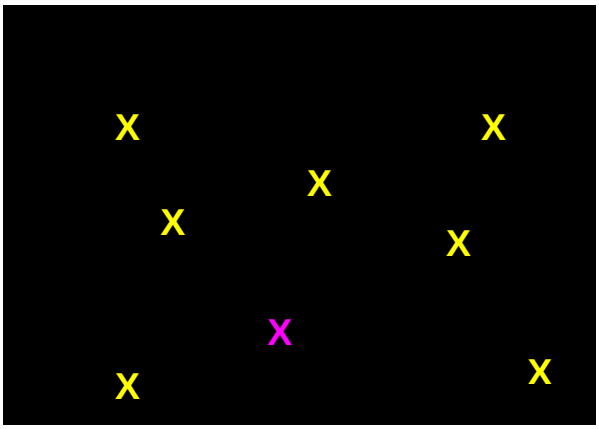
Details of the target-distractor combinations used in the colour, size and shape search tasks

Task	**Target-distractor combinations**		
	Stimuli colour	Stimuli size	Stimuli shape
Colour	C-Y, C-M, C-R, Y-M, Y-R, R-M	24-24	X-X, M-M, E-E, A-A
Size	C-C, Y-Y, M-M, R-R	20-10, 22-12, 24-14, 26-16	X-X, M-M, E-E, A-A
Shape	C-C, Y-Y, M-M, R-R	24-24	X-M, X-A, X-E, M-A, M-E, A-E

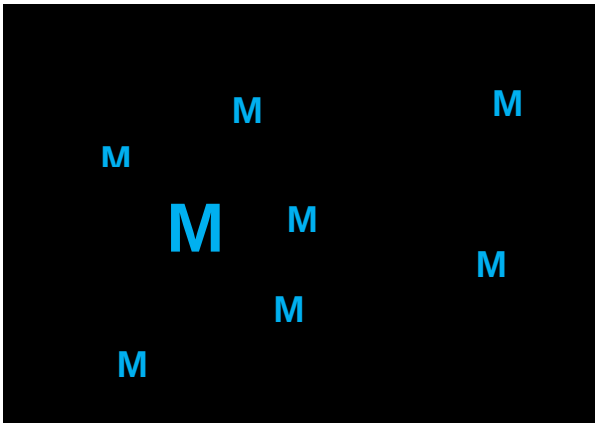
Note: Stimuli colour: C (cyan), M (magenta), R (red), Y (yellow)
Stimuli size: in point unit
Stimuli shape: X, M, E or A letter

The number of items (set-size) in each search array was 4, 8 or 12, and there were an equal number of trials for each set-size. The items in the array were always non-overlapping and the location was random. Half of the trials were target-present trials, and the other half were target-absent trials. In target-absent trials all distractors

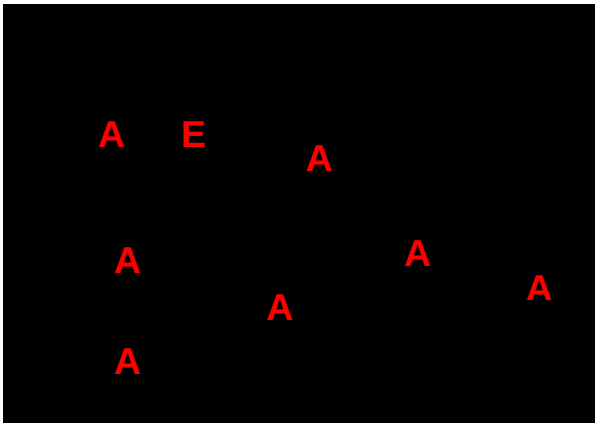
were identical. Every task consisted of a total of 240 trials, which were divided equally into two blocks. Figure 7.2 illustrates the examples of the search tasks.



a. Colour search task



b. Size search task



c. Shape search task

Figure 7.2 Diagrams illustrating three examples of a visual array used in the colour, size and shape tasks (not to scale): **a.** The target was letter 'X' in magenta among yellow distractors, **b.** The target was letter 'M' in large size among small distractors, and **c.** The target was letter 'E' among different shape distractors. Not to scale.

7.2.1.5 Procedure

After obtaining written consent and testing VA, participants were asked to complete six blocks: two blocks each of the colour, size, and shape search tasks (see Figure 7.1). The test was done under normal room illumination. While completing the tests, participants placed their head on the chin rest to minimise the head movement and maintain the test distance. During the testing, participants were required to find a specific visual target amongst a number of distractors (e.g. letters of different colours) as per the tests described above. Participants responded to the target presence or absence using a keyboard press, and the accuracy and speed of the response were recorded. Participants were instructed to perform the tests as accurately and as quickly as possible. A break between blocks was given if needed. Percentage accuracy and mean search time was provided in a feedback screen at the end of each block.

7.2.1.6 Statistical analysis

Analyses concentrated on the mean reaction time (RT) for correct target-present trials, with data from trials where the response was incorrect and outliers (SD values beyond calculated upper and lower quartile boundaries) removed. A (3 × 3) × 4 mixed model analysis of variance (ANOVA) was conducted to investigate the interaction between Task (colour, size and shape), Set-size (4 items, 8 items and 12 items), and Group (no blur, mild blur, moderate blur and severe blur). The sphericity of all repeated measures effects was tested using Mauchly's test; the data were normal unless otherwise stated, and the Greenhouse-Geisser adjustment was used as required. Post-hoc Bonferroni pairwise comparisons were applied when necessary to explore interactions. The inferential statistics used a significance level of $p < 0.05$, except when multiple comparisons were performed in which case a Bonferroni correction was applied.

7.2.2 Results

The 3 (Task: colour, size and shape) × 3 (Set-size: 4 items, 8 items and 12 items)] × 4 (Group: no blur, mild blur, moderate blur and severe blur) mixed model ANOVA revealed a statistically significant interaction between Task, Set-size and Group, $F_{(12,304)} = 2.01$, $p = 0.023$. Thus, the analysis was broken down to each task. The mean accuracy was above 91% in all conditions and there were no significant differences between conditions ($p \geq 0.122$).

7.2.2.1 Colour search task

The 3 (Set-size: 4 items, 8 items and 12 items) × 4 (Group: no blur, mild blur, moderate blur and severe blur) mixed model ANOVA revealed no effect of Set-size, $F_{(2,152)} = 1.52$, $p = 0.222$, Group, $F_{(3,76)} = 2.68$, $p = 0.053$, or interaction between Set size and Group, $F_{(6,152)} = 1.54$, $p = 0.170$. Pairwise comparisons revealed a significant difference of the mean RT between no blur and mild blur groups ($p = 0.018$), and mild blur and severe blur groups ($p = 0.016$; see Figure 7.3) such that participants from the mild blur groups performed significantly faster than those from no blur and severe blur groups in the colour search task.

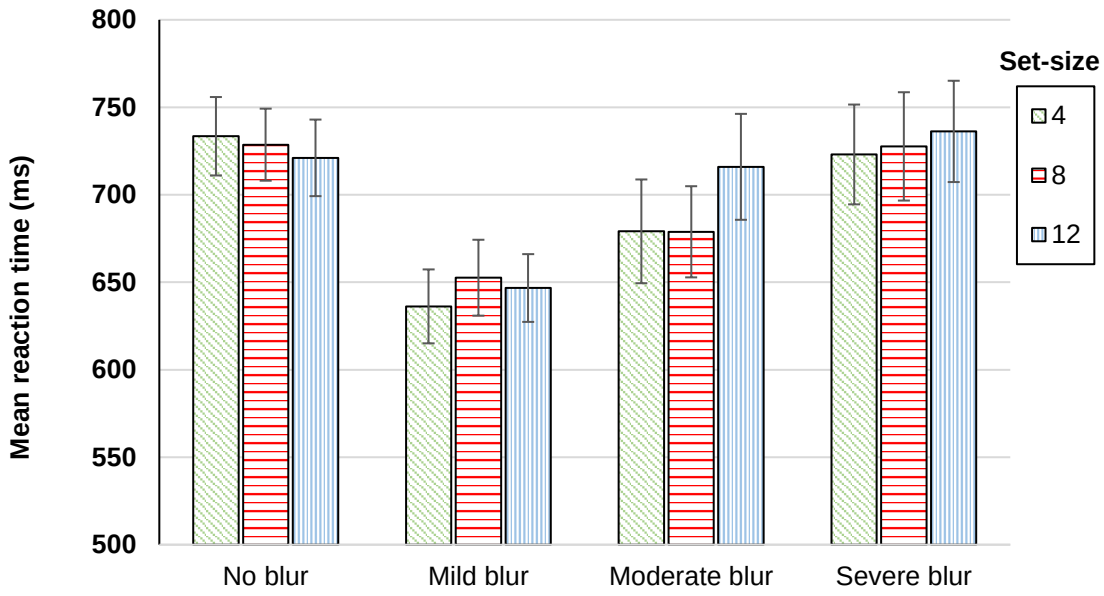


Figure 7.3 Bar chart to illustrate the mean reaction time (in milliseconds) for the different number of items (4, 8 and 12) across four different Groups (no blur, low blur, moderate blur and severe blur) in the colour search task. The error bars represent the standard error of the mean.

7.2.2.2 Size search task

The 3 (Set-size: 4 items, 8 items and 12 items) × 4 (Group: no blur, mild blur, moderate blur and severe blur) mixed model ANOVA revealed a main effect of Set-size, $F_{(2,152)} = 54.86$, $p < 0.001$); as the set-size increased, the mean RT increased as well. The main effect of Group was significant, $F_{(3,76)} = 5.02$, $p = 0.003$, such that the mean RT reduced as the severity of blur increased. There was a non-significant interaction between Set-size and Group, $F_{(6,152)} = 2.00$, $p = 0.069$. Pairwise comparisons revealed a significant difference of the mean RT between mild blur and no blur groups ($p = 0.49$), mild blur and moderate blur groups ($p = 0.018$), and mild blur and severe blur group ($p < 0.001$) such that participants from the mild blur group were faster than those from the no blur, moderate and severe blur groups in the size search task (see Figure 7.4).

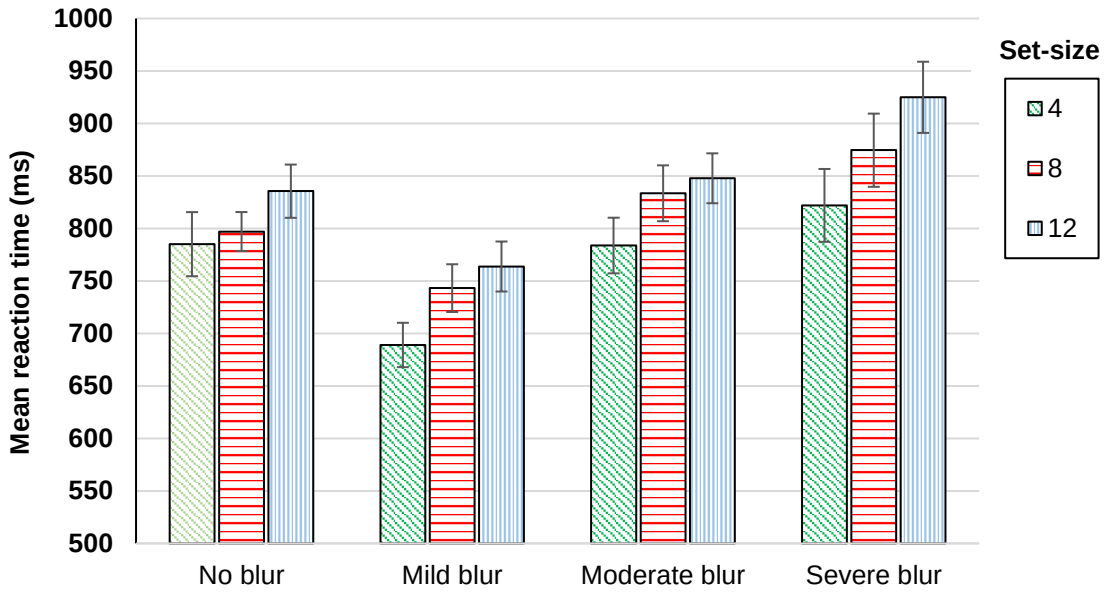


Figure 7.4 Bar chart to illustrate the mean reaction time (in milliseconds) for the different number of items (4, 8 and 12) across four different Groups (no blur, low blur, moderate blur and severe blur) in the size search task. The error bars represent the standard error of the mean.

7.2.2.3 Shape search task

The 3 (Set-size: 4 items, 8 items and 12 items) × 4 (Group: no blur, mild blur, moderate blur and severe blur) mixed model ANOVA revealed a significant effect of Set-size, $F_{(2,152)} = 62.11$, $p < 0.001$, Group, $F_{(3,76)} = 38.72$, $p < 0.001$, and interaction between Set-size and Group, $F_{(6,152)} = 3.04$, $p = 0.008$.

Bonferroni pairwise comparisons for Set-size showed that as the set-size increased, the mean RT significantly increased ($p < 0.001$). For Group comparisons, participants from the no blur group performed significantly faster than those from the moderate blur or severe blur groups ($p \leq 0.007$), however no significant differences in the mean search time were found in other blur condition comparisons ($p \geq 0.647$). Figure 7.5 illustrates the mean RT at each level of blur.

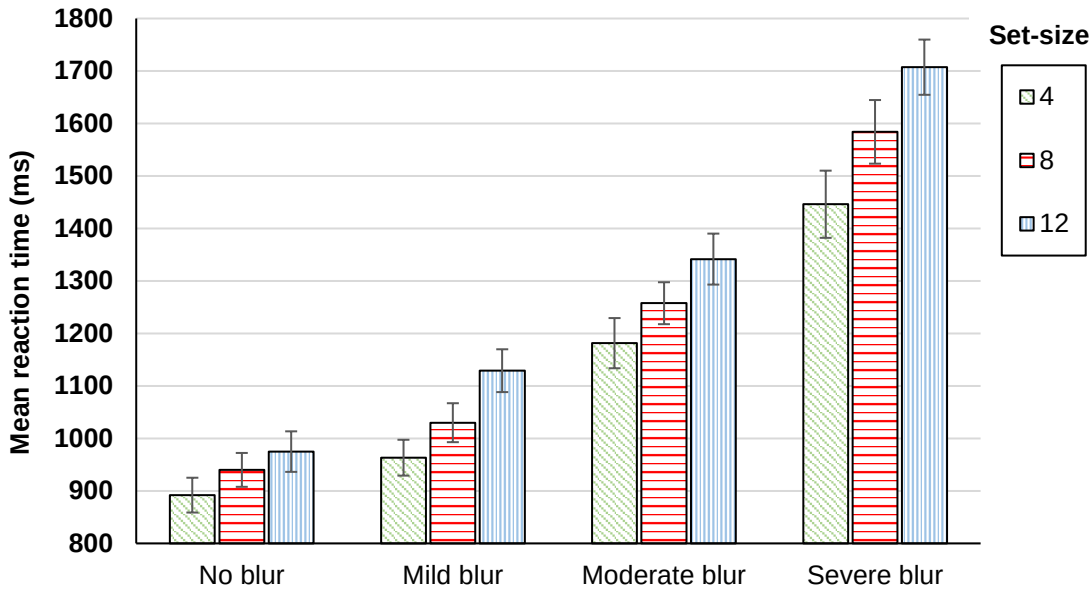


Figure 7.5 Bar chart to illustrate the mean reaction time (in milliseconds) for the different number of items (4, 8 and 12) across four different Groups (no blur, low blur, moderate blur and severe blur) in the shape search task. The error bars represent the standard error of the mean.

To investigate further the interaction between Set-size and Group and the efficiency of search performance, mean search slopes (or search rates) for each level of blur were calculated using the following formula (y2-y1/x2-x1), and were compared using a single-factor between-subject ANOVA. Figure 7.6 shows that the mean reaction time slope steepened across the three Set-sizes, demonstrating that participants with a greater blurring of vision performed increasingly slower when more distractors were presented. The single-factor between-subject ANOVA revealed that there was a significant effect of Group, $F_{(3,79)} = 4.567$, $p = 0.005$, such that participants from the no blur group were significantly faster in the shape search task (10.37 ms/item; SD = 13.86) than those from the severe blur group (32.64 ms/item; SD = 25.62; $p = 0.003$). Other group comparisons were not significantly different ($p \geq 0.239$).

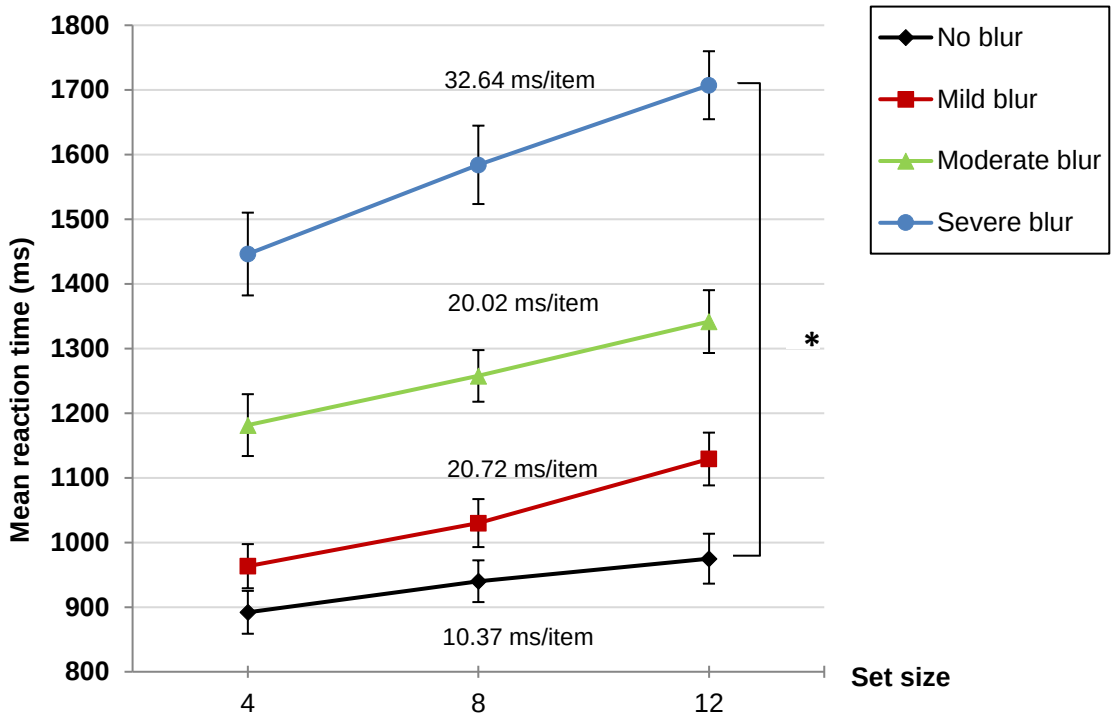


Figure 7.6 Line chart to illustrate the mean search time slopes for the four different Groups (no blur, low blur, moderate blur and severe blur) in the shape search task. The error bars represent the standard error of the mean and '*' represents a significant difference.

7.2.3 Interim Discussion

Does Blurred Vision Affect Visual Search Performance?

The results of the present study show that blurred vision significantly affects visual search performance, however, this is task dependant with the colour search task being relatively unaffected by the extent of the blur. In other words, participants in the blurring groups were equally fast on the colour search task as the no blurred controls across all set-sizes, but become slow and inefficient on the size and shape search tasks with increasing blur. However, there is an exception for those with 6/15 acuity; they can perform very well in all visual search tasks showing that the visual search results obtained from people with minimal blurred vision can still be accepted and considered as an efficient search.

The reason for the poor visual search performance in the shape and size tasks is likely due to reduced saliency of visual features that comes with blurring of vision. Earlier studies reported that when the shape information is degraded as a result of blur, a colour cue is more meaningful and helpful in visual search (Markoff, 1972) and object recognition (Wurm, Legge, Isenberg, & Luebker, 1993). Markoff (1972) conducted a study by blurring black-and-white and colour slides displaying specific targets like a human or a jeep that were hidden in real-world backgrounds. For the colour slides, reaction time was shorter compared to the black-and-white slides, and the advantage of colour over black-and-white performance increased with the amount of blur. In the present study, blurring was uniformly distributed throughout the display, affecting both target and distractors equally. As the saliency of stimuli gradually reduces, the target which has a different shape appears less distinguishable than its homogeneous, blurred distractors thereby diminishing the pop-out characteristic resulting in more difficult search. Consistent with the information degradation hypothesis, it has been shown that participants in lower visual acuity groups perform worse on tests designed to evaluate executive function, perceptual reasoning, visual search, and processing speed (Bertone, Bettinelli, & Faubert, 2007; Skeel et al., 2003).

The visual search mechanism underlying the effects of blurring in the size and shape search tasks remains unclear. The predicted strategy in these search tasks is parallel searching, whereby the array of items is searched simultaneously and the target easily recognised in a ‘pop out’ manner (Treisman & Gelade, 1980). In contrast to this, the participants executed serial scanning from the beginning, examining each item in turn until one item that is perceived as the target is found. Nagy and Sanchez (1990) suggested that a serial search may be attained if the perceived difference between target and distractors is small, and so this may have been the case for the size and shape tasks more than for colour under blurring conditions in particular.

In summary, this study found that visual search speed reduces in size and shape search tasks as the severity of blurred vision increases, indicating a serious disability which could limit the execution of most activities that require efficient visual search like navigation and finding objects. Therefore, Study 9 will investigate if this impaired visual search due to blurred vision can be improved via search training.

7.3 Study 9

7.3.1 Methods

7.3.1.1 Study design

In this mixed design study, participants completed vision testing and pre-training assessments before performing five sessions of search training, and then repeating the same assessments in a post-training session. The primary outcome measures were the mean RT and mean accuracy of the find-the-number, colour, size and shape search tasks. The study ethics approval was obtained from the Psychology department ethics committee at Durham University. All participants provided informed consent to participate in the study in accordance with the Declaration of Helsinki. Figure 7.7 shows the overall flow of the study.

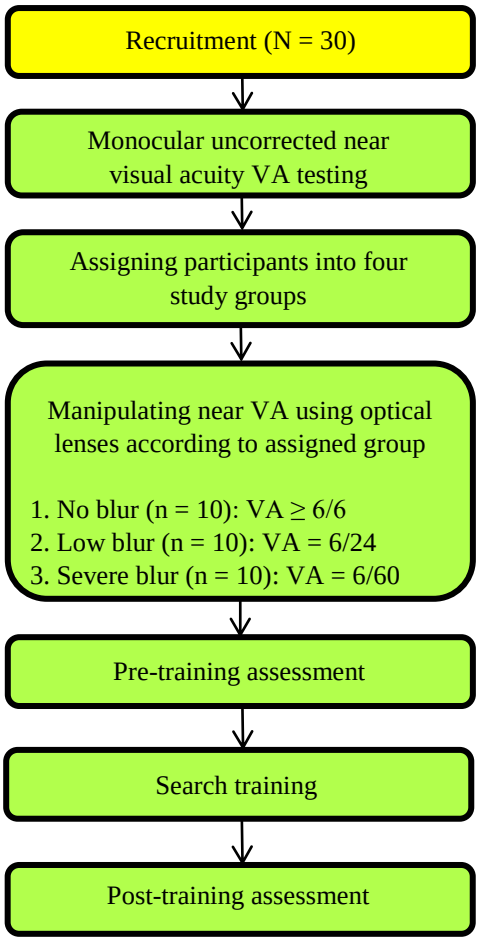


Figure 7.7 Flowchart illustrating overall study flow. VA is the abbreviation for visual acuity.

7.3.1.2 Participants

Thirty volunteers (12 males, 18 females) aged between 18 and 35 years (mean age = 23.5 years; SD = 0.90) were recruited from Durham University. Psychology undergraduates who participated in the study received course credit in accordance with the experiment duration. The inclusion criteria were the same as Study 8. In total, 15 participants did not wear any refractive correction, whilst 15 participants wore spectacles, contact lenses or both.

7.3.1.3 Near vision testing and manipulations

The methods used for testing near vision and allocating participants into the experimental groups were identical with Study 8, except that this experiment only

included three experimental groups which were no blur (6/6), low blur (6/24), and severe blur (6/60) groups. Study 8 showed that there was no significant difference in mean search time between mild and moderate blur groups in all search tasks. Therefore, in this study, a low blur (6/24) group was selected which was described as the mid-VA between 6/15 (mild blur) and 6/30 (moderate blur).

7.3.1.4 Pre- and post-training assessments

7.3.1.4.1 Find-the-number search task

See find-the-number search task description in the methods section of Study 1 (pp. 47).

7.3.1.4.2 Colour, size and shape search task

See colour, size and shape search tasks description in the methods section of Study 8 (pp.186-188).

7.3.1.5 Training

The search training consisted of three visual search tasks where the target item and distribution of trials were the same as the one used in the colour, size and shape search tasks. However, the number of items (set-size) in each array was 10 (including one target), and it remained constant throughout the training. The training components like the task and the way of responding to the task were adopted from the visual exploration training in the DREX programme. The training was divided into five sessions and each session consisted of two blocks of colour, size and shape tasks. Every block comprised 100 trials, thus making 3000 trials in total. Table 7.2 shows the combinations of items in each task for the search training. The only change made was the combination of target-distractor for the size task.

Table 7.2

Details of the target-distractor combinations used in the search training

Task	**Target-distractor combinations**		
	Stimuli colour	Stimuli size	Stimuli shape
Colour	C-Y, C-M, C-R, Y-M, Y-R, R-M	24-24	X-X, M-M, E-E, A-A
Size	C-C, Y-Y, M-M, R-R	24-14	X-X, M-M, E-E, A-A
Shape	C-C, Y-Y, M-M, R-R	24-24	X-M, X-A, X-E, M-A, M-E, A-E

Note: Stimuli colour: C (cyan), M (magenta), R (red), Y (yellow)
Stimuli size: in point unit
Stimuli shape: X, M, E or A letter

7.3.1.6 Procedure

After obtaining written consent and testing VA, participants were asked to complete pre-training assessments: find-the-number search task as well as colour, size and shape search tasks (see Figure 7.3). For both assessment tasks, participants responded to the target presence or absence using an appropriate key press, and the accuracy and speed of the response were recorded. A break between blocks was given if required. After the pre-training assessments had finished, participants completed five sessions of search training consecutively with performance recorded in the same way. Then, participants repeated the pre-training assessments at the post-training session. The assessments and training were done under normal room illumination and the chin rest was used throughout the assessments and training sessions to maintain the head movement and testing distance. A written instruction was provided, and participants were instructed to perform the assessments and training as accurately and as quickly as possible. A feedback screen summarising their performance and accuracy was displayed at the end of each assessment or training.

7.3.1.7 Statistical analysis

The feature search tasks were restricted to correct target-present responses such that incorrect responses and outliers (SD values beyond calculated upper and lower boundaries) were removed. A 2 × 3 mixed model ANOVA was done for the find-the-number search with the factors Session (pre- and post-training) and Group (no blur, low blur and severe blur). A (3 × 2) × 4 mixed model ANOVA was done for colour, size and shape search tasks, with the factors Set-size (4 items, 8 items and 12 items), Session (pre- and post-training) and Group (no blur, low blur and severe blur). The sphericity of all repeated measures effects was tested using Mauchly's test; the data were normal unless otherwise stated, and the Greenhouse-Geisser adjustment was used as required. In addition, post-hoc Bonferroni pairwise comparisons were performed if necessary and inferential statistics used a significance level of $p < 0.05$. If required, a 2 (Session: pre- and post-training) × 3 (Group: no blur, low blur and severe blur) mixed model ANOVA was done to study the mean search slope for each task.

7.3.2 Results

7.3.2.1 Outcome measures

7.3.2.1.1 Find-the-number search task

The 2 (Session: pre- and post-training) × 3 (Group: no blur, low blur and severe blur) mixed model ANOVA on mean RT revealed a main effect of Session, $F_{(1,27)} = 6.47$, $p = 0.017$, and of Group, $F_{(2,27)} = 34.16$, $p < 0.001$; the mean RT decreased after training in each blur condition (Figure 7.8). There was no interaction between Session and Group, $F_{(2,27)} = 0.77$, $p = 0.475$.

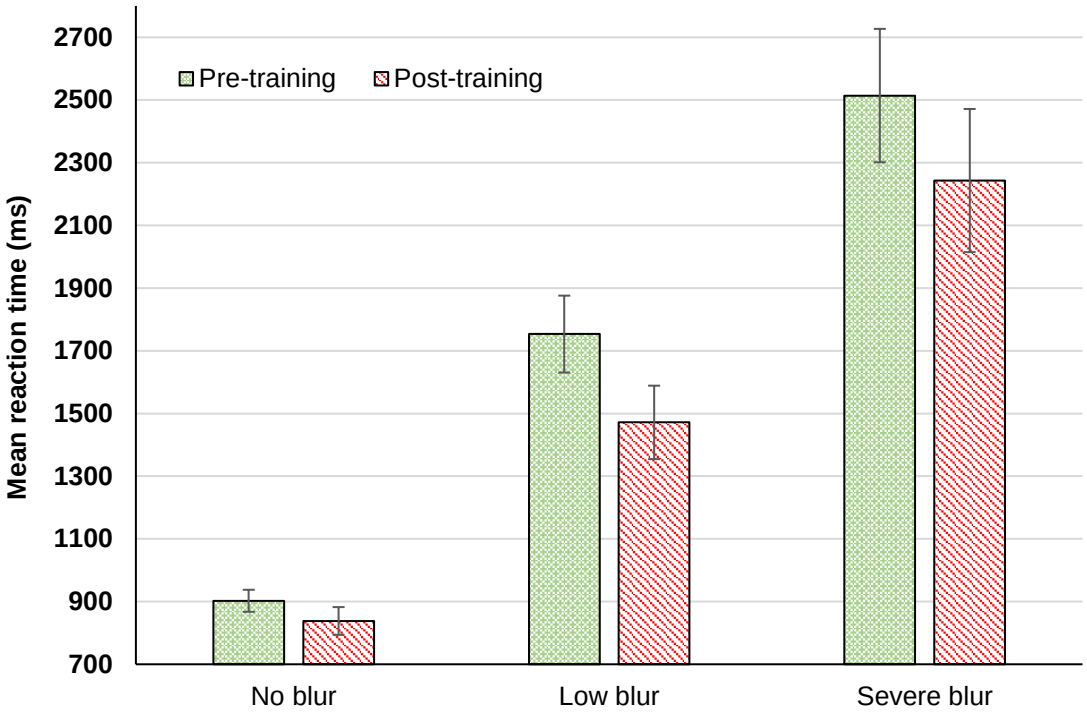


Figure 7.8 Graph to illustrate the mean reaction time (in milliseconds) for each of the groups at pre- and post-training for the find the number search task. The error bars represent the standard error of the mean.

The 2 (Session: pre- and post-training) × 3 (Group: no blur, low blur and severe blur) mixed model ANOVA on mean accuracy revealed a main effect of Session, $F_{(1,27)} = 10.93$, $p = 0.003$, Group, $F_{(2,27)} = 6.26$, $p = 0.006$, and interaction between Session and Group, $F_{(2,27)} = 5.16$, $p = 0.013$. Pairwise comparisons revealed that the mean accuracy of the no blur group remained relatively unchanged and high, $t_{(9)} = 1.56$, $p = 0.154$. The mean accuracy for the low blur, $t_{(9)} = -2.30$, $p = 0.047$, and severe blur, $t_{(9)} = -2.89$, $p = 0.018$, groups increased significantly after the training, and the increment was by 5.65% and 11.15% respectively (see Figure 7.9).

Pearson correlation coefficients between the mean RT and mean accuracy at post-training was not significant for all blur groups; no blur, ($r = 0.534$, $p = 0.112$), low blur ($r = 0.367$, $p = 0.296$), and severe blur ($r = -0.315$, $p = 0.375$), showing that there was no speed-accuracy trade off effect.

Figure 7.9 Graph to illustrate the mean accuracy (in percentage) for each of the groups at pre- and post-training for the find the number search task. The error bars represent the standard error of the mean and '*' represents a significant difference.

7.3.2.1.2 Colour search task

The [3 (Set-size: 4 items, 8 items and 12 items) × 2 (Session: pre- and post-training)] × 3 (Group: no blur, low blur and severe blur) mixed model ANOVA on the mean RT revealed a significant effect of Session, $F_{(1,27)} = 65.27$, $p < 0.001$, such that the search speed was significantly faster post-training compared to pre-training (see Figure 7.10). The remaining main effects and interactions were all non-significant ($p \geq .175$).

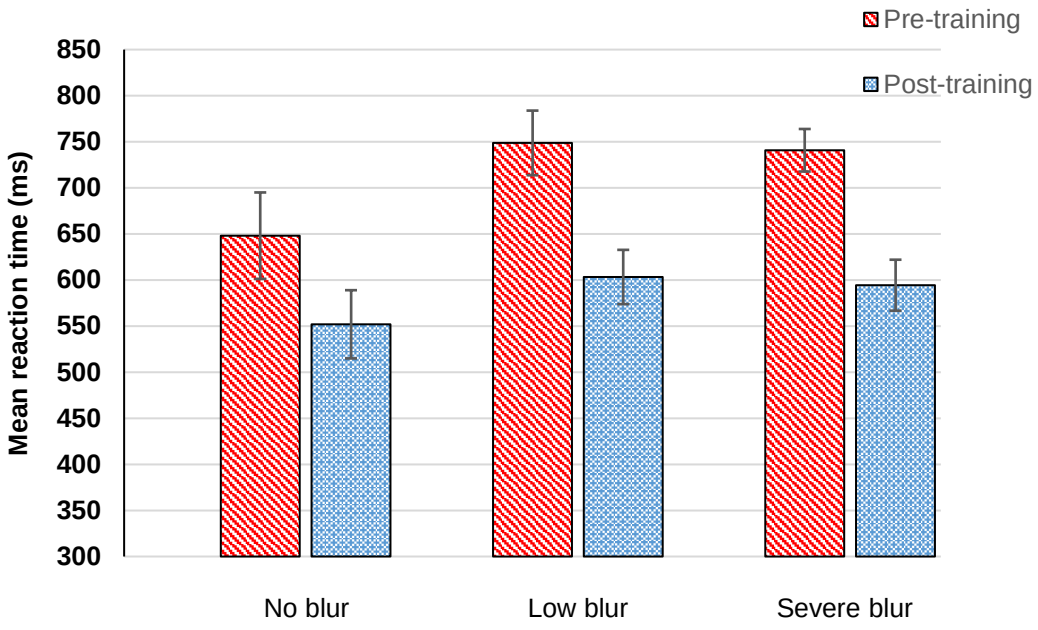


Figure 7.10 Graph to illustrate the mean reaction time (in milliseconds) in the colour search task for each of the groups at pre- and post-training. The error bars represent the standard error of the mean.

7.3.2.1.3 Size search task

The 3 (Set-size: 4 items, 8 items and 12 items) × 2 (Session: pre- and post-training)] × 3 (Group: no blur, low blur and severe blur) mixed model ANOVA on the mean RT revealed significant effects of Session, $F_{(1,27)} = 65.17$, $p < 0.001$, and Set-size, $F_{(2,54)} = 53.97$, $p < 0.001$, such that the search speed was significantly faster post-training compared to pre-training (see Figure 7.11), but slower as the number of items displayed increased. There was no significant effect of Group and interactions were all non-significant ($p \geq .057$).

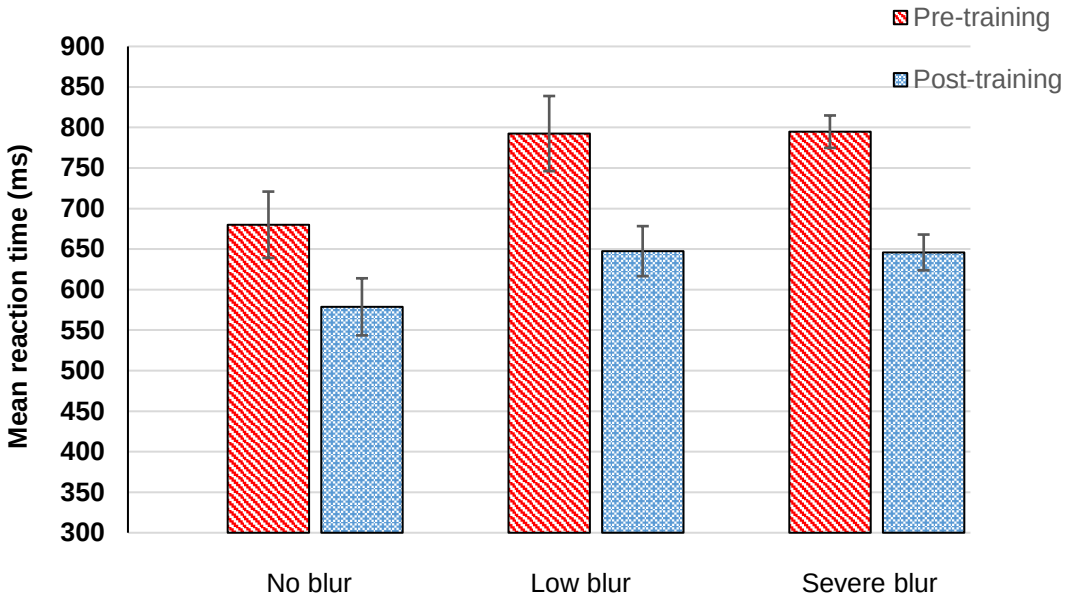


Figure 7.11 Graph to illustrate the mean reaction time (in milliseconds) in the size search task for each of the groups at pre- and post-training. The error bars represent the standard error of the mean.

7.3.2.1.4 Shape search task

The [3 (Set-size: 4 items, 8 items and 12 items) × 2 (Session: pre- and post-training)] × 3 (Group: no blur, low blur and severe blur) mixed model ANOVA on the mean RT revealed significant effects of Session, $F_{(1,27)} = 93.24$, $p < 0.001$, Set-size, $F_{(2,54)} = 45.47$, $p < 0.001$, and Group, $F_{(2,27)} = 13.20$, $p < 0.001$. There were significant interactions between Set-size and Group, $F_{(4,54)} = 3.56$, $p = 0.012$, and Session and Group, $F_{(2,27)} = 3.43$, $p = 0.047$, but no significant interactions between Set-size and Session, $F_{(2,54)} = 2.82$, $p = 0.068$, and Set-size, Session and Group, $F_{(4,54)} = 0.49$, $p = 0.740$ were found. Figure 7.12 shows the mean RT during pre- and post-training for all groups.

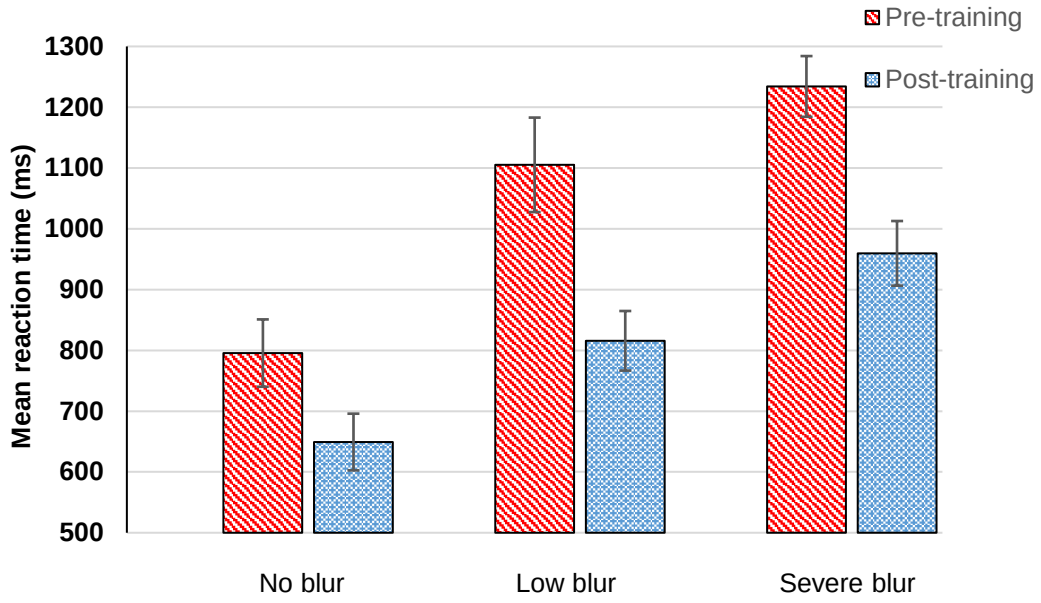


Figure 7.12 Graph to illustrate the mean reaction time (in milliseconds) in the shape search task for each of the groups at pre- and post-training. The error bars represent the standard error of the mean.

To investigate the effect of training on the efficiency of visual search in the shape search task, the mean search slope was calculated using the following formula (y2-y1/x2-x1). Figure 7.13 illustrates the mean search slope for each level of blurring for pre- and post-training.

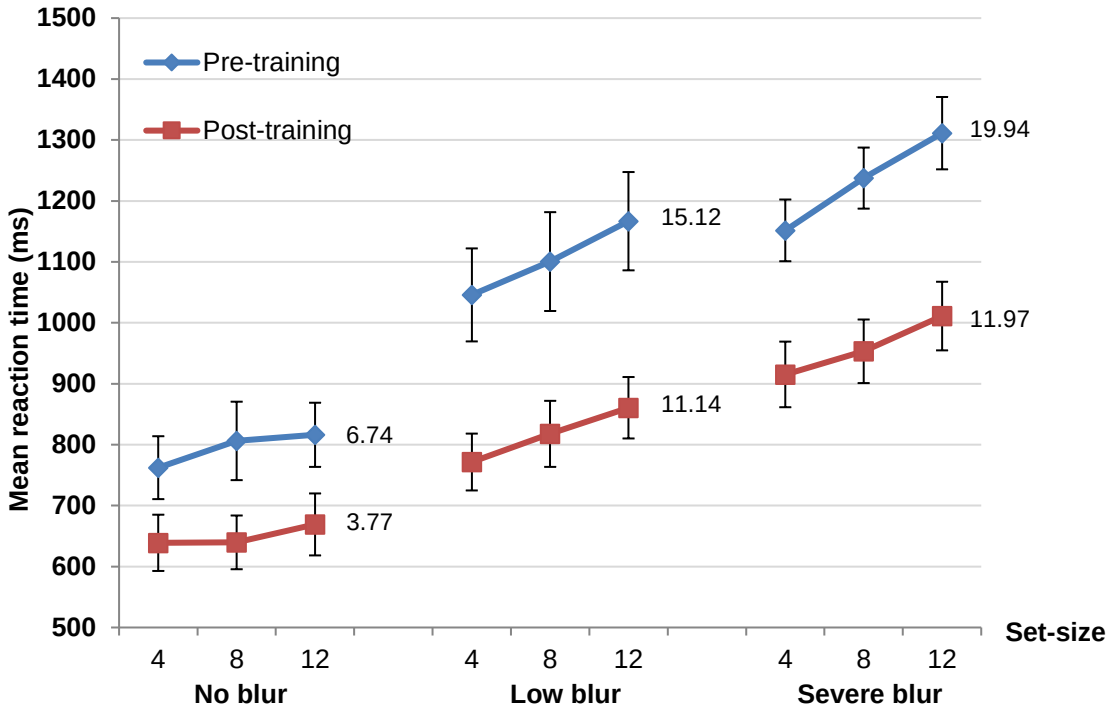


Figure 7.13 Graph to illustrate the mean search time slopes pre- and post-training across the three different Groups (no blur/low blur/severe blur) in the shape search task. The error bars represent the standard error of the mean, and the mean search slope unit is ms/item.

The 2 (Session: pre- and post-training) × 3 (Group: no blur, low blur and severe blur) mixed model ANOVA on the mean search slope revealed significant effects of Session, $F_{(1,27)} = 7.04$, $p = 0.013$ and Group, $F_{(2,27)} = 5.52$, $p = 0.010$; the mean search slope significantly reduced after the training, and the no blur group experienced a significantly greater decrease in the search slope relative to the severe blur group ($p = 0.010$). However, there were no interactions between Session and Group, $F_{(2,27)} = 0.663$, $p = 0.523$.

7.3.2.1.6 Search accuracy of colour, size and shape search tasks

Mean accuracy was above 94% in all conditions and there were no significant differences between conditions ($p \geq 0.197$). Table 7.2 shows the Pearson correlation coefficient between the mean reaction time and mean accuracy at post-training for all blur groups in each task; there was no speed-accuracy trade off effect.

Table 7.3

Pearson correlation analysis between mean reaction time and mean accuracy at post-training

Task	Pearson correlation, r (p)		
	No blur	Mild blur	Severe blur
Colour	0.481 (0.159)	-0.286 (0.424)	-0.005 (0.989)
Size	0.361 (0.305)	0.315 (0.375)	0.010 (0977)
Shape	0.389 (0.266)	0.343 (0.331)	0.011 (0.977)

7.3.2.2 Training

The training data was collapsed across the three different search tasks (colour, size and shape) and the mean RT (target-present condition) for each training session was calculated for each blur group (See Figure 7.14).

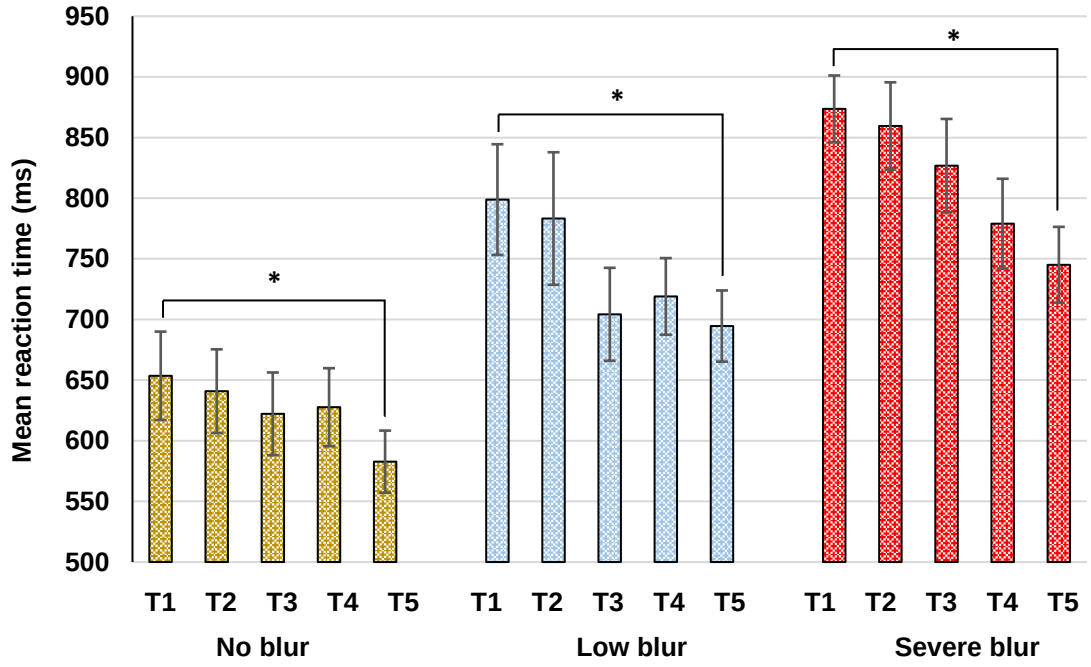


Figure 7.14 Graph to illustrate the mean reaction time (in milliseconds) for each of the group in every training session. The error bars represent the standard error of the mean and '*' represents a significant difference.

Overall, the mean RT decreased in the second training session (T_2) relative to the first (T_1), and then reduced consistently across the five training sessions, except for

a slight increase of the mean RT for the no blur and low blur groups during the fourth training session (T_4; see Figure 7.9). The decrease in mean RT in T_5 relative to T_1 for no blur, low blur and severe blur groups were 70.76ms, 104.26ms, and 128.58ms, which represents a significant improvement across the course of the training of 10.8% (t_9 = 2.49, p = 0.034), 13.1% (t_9 = 4.07, p = 0.003) and 14.7% (t_9 = 3.58, p = 0.006) respectively.

7.3.3 Interim Discussion

Does Search Training under Blurring Conditions Improve Visual Search Performance?

All participants irrespective of the level of blurring improved significantly in their visual search performance after search training; a substantial level of transfer from search training to find-the-number, colour, size and shape search tasks was reported. However, the mean search improvement was actually higher in the blurring groups than the no blurring group. It seems likely that this was due to the baseline visual search speed in the blurring groups being slower relative to the no blurring group. No blur participants therefore had less opportunity to gain as much improvement after the training, a phenomenon not uncommon in the literature (see Liu et al., 2007). Examining the mean reaction time across all five sessions of training, the mean reaction time continued to reduce in each session, and the magnitude was greater for the more difficult shape search task. A significant improvement in speed was observed between the first and final sessions regardless of blurring group, and thus it is anticipated that if the training session were to be extended that increased benefits could be gained.

For the mechanism that led to an improved search speed in blurred participants after the training, we speculate that learning in visual search in those participants is not

task-specific, but to some extent reflects an enhanced search strategy as evidenced in the find-the-number, colour, size and shape search tasks. Generally, normally sighted subjects learn to improve their search speed by initially making several scanning movements, which are then progressively reduced after extensive practice (Ahissar & Hochstein, 1996; Ahissar & Hochstein, 1993; Ellison & Walsh, 1998; Leonards, Rettenbach, Nase, & Sireteanu, 2002; Sireteanu & Rettenbach, 1995, 2000; Treisman & Gelade, 1980). It seems possibly that the same modification has been adopted by the optically blurred participants. The only difference is that their searching behaviour is influenced by the use of their residual acuity in performing the visual search. When the perceived visual information is limited by the induced blurring, participants initially begin the visual searching by utilising any feature details available, making more saccades and serially checking on all displayed stimuli until a target is identified. Liu et al. (2007) trained search in visually impaired patients where parts of the field being viewed were expected to be obscured. They suggested that eye movements are almost compulsory, and patients made numerous saccades in order to locate the target. This is supported by eye movement studies among subjects with AMD, where their central vision is also impaired; subjects produced a high number of saccades towards the area of interest during visual search (Cornelissen et al., 2005; Taylor, Smith, & Crabb, 2017). This search strategy improves after several trials as participants quickly discriminate the identical features of distractors and allocate more attention on the outstanding item that is believed to be the target of interest. Therefore, the search rate improves significantly after extensive practice as participants become more familiar with the task and learn to use their residual acuity more efficiently. The improvement of eye movement control in the blur groups could be evaluated by comparing saccadic behavior pre- and post-training, and this would be an avenue worth investigating in the future among patients with visual field defects with comorbid blurred vision or optically

induced blurred vision. This will have a direct implication on DREX training especially when patients also have blurred vision.

7.4 General discussion and conclusion

Study 8 demonstrated that increasing blur from 6/30 (moderate blur) to 6/60 (severe blur) had a marked effect on the speed but not the accuracy of visual search for size and shape search tasks. Therefore, this finding suggests that it is very important that blurred vision is to be corrected in order to attain fast and efficient visual search. Unfortunately, in some cases like in AMD patients, the blurring of vision is usually untreatable and thus their visual search performance will remain poor. The finding in Study 9 however revealed that impaired visual search can still be improved even if the vision is severely blurred. Evidence was found for a post-training improvement in mean RT in all tasks including the untrained find-the-number task, demonstrating the transfer effect of search training to the search tasks.

In conclusion, patients with blurred vision can still benefit from the DREX training. In fact, patients with visual acuity 6/15 could gain improvement in visual search that is equal to those with normal visual acuity, meaning that these patients may not need to have their vision corrected to perform DREX training efficiently. Additionally, these studies address the importance of identifying any coexistent visual impairment, like blurred vision, prior to any rehabilitative training to limit its undesirable effect on the training outcome.

Chapter 8

General Discussion

Partial visual field defects are a common result of brain injury (Gilhotra, Mitchell, Healey, Cumming, & Currie, 2002; Rowe et al., 2013; Zihl, 2010) and chronic eye diseases (Hartong et al., 2006; Klein & Klein, 2013; Leat & Lovie-Kitchin, 2006; Nilsson et al., 2003; Ross et al., 1984), and thus numerous efforts have been undertaken to develop an effective treatment to ameliorate the resulting disabilities. Compared to other rehabilitation treatments (see reviews by Lane, Smith, & Schenk, 2008; Pollock et al., 2011), compensatory training seems to be the most promising option for the rehabilitation of HVFDs (Hanna & Rowe, 2017; Trauzettel-Klosinski, 2017), and positive therapeutic effects of this approach have also been reported among those with tunnel vision (Ivanov et al., 2016) and central visual field loss (Seiple et al., 2005). In this thesis, studies have been presented that investigate the efficacy of an app-based compensatory training called DREX training for HVFDs (Studies 1 to 6) and other types of partial visual field defects (Studies 7). This chapter will discuss and summarise the findings from these studies, as well as the findings from two experimental studies examining the effects of comorbid blurred vision on the outcomes of visual exploration training (Studies 8 and 9).

8.1 Does DREX training work in the rehabilitation of partial visual field defects?

Absolutely, yes! DREX training is significantly and clinically effective in improving visual exploration and reading performance among HVFD patients, by at

least 28% and 20% respectively, which confirms the earlier studies (see reviews by Hanna, Hepworth, & Rowe, 2017; Lane et al., 2008). Furthermore, the benefit of DREX training is not limited to only HVFDs but may also help other types of partial visual field defects; the preliminary results show that patients with central vision loss and tunnel vision have improved visual search and reading after training. DREX training therefore seems to facilitate the development of systematic eye movement strategies for efficient visual exploration and reading in all patients with some form of visual field defect. Importantly, patients reported decreased difficulties in many common activities of daily living like navigating, avoiding obstacles and finding objects demonstrating meaningful training-induced changes in quality of life and these benefits are sustained over a period of 3 months, showing that there is scope for the DREX training to result in stable improvements. This thesis presents the first controlled study to show that visual compensatory training can be used successfully on a touchscreen tablet (visuomotor version), and that this new training mode is as effective as the computer version. However, there are factors that may affect the efficacy of the training such as blurring of vision, motivation towards rehabilitation and confidence in using technology which will be discussed in the next sections, and finally some modifications on the existing DREX training have been proposed in order to maximise its efficacy for all potential users.

The results showed that the effect of the DREX training on reading using the tablet mode is slightly lower compared to the computer version. Although the difference in the reading improvement between these two training modes was not significant, it is interesting to discuss this as it was the first attempt training reading using a small screen display like a touchscreen tablet. We speculate that this slightly worse performance might be due to the macular sparing in the patients trained using the touchscreen tablet which was not explicitly explored. Whilst it is well-established that the presence and size of macular sparing could predict the outcomes of reading training (Leff, 2004;

McFadzean et al., 1994; Zihl, 2010), reduced visual acuity could also be a factor. Reading training using the same tablet version but on patients with tunnel vision who have an intact macular area, revealed a substantial improvement in their reading performance after the training. However, the participant who had smaller remaining central field vision and poorer visual acuity gained a greater improvement in reading speed than the participant who had a larger central visual field and normal visual acuity. Most probably, there are other factors besides the extent of visual impairment that influence the training outcome such as individual motivation and desire to improve. Study 1 showed that patients who had higher initial motivation gained greater improvement in visual exploration, and further work examining the range of influencing factors would be beneficial. At least for now we know that reading training can be effectively performed on a touchscreen tablet.

In reality, many patients who have visual field defects may also present with coexistent blurred vision (Rowe et al., 2013). Normally blurred vision caused by chronic eye disease such AMD is likely to be a permanent impairment (see Study 6 about the common visual characteristic of AMD). Study 8 identified that visual search performance is greatly reduced when the vision is severely blurred, suggesting that vision must be corrected in order to obtain an efficient visual search. However, subjects with severely blurred vision can still improve their visual search performance from the search training (Study 9). This finding is very important because it demonstrated that patients with permanent blurred vision can still gain some benefit from visual search training and potentially use DREX training to rehabilitate themselves. In the case series, Participant 4 had AMD and permanent blurred vision at near distance which could not be improved even with a multifocal spectacle. However, this participant still obtained improvement in both reading and visual exploration after DREX training, albeit a lesser improvement than another AMD patient (Participant 3) who had clearer vision. Again,

the finding of this study convincingly shows that DREX can be successfully used and effective for patients with permanent blurred vision.

On a practical note, the improvements after training for a person with permanent blurred vision can be enhanced by improving the visibility of the visual items presented on the training display. This could be achieved by increasing the magnification of items using the relative distance magnification method which proved helpful and successful as seen in Participant 2 in Study 6. However, this method might not work in all patients especially those who require stronger magnification (Lovie-Kitchen & Whittaker, 1998). Although an optical magnifier can help to provide the higher magnification, this method however is not practical for individuals with restricted visual field, who are the main users of DREX, because the use of a magnifier with greater magnification will further reduce the total functional field of view (Cheong, Lovie-Kitchin, & Bowers, 2002; Watson, 2001) and consequently reduces overall visual search improvement. Alternatively, the magnification can easily be achieved by calculating the magnification needed using the "reciprocal of near vision" formula (Wolffsohn & Eperjesi, 2004; Cheong et al., 2002; Lovie-Kitchin & Whittaker, 1999). For example, if patient's near visual acuity is 6/30, the magnification that this patient may require to see the items clearly is 1.25×, which is computed using this formula: (denominator/numerator)/4 (Wolffsohn & Eperjesi, 2004). Therefore, one possible modification that could be made to the DREX programme is adding a vision testing into the existing assessments or testing the vision separately before entering the result into the DREX system. From the vision testing result, the DREX system could then automatically calculate the magnification required and increase the size of the visual items accordingly so that patients can clearly see the items. Ultimately, this will enhance the training experience and impact. Such a modification would be very advantageous for patients who prefer not to use any optical correction while doing the training, due either to the limited field

of view resulting from a spectacle frame or any cosmetic reason. Notwithstanding this, the present version of DREX is effective for patients with HFVDs, and other type of visual field defects, with or without blurred vision.

In addition, some consideration on modifying the brightness and contrast level of the training display may be needed, because very often tunnel vision patients present with reduced contrast sensitivity (Alexander et al., 1995; Lindberg et al., 1981) which could decrease their visual search performance (Liu et al., 2007). For example, Participant 2 in study 6 had more severe tunnel vision and greater contrast sensitivity loss compared to Participant 1. After a modification on the training such as display contrast and brightness, Participant 2 was able to perform the training task very well. Alternatively, modification to the colour and contrast of the training stimuli and background display could also be done, however this option is not yet available in the current DREX version.

8.2 Clinical implications of the research findings

It is expected that improving health care and expanding patient life span will increase the prevalence of HVFDs and thereby the demand for an effective training (Goodwin, 2014). DREX can be offered as an effective rehabilitation aid to many patients with HVFDs within the NHS or any rehabilitation setting globally. It is available as a web-version and a downloadable app for touchscreen tablets that allows this training programme to be accessible to as many people as possible using a device they already own without any additional cost.

Furthermore, as has been demonstrated in this thesis, DREX training contains reliable and valid built-in assessments that can measure and monitor the outcomes of DREX training accurately or could be used independently as a supplementary assessment test. For example, the DREX perimetry test demonstrated good sensitivity

and specificity in detecting the presence of prominent visual field defects, and therefore could be used extensively in hospitals as a portable test for visual field screening and as an alternative to the gross confrontation method. Furthermore, being built into the training app makes the visual field test convenient for every assessment session, without patients needing to undergo a supervised face-to-face testing like confrontation or HVF, at least for the purpose of monitoring the training progression. This will save patients' and clinicians' time. Most importantly, clinicians can make a decision and recommendation more quickly based on the findings of the built-in DREX assessments, as the use of mobile electronic devices abridges data acquisition and removes intermediate processing steps which eventually enhances the quality of care (Sudano Jr, Kofford, & Wotman, 2005).

Another advantage of DREX is that it can be used successfully by elderly patients; the average age of patients from Study 1 was 60 years. This view however should be interpreted with caution. There could be a recruitment bias such that patients who are not confident to use technology may choose not to partake in the study where this would be a requirement. Prior to recruitment, information about the study was provided to potential participants which included a detailed illustrated guideline on how to download and run the training. This could have given all patients, including those who felt uncertain about taking part in the study, an overview about the training and at the same time could have lessened their worries about using technology. After all, the majority of participants indicated that they were confident using a computer or touchscreen tablet. Furthermore, the use of technology and electronic devices are not something new to many people and they have been accepted as assistive aids to the elderly (McCreadie & Tinker, 2005) and disabled adults (Gell, Rosenberg, Demiris, LaCroix, & Patel, 2015) for communicating, monitoring health and supporting them in doing routine activities like shopping. In fact, the use of touchscreen tablet has been

found to increase patients' motivation to engage in their rehabilitation (see Study 1). Therefore, clinicians could recommend DREX training to their elderly patients as an alternative to other training methods like paper-based search task which could be very laborious.

Setting a goal is standard practice within most rehabilitation and is thought to enhance motivation (Wade, 2009). In Study 1, some patients did indicate a positive change after training such as they felt less impaired in reading and able to enjoy reading more, which is the skill that they identified as their initial goal. The same is true for other activities like finding objects and visiting people. Another clear example is from the case series study, where Participant 5 complained of having difficulties in seeing objects and navigation which were more prominent than her problem with reading. After the training, this participant gained greater improvement in visual exploration than reading. This improvement was supported by the subjective improvement in seeing objects, avoiding obstacles and finding their way, but no change in reading performance was reported although the reading testing showed a slight increment in her reading speed. This clearly shows that the training must be relevant to the need or goal of the individual patient and should result in a specific effect on the impaired skill. In Study 2, it was reported that although both the visual exploration and reading components of DREX resulted in some improvements in both behaviours, the maximal gains were seen after the congruent training: visual exploration training resulted in larger gains for exploration than for reading, and vice versa. Therefore, it is very important for patients (and clinicians) to identify activities or skills that they want to improve so that the more appropriate training could be chosen from the DREX programme. By setting up their rehabilitation goals, it will help them to keep their focus and motivation towards the training. However, if both visual exploration and reading are impaired, completing both visual exploration and reading training from the DREX training package is

recommended as the effects are more superior than either component alone (see Study 1). Furthermore, the ultimate goal is to encourage patients to actively apply the skills they have learned in therapy to real life situations such as searching the items they want on a shelf during shopping, which has also been recommended in several studies (Kerkhoff et al., 1994; Krakauer, 2006; Veerbeek et al., 2014).

Finally, it is also worth stating the importance of knowing patients' visual acuity prior to the DREX training. This information will help therapists to know whether patients can sufficiently see the targets presented during the training. Although it appears that the effect of blurred vision is minimal to the final improvement after the training (percentage of visual search improvement is nearly equivalent to that of normal vision people), patients might not be able to fully appreciate the changes as the effect of blurring is persistent and more prominent, interfering with the overall clarity of the objects presented within their surroundings. Therefore, suggesting patients to use optical correction like spectacles or contact lenses during the training would be the best option. In the situation where DREX training is done with the blurred vision, patients must be reminded about the potentially variable training outcomes as a consequence of the blurring.

8.3 Limitations and recommendations for future research

The studies on the effect of blurred vision on visual search performance (Studies 8 and 9) were done on normal subjects with intact visual fields. Furthermore, the blurred vision was induced using optical lenses which did not represent those who had blurred vision due to other origins like cerebral insult and retinal diseases. Although a positive effect of search training under blurring conditions has been reported, it is practically important to examine the effect of training among patients with visual field defects and blurred vision. An additional element to investigate would be whether or not

extending the duration of search training under blurring conditions could increase the efficacy of the training and could then lead to improvement in the search performance that is comparable to the no blurring condition. Performance did not appear to plateau after the five sessions of training in the severe blurring group, whereas for the no and low blurring group there was minimal change in the final three training sessions. This indicates that there is a chance for greater improvement in the severe blurring group compared to other groups if the training is extended. The investigation should be done among patients with visual field defects.

In the computer-based compensatory training, patients need to respond to the task using an appropriate computer-mouse click while sitting centrally in front of the computer screen. However, for the visuomotor version, patients have to hold or prop up the touchscreen tablet at normal reading distance, approximately 35 to 45 cm, and tap the screen when responding. There is therefore a greater possibility that the distance of testing might be varied throughout the testing for the tablet group. For instance, some patients with hemiparesis, which is very common among stroke patients (Bonita & Beaglehole, 1988; Langhorne, Coupar, & Pollock, 2009), might have a problem sustaining a fixed distance. Sometimes, novice users might also encounter the same problem. In the present thesis, none of the patients had a comorbid hemiparesis. However, to limit the effect of inconsistent training distance, two additional measures were taken. Firstly, set up and training instructions were provided by the investigator during the initial appointment, and also an illustrated instruction is included in the app on how the device should be positioned every time the patient performed the training; patients were asked to place the device centrally so that the training effect can be optimised. Secondly, patients were asked to put their device on a tablet stand throughout the training so that the distance of training could be controlled. Study 1 did not find any significant difference between the improvement in visual exploration and reading

between those trained using a touchscreen tablet or computer. This may be because most patients who participated in this study were highly confident with technology and did not have any difficulty to use the devices. Still, it would be interesting to investigate specific ancillary questions such as does hemiparesis significantly impact on patients' performance in the DREX training? Therefore, a comparative clinical study is proposed to examine the effect of DREX training among people with HVFDs with or without hemiparesis. Additionally, it would be beneficial to investigate the effects of various other comorbidities associated with visual field defects such as cognitive deficit, visual neglect and language difficulties on the efficacy of DREX training. Patients with brain damage often present with somewhat unspecific ophthalmological symptoms like glaring, reduced contrast sensitivity, oculomotor disorders, strabismus, and diplopia (Rowe et al., 2009; Rowe et al., 2013; Trauzettel-Klosinski, 2017) which can be very debilitating and that restrict the rehabilitation efforts. These factors must be carefully investigated about their effects on the DREX training. This thesis has first examined the effect of blurred vision and revealed the adverse effect of this comorbidity impairment on visual search performance. The results could remarkably change the current practice in the rehabilitation of patients with partial visual field defects. Therefore, future work should look at the impact of comorbid impairments on the training outcomes.

Finally, the findings from the case series (Study 6) showed that DREX training may be beneficial for other types of partial visual field defects like tunnel vision and could potentially transfer the benefit to activities of daily living. The results are very motivating and clinically useful for the development of a comprehensive rehabilitation approach that is not focused on only one visual field defect. This finding requires further evaluation in a controlled study to demonstrate the efficacy of DREX for a range of potential users however.

8.4 Conclusion

Overall, the findings of this thesis confirm that DREX training is clinically effective for the rehabilitation of visual exploration and reading impairments due to HVFDs and could potentially benefit patients with other types of partial visual field defect and reduced visual acuity too. The effects are transferable to most of the common activities of daily living assessed and are stable over a three-month period of non-training. Importantly, both computer and touchscreen tablet versions of DREX are equally effective and can be used successfully for visual field defect rehabilitation. This multiplatform training allows many patients to train independently at their home using equipment that they already own, thereby reducing the cost, increasing access and improving overall rehabilitation ease. The research further highlights the reliability and validity of the assessments that have been incorporated into the DREX training, which provide a means for both patients and clinicians being able to monitor the training progress and future recovery remotely without recourse to many additional measures. In conclusion, DREX provides an effective rehabilitation package for visual field defects, and it could now be offered to many patients anywhere around the globe.

References

Ackland, P., Resnikoff, S., & Bourne, R. (2017). World blindness and visual impairment: despite many successes, the problem is growing. *Community Eye Health, 30*(100), 71.

Ahissar, M., & Hochstein, S. (1993). Attentional control of early perceptual learning. *Proceedings of the National Academy of Sciences, 90*(12), 5718–5722.

Ahissar, M., & Hochstein, S. (1996). Learning pop-out detection: specificities to stimulus characteristics. *Vision Research, 36*(21), 3487–3500.

Aimola, L., Lane, A. R., Smith, D. T., Kerkhoff, G., Ford, G. A., & Schenk, T. (2014). Efficacy and feasibility of home-based training for individuals with homonymous visual field defects. *Neurorehabiliation and Neural Repair, 28*(3), 207–218.

Alexander, K. R., Derlacki, D. J., & Fishman, G. A. (1995). Visual acuity vs letter contrast sensitivity in retinitis pigmentosa. *Vision Research, 35*(10), 1495–1499.

Ali, M., Hazelton, C., Lyden, P., Pollock, A., & Brady, M. (2013). Recovery From Poststroke Visual Impairment Evidence From a Clinical Trials Resource. *Neurorehabilitation and Neural Repair, 27*(2), 133–141.

Alma, M. A., Van der Mei, S. F., Melis-Dankers, B. J. M., Van Tilburg, T. G., Groothoff, J. W., & Suurmeijer, T. P. B. M. (2011). Participation of the elderly after vision loss. *Disability and Rehabilitation, 33*(1), 63–72.

Ameer, K., & Ali, K. (2017). iPad use in stroke neuro-rehabilitation. *Geriatrics, 2*(1), 2.

Amsler, M. (1953). Earliest Symptoms of Diseases of the Macula. *The British Journal of Ophthalmology, 37*(9), 521–537.

Anderson, C., Laubscher, S., & Burns, R. (1996). Validation of the Short Form 36 (SF-36) health survey questionnaire among stroke patients. *Stroke, 27*(10), 1812–1816.

Anderson, S. W., & Rizzo, M. (1994). Recovery and rehabilitation of visual cortical dysfunction. *NeuroRehabilitation, 5*(2), 129–140.

Arditi, A. (2005). Improving the design of the letter contrast sensitivity test. *Investigative Ophthalmology and Visual Science, 46*(6), 2225–2229.

Age-Related Eye Disease Study Research Group. (2005). Risk factors for the incidence of advanced age-related macular degeneration in the Age-Related Eye Disease Study (AREDS): AREDS report no. 19. *Ophthalmology, 112*(4), 533-539.

August, C. (2010). Assessment of functional vision and its rehabilitation. *Acta Ophthalmologica, 88*(2), 163–173.

Augustin, A., Sahel, J.-A., Bandello, F., Dardennes, R., Maurel, F., Negrini, C., … Berdeaux, G. (2007). Anxiety and depression prevalence rates in age-related macular degeneration. *Investigative Ophthalmology and Visual Science, 48*(4), 1498–1503.

Avlund, K., Lund, R., Holstein, B. E., & Due, P. (2004). Social relations as determinant of onset of disability in aging. *Archives of Gerontology and Geriatrics, 38*(1), 85–99.

Barbur, J. L., Forsyth, P. M., & Findlay, J. M. (1988). Human saccadic eye movements in the absence of the geniculocalcarine projection. *Brain, 111*(1), 63–82.

Becker, M., Masterson, K., Delavelle, J., Viallon, M., Vargas, M., & D Becker, C. (2010). Imaging of the optic nerve. *European journal of radiology, 74*(2), 299-313.

Behrmann, M., Marotta, J., Gauthier, I., Tarr, M. J., & McKeeff, T. J. (2005). Behavioral change and its neural correlates in visual agnosia after expertise training. *Journal of Cognitive Neuroscience, 17*(4), 554–568.

Berger, K., Hense, H. W., Rothdach, A., Weltermann, B., & Keil, U. (2000). A single question about prior stroke versus a stroke questionnaire to assess stroke prevalence in populations. *Neuroepidemiology, 19*(5), 245–257.

Bertone, A., Bettinelli, L., & Faubert, J. (2007). The impact of blurred vision on cognitive assessment. *Journal of Clinical and Experimental Neuropsychology, 29*(5), 467–476.

Black, A., Lovie-Kitchin, J. E., Woods, R. L., Arnold, N., Byrnes, J., & Murrish, J. (1997). Mobility performance with retinitis pigmentosa. *Clinical and Experimental Optometry, 80*(1), 1–12.

Bolognini, N., Rasi, F., Coccia, M., & Làdavas, E. (2005). Visual search improvement in hemianopic patients after audio-visual stimulation. *Brain, 128*(12), 2830–2842.

Bonita, R., & Beaglehole, R. (1988). Recovery of motor function after stroke. *Stroke, 19*(12), 1497–1500.

Boosman, H., van Heugten, C. M., Winkens, I., Smeets, S. M. J., & Visser-Meily, J. M. A. (2016). Further validation of the Motivation for Traumatic Brain Injury Rehabilitation Questionnaire (MOT-Q) in patients with acquired brain injury. *Neuropsychological Rehabilitation, 26*(1), 87–102.

Bouwmeester, L., Heutink, J., & Lucas, C. (2007). The effect of visual training for patients with visual field defects due to brain damage: a systematic review. *Journal of Neurology, Neurosurgery and Psychiatry, 78*, 555-564.

Bowers, A. R., Mandel, A. J., Goldstein, R. B., & Peli, E. (2009). Driving with hemianopia, I: Detection performance in a driving simulator. *Investigative Ophthalmology and Visual Science, 50*(11), 5137–5147.

Bowers, A. R., Tant, M., & Peli, E. (2012). A pilot evaluation of on-road detection performance by drivers with hemianopia using oblique peripheral prisms. *Stroke Research and Treatment, 2012.*

Brody, B. L., Gamst, A. C., Williams, R. A., Smith, A. R., Lau, P. W., Dolnak, D., … Brown, S. I. (2001). Depression, visual acuity, comorbidity, and disability associated with age-related macular degeneration. *Ophthalmology*, *108*(10), 1893–1900

Brown, A. G. (2011). An examination of the relationship between death anxiety, optimism, depression, and anxiety (Doctoral dissertation).

Bullimore, M. A., & Bailey, I. L. (1995). Reading and eye movements in age-related maculopathy. *Optometry and Vision Science*, *72*(2), 125–138.

Burkhard, M., & Koch, M. (2012). Evaluating Touchscreen Interfaces of Tablet Computers for Elderly People. In *Mensch and Computer Workshopband*, 53–59.

Burton, C. R. (2000). Living with stroke: a phenomenological study. *Journal of Advanced Nursing*, *32*(2), 301–309.

Carson, A. J., MacHale, S., Allen, K., Lawrie, S. M., Dennis, M., House, A., & Sharpe, M. (2000). Depression after stroke and lesion location: a systematic review. *The Lancet*, *356*(9224), 122–126.

Cassidy, T. P., Bruce, D. W., & Gray, C. S. (2001). Visual field loss after stroke: Confrontation and perimetry in the assessment of recovery. *Journal of Stroke and Cerebrovascular Diseases*, *10*(3), 113–117.

Cassidy, T. P., Bruce, D. W., Lewis, S., & Gray, C. S. (1999). The association of visual field deficits and visuo-spatial neglect in acute right-hemisphere stroke patients. *Age and Ageing*, *28*(3), 257–260.

Chedru, F., Leblanc, M., & Lhermitte, F. (1973). Visual searching in normal and brain-damaged subjects (contribution to the study of unilateral inattention). *Cortex*, *9*(1), 94–111.

Chen, C. S., Lee, A. W., Clarke, G., Hayes, A., George, S., Vincent, R., … Daly, A. (2009). Vision-related quality of life in patients with complete homonymous hemianopia post stroke. *Topics in Stroke Rehabilitation*, *16*(6), 445–453.

Chen, J., & Smith, L. E. H. (2007). Retinopathy of prematurity. *Angiogenesis*, *10*(2), 133–140.

Cheong, A. M. Y., Lovie-Kitchin, J. E., & Bowers, A. R. (2002). Determining magnification for reading with low vision. *Clinical and Experimental Optometry*, *85*(4), 229–237.

Chervinsky, A. B., Ommaya, A. K., deJonge, M., Spector, J., Schwab, K., & Salazar, A. M. (1998). Motivation for traumatic brain injury rehabilitation questionnaire (MOT-Q): reliability, factor analysis, and relationship to MMPI-2 variables. *Archives Clinical Neuropsychology*, *13*(5), 433–446.

Cheung, S.-H., & Legge, G. (2005). Functional and cortical adaptations to central vision loss. *Visual Neuroscience*, *22*(2), 187-201.

Chhablani, J., Kaja, S., & Shah, V. A. (2012). Smartphones in ophthalmology. *Indian Journal of Ophthalmology*, *60*(2), 127.

Chopdar, A., Chakravarthy, U., & Verma, D. (2003). Age related macular degeneration. *British Medical Journal*, *326(7*387), 485–488.

Cicerone, K. D., Dahlberg, C., Malec, J. F., Langenbahn, D. M., Felicetti, T., Kneipp, S., … Harley, J. P. (2005). Evidence-based cognitive rehabilitation: updated review of the literature from 1998 through 2002. *Archives of Physical Medicine and Rehabilitation*, *86*(8), 1681–1692.

Coco-Martín, M. B., López-Miguel, A., Cuadrado, R., Mayo-Iscar, A., Herrero, A. J., Pastor, J. C., & Maldonado, M. J. (2017). Reading Performance Improvements in Patients with Central Vision Loss without Age-Related Macular Degeneration after Undergoing Personalized Rehabilitation Training. *Current Eye Research*, *42*(9), 1260–1268.

Coeckelbergh, T. R. M., Brouwer, W. H., Cornelissen, F. W., & Kooijman, A. C. (2001). Training compensatory viewing strategies: Feasibility and effect on practical fitness to drive in subjects with visual field defects. *Visual Impairment Research*, *3*(2), 67–83.

Colenbrander, A., & De Laey, J.-J. (2006). Vision requirements for driving safety. *Report of the International Council of Ophthalmology*.

Cornelissen, F. W., Bruin, K. J., & Kooijman, A. C. (2005). The influence of artificial scotomas on eye movements during visual search. *Optometry and Vision Science : Official Publication of the American Academy of Optometry*, *82*(1), 27–35.

Cott, C. (2004). Client-centred rehabilitation: client perspectives. *Disability and Rehabilitation*, *26*(24), 1411–1422.

Crossland, M., & Rubin, G. (2007). The Amsler chart: absence of evidence is not evidence of absence. *The British Journal of Ophthalmology*, *91*(3), 391–393.

Crossland, M., Culham, L. E., & Rubin, G. S. (2004). Fixation stability and reading speed in patients with newly developed macular disease. *Ophthalmic and Physiological Optics*, 24(4), 327-333

Culén, A. L., & Bratteteig, T. (2013). Touch-screens and elderly users: A perfect match? *Changes*, *7*, 15.

Dandona, L., & Dandona, R. (2006). Revision of visual impairment definitions in the International Statistical Classification of Diseases. *BMC Medicine*, *4*, 7.

de Haan, G. A., Heutink, J., Melis-Dankers, B. J. M., Tucha, O., & Brouwer, W. H. (2014). Spontaneous recovery and treatment effects in patients with homonymous visual field defects: a meta-analysis of existing literature in terms of the ICF framework. *Survey of Ophthalmology*, *59*(1), 77–96.

de Haan, G. A., Melis-Dankers, B. J. M., Brouwer, W. H., Tucha, O., & Heutink, J. (2015). The Effects of Compensatory Scanning Training on Mobility in Patients with Homonymous Visual Field Defects: A Randomized Controlled Trial. *PloS One*, *10*(8), e0134459.

de Haan, G. A., Melis-Dankers, B. J. M., Brouwer, W. H., Tucha, O., & Heutink, J. (2016). The effects of compensatory scanning training on mobility in patients with homonymous visual field defects: further support, predictive variables and follow-up. *PloS One*, *11*(12), e0166310.

de Jong, D., Kaufmann-Ezra, S., Meichtry, J. R., von Arx, S., Cazzoli, D., Gutbrod, K., & Müri, R. M. (2016). The influence of reading direction on hemianopic reading disorders. *Journal of clinical and experimental neuropsychology*, *38*(10), 1077-1083.

De Luca, M., Spinelli, D., & Zoccolotti, P. (1996). Eye movement patterns in reading as a function of visual field defects and contrast sensitivity loss. *Cortex*, *32*(3), 491–502.

Dersu, I., Wiggins, M. N., Luther, A., Harper, R., & Chacko, J. (2006). Understanding visual fields, part I; Goldmann perimetry. *Journal of Ophathalmic Medical Technology*, *2*, 1-10.

Dougherty, B. E., Flom, R. E., & Bullimore, M. A. (2005). An evaluation of the Mars Letter Contrast Sensitivity Test. *Optometry and Vision Science*, *82*(11), 970–975.

Dougherty, B. E., Martin, S. R., Kelly, C. B., Jones, L. A., Raasch, T. W., & Bullimore, M. A. (2009). The development of a battery of functional tests for low vision. *Optometry and Vision Science*, *86*(8), 955.

DVLA Driver and Vehicle Licensing Agency, 2016. A*ssessing Fitness to Drive: A Guide for Medical Professionals*. Department of Transport, London, United Kingdom.

Dworkin, R.H., Turk, D.C., Wyrwich, K.W., et al (2008). Interpreting the clinical importance of treatment outcomes in chronic pain clinical trials: IMMPACT recommendations. *Journal of Pain*, 9:105-121.

Ellison, A., & Walsh, V. (1998). Perceptual learning in visual search: Some evidence of specificities. *Vision Research*, *38*(3), 333–345.

Ergun, E., Maár, N., Radner, W., Barbazetto, I., Schmidt-Erfurth, U., & Stur, M. (2003). Scotoma size and reading speed in patients with subfoveal occult choroidal neovascularization in age-related macular degeneration. *Ophthalmology*, *110*(1), 65-69.

Ferris, F. L. 3rd. (1983). Senile macular degeneration: review of epidemiologic features. *American Journal of Epidemiology*, *118*(2), 132–151.

Findlay, J. M., & Walker, R. (1999). How are saccades generated? *Behavioral and Brain Sciences*, *22*(4), 706–713.

Fingert, J. H., Oh, K., Chung, M., Scheetz, T. E., Andorf, J. L., Johnson, R. M., ... & Stone, E. M. (2008). Association of a novel mutation in the retinol dehydrogenase 12 (RDH12) gene with autosomal dominant retinitis pigmentosa. *Archives of ophthalmology*, *126*(9), 1301-1307.

Flaxman, S. R., Bourne, R. R. A., Resnikoff, S., Ackland, P., Braithwaite, T., Cicinelli, M. V, … Kempen, J. H. (2017). Global causes of blindness and distance vision impairment 1990–2020: a systematic review and meta-analysis. *The Lancet Global Health*, *5*(12), e1221–e1234.

Fletcher, D. C., Schuchard, R. A., & Renninger, L. W. (2012). Patient awareness of binocular central scotoma in age-related macular degeneration. *Optometry and Vision Science*, *89*(9), 1395–1398.

Flinn, N. A., & Stube, J. E. (2010). Post-stroke fatigue: qualitative study of three focus groups. *Occupational Therapy International*, *17*(2), 81–91.

Fuhr, P. S., Liu, L., Kuyk, T. K., & Article, O. (2007). Relationships between feature search and mobility performance in persons with severe visual impairment. *Optometry and Vision Science*, *84*(5), 393–400.

Fujimoto, N., & Adachi-Usami, E. (1998). Use of blue-on-yellow perimetry to demonstrate quadrantanopia in multiple sclerosis. *Archives of Ophthalmology*, *116*(6), 828–829.

Gall, C., Lucklum, J., Sabel, B. A., & Franke, G. H. (2009). Vision-and health-related quality of life in patients with visual field loss after postchiasmatic lesions. *Investigative Ophthalmology and Visual Science*, *50*(6), 2765–2776.

Gassel, M. M., & Williams, D. (1963). Visual function in patients with homonymous hemianopia part II. Oculomotor mechanisms. *Brain*, *86*(1), 1–36.

Gell, N. M., Rosenberg, D. E., Demiris, G., LaCroix, A. Z., & Patel, K. V. (2015). Patterns of Technology Use Among Older Adults With and Without Disabilities. *The Gerontologist*, *55*(3), 412–421.

Geruschat, D. R., Turano, K. A., & Stahl, J. W. (1998). Traditional measures of mobility performance and retinitis pigmentosa. *Optometry and Vision Science*, *75*(7), 525–537.

Gilhotra, J. S., Mitchell, P., Healey, P. R., Cumming, R. G., & Currie, J. (2002). Homonymous Visual Field Defects and Stroke in an Older Population. *Stroke*, *33*(10), 2417–2420.

Glazier, S. R., Schuman, J., Keltz, E., Vally, A., & Glazier, R. H. (2004). Taking the next steps in goal ascertainment: a prospective study of patient, team, and family perspectives using a comprehensive standardized menu in a geriatric assessment and treatment unit. *Journal of the American Geriatrics Society*, *52*(2), 284–289.

Glei, D. A., Landau, D. A., Goldman, N., Chuang, Y.-L., Rodriguez, G., & Weinstein, M. (2005). Participating in social activities helps preserve cognitive function: an analysis of a longitudinal, population-based study of the elderly. *International Journal of Epidemiology*, *34*(4), 864–871.

Glisson, C. C. (2014). Visual loss due to optic chiasm and retrochiasmal visual pathway lesions. *Continuum: Lifelong Learning in Neurology*, *20*(4), 907–921.

Goodwin, D. (2014). Homonymous hemianopia: challenges and solutions. *Clinical Ophthalmology*, *8*, 1919.

Graham, M. V, & Wakefield, G. J. (1973). Bitemporal visual field defects associated with anomalies of the optic discs. *The British Journal of Ophthalmology*, *57*(5), 307.

Gray, C. S., French, J. M., Bates, D., Cartlidge, N. E., Venables, G. S., & James, O. F. W. (1989). Recovery of visual fields in acute stroke: homonymous hemianopia associated with adverse prognosis. *Age and Ageing*, *18*(6), 419–421.

Green, A., Felmingham, K., Baguley, I. J., Slewa-Younan, S., & Simpson, S. (2001). The clinical utility of the Beck Depression Inventory after traumatic brain injury. *Brain Injury*, *15*(12), 1021–1028.

Grover, S., Fishman, G. A., Anderson, R. J., Tozatti, M. S. V, Heckenlively, J. R., Weleber, R. G., … Brown Jr, J. (2018). Visual acuity impairment in patients with retinitis pigmentosa at age 45 years or older. *Ophthalmology*, *106*(9), 1780–1785.

Hackett, M. L., & Anderson, C. S. (2005). Predictors of depression after stroke: a systematic review of observational studies. *Stroke*, *36*(10), 2296–2301.

Hall, E. C., & Ciuffreda, K. J. (2001). Eccentric viewing training in macular degeneration using auditory ocular motor biofeedback. *Journal of Behavioral Optometry*, *12*(4), 87–93.

Hanna, K. L., Hepworth, L. R., & Rowe, F. J. (2017). The treatment methods for post-stroke visual impairment: A systematic review. *Brain and Behavior*, *7*(5), e00682.

Hanna, K. L., & Rowe, F. J. (2017). Clinical versus Evidence-based Rehabilitation Options for Post-stroke Visual Impairment. *Neuro-Ophthalmology*, *41*(6), 297–305.

Harper, R., Doorduyn, K., Reeves, B., & Slater, L. (1999). Evaluating the outcomes of low vision rehabilitation. *Ophthalmic and Physiological Optics*, *19*(1), 3–11.

Hartong, D. T., Berson, E. L., & Dryja, T. P. (2006). Retinitis pigmentosa. *The Lancet*, *368*(9549), 1795–1809

Hashmani, S., Hashmani, N., Kumar, S., Kumar, S., Dhomeja, V., Razak, S., … Adhi, I. (2017). Reasons for refusing laser-assisted in situ keratomileusis in a Pakistani population. *Cureus*, *9*(6).

Haymes, S. A., Roberts, K. F., Cruess, A. F., Nicolela, M. T., LeBlanc, R. P., Ramsey, M. S., … Artes, P. H. (2006). The Letter Contrast Sensitivity Test: Clinical Evaluation of a New Design. *Investigative Ophthalmology and Visual Science*, *47*(6), 2739–2745

Haymes, S., Guest, D., Heyes, A., & Johnston, A. (1996). Mobility of people with retinitis pigmentosa as a function of vision and psychological variables. *Optometry and Vision Science* , *73*(10), 621—637.

Herse, P. (2005). Retinitis pigmentosa: visual function and multidisciplinary management. *Clinical and Experimental Optometry*, *88*(5), 335–350.

Hiroe, T., Kojima, M., Yamamoto, I., et al (2005). Gradations of clinical severity and sensitivity to change assessed with the Beck Depression Inventory-II in Japanese patients with depression. Psychiatry Ressearch, 135:229-235

Hirvela, H., Koskela, P., & Laatikainen, L. (1995). Visual acuity and contrast sensitivity in the elderly. *Acta Ophthalmologica Scandinavica*, *73*(2), 111–115.

Holden, B. A. (2008). Global Vision Impairment Due to Uncorrected Presbyopia. *Archives of Ophthalmology*, *126*(12), 1731.

Holzinger, A. (2002). Finger instead of mouse: touch screens as a means of enhancing universal access. In *ERCIM Workshop on User Interfaces for all*, 387–397.

Horowitz, A., Reinhardt, J. P., & Boerner, K. (2005). The effect of rehabilitation on depression among visually disabled older adults. *Aging & Mental Health*, *9*(6), 563–570.

Horowitz, A., Leonard, R., & Reinhardt, J. (2000). Measuring Psychosocial and Functional Outcomes of a Group Model of Vision Rehabilitation Services 1for Older Adults. *Journal of Visual Impairment & Blindness*, *94*(5).

Houston, K. E., Peli, E., Goldstein, R. B., & Bowers, A. R. (2018). Driving With Hemianopia VI: Peripheral Prisms and Perceptual-Motor Training Improve Detection in a Driving Simulator. *Translational Vision Science and Technology*, *7*(1), 5.

Humphrey, D. G., & Kramer, A. F. (1997). Age differences in visual search for feature, conjunction, and triple-conjunction targets. *Psychology and Aging*, *12*(4), 704–717.

Huurneman, B., & Boonstra, F. N. (2014). Training shortens search times in children with visual impairment accompanied by nystagmus. *Frontiers in Psychology*, *5*, 988.

Huurneman, B., Cox, R. F. A., Vlaskamp, B. N. S., & Boonstra, F. N. (2014). Crowded visual search in children with normal vision and children with visual impairment. *Vision Research*, *96*, 65–74.

Hyvarinen, L., Rovamo, J., Laurinen, P., & Pelromaa, A. (1981). Contrast sensitivity function in evaluation of visual impairment due to retinitis pigmentosa. *Acta ophthalmologica*, *59*(5), 763-773.

Irvine, D., Zemke, A., Pusateri, G., Gerlach, L., Chun, R., & Jay, W. M. (2014). Tablet and smartphone accessibility features in the low vision rehabilitation. *Neuro-Ophthalmology*, *38*(2), 53–59.

Ishiai, S., Furukawa, T., & Tsukagoshi, H. (1987). Eye-fixation patterns in homonymous hemianopia and unilateral spatial neglect. *Neuropsychologia*, *25*(4), 675–679.

Ivanov, I. V, Mackeben, M., Vollmer, A., Martus, P., Nguyen, N. X., & Trauzettel-Klosinski, S. (2016). Eye Movement Training and Suggested Gaze Strategies in Tunnel Vision - A Randomized and Controlled Pilot Study. *PLOS One*, *11*(6), e0157825.

Jacko, J. A., Barreto, A. B., Chu, J. Y. M., Scott, I. U., Rosa Jr, R. H., & Pappas Jr, C. C. (2000). Macular degeneration and visual search: What we can learn from eye movement analysis. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *44*, 116–119.

Jacko, J. A., Barreto, A. B., Marmet, G. J., Chu, J. Y. M., Bautsch, H. S., Scott, I. U., & Rosa Jr, R. H. (2000). Low vision: the role of visual acuity in the efficiency of cursor movement. In *Proceedings of the fourth international ACM conference on Assistive technologies.* 1–8.

Jacquin-Courtois, S., Bays, P. M., Salemme, R., Leff, A. P., & Husain, M. (2013). Rapid compensation of visual search strategy in patients with chronic visual field defects. *Cortex*, *49*(4), 994–1000.

Janssen, C. P., & Verghese, P. (2016). Training eye movements for visual search in individuals with macular degeneration. *Journal of Vision*, *16*(15), 29.

Johnson, C. A., Thapa, S., George Kong, Y. X., & Robin, A. L. (2017). Performance of an iPad Application to Detect Moderate and Advanced Visual Field Loss in Nepal. *American Journal of Ophthalmology*, *182*, 147–154.

Jorge, R. E., Robinson, R. G., Moser, D., Tateno, A., Crespo-Facorro, B., & Arndt, S. (2004). Major depression following traumatic brain injury. *Archives of General Psychiatry*, *61*(1), 42–50.

Kasneci, E., & Hardiess, G. (2017). Driving with Homonymous Visual Field Defects. In *Homonymous Visual Field Defects*, 135–144.

Kerkhoff, G., Schaub, J., & Zihl, J. (1990). Assessment of cerebral visual disorders by patient-questionnaire. *Nervenarzt*, *61*(12), 711-718.

Kerkhoff, G. (1999). Restorative and compensatory therapy approaches in cerebral blindness. A review. *Restorative Neurology and Neuroscience*, *13*, 255–271.

Kerkhoff, G. (2000). Neurovisual rehabilitation: recent developments and future directions. *Journal of Neurology, Neurosurgery & Psychiatry*, *68*(6), 691–706.

Kerkhoff, G., Münßinger, U., Eberle-Strauss, G., & Stögerer, E. (1992a). Rehabilitation of hemianopic alexia in patients with postgeniculate visual field disorders. *Neuropsychological Rehabilitation, 2*(1), 21–42.

Kerkhoff, G., Münßinger, U., Haaf, E., Eberle-Strauss, G., & Stögerer, E. (1992b). Rehabilitation of homonymous scotomata in patients with postgeniculate damage of the visual system: saccadic compensation training. *Restorative Neurology and Neuroscience, 4*(4), 245–254.

Kerkhoff, G., Münβinger, U., & Meier, E. K. (1994). Neurovisual rehabilitation in cerebral blindness. *Archives of Neurology, 51*(5), 474–481.

Kerr, N. M., Chew, S. S. L., Eady, E. K., Gamble, G. D., & Danesh-Meyer, H. V. (2010). Diagnostic accuracy of confrontation visual field tests. *Neurology, 74*(15), 1184–1190.

Kerrison, J. B., Lynn, M. J., Baer, C. A., Newman, S. A., Biousse, V., & Newman, N. J. (2000). Stages of improvement in visual fields after pituitary tumor resection. *American Journal of Ophthalmology, 130*(6), 813–820.

Klauber, A., Rasmussen, P., & Lindholm, J. (1978). Pituitary adenoma and visual function. *Acta Ophthalmologica, 56*(2), 252–263.

Klein, R., & Klein, B. E. (2013). The prevalence of age-related eye diseases and visual impairment in aging: current estimates. *Investigative Ophthalmology and Visual Science*, 54(14), ORSF5-ORSF13.

Koiava, N., Ong, Y. H., Brown, M. M., Acheson, J., Plant, G. T., & Leff, A. P. (2012). A 'web app'for diagnosing hemianopia. *Journal of Neurology, Neurosurgery and Psychiatry*, 83(12), 1222-1224.

Kooijman, A., Brouwer, W., Coeckelbergh, T., Tant, M., Cornelissen, F., Bredewoud, R., & Melis-Dankers, B. (2004). Compensatory viewing training improves practical fitness to drive of subjects with impaired vision. *Visual Impairment Research, 6*(1), 1–27.

Kosmorsky, G. S., Dupps, W. J., & Drake, R. L. (2008). Nonuniform pressure generation in the optic chiasm may explain bitemporal hemianopsia. *Ophthalmology, 115*(3), 560–565.

Kotila, M., Numminen, H., Waltimo, O., & Kaste, M. (1999). Post-stroke depression and functional recovery in a population-based stroke register. The Finnstroke study. *European Journal of Neurology, 6*(3), 309–312.

Krakauer, J. W. (2006). Motor learning: its relevance to stroke recovery and neurorehabilitation. *Current Opinion in Neurology, 19*(1), 84-90.

Kuyk, T. K., Liu, L., & Fuhr, P. S. W. (2005). Feature search in persons with severe visual impairment. *Vision Research, 45*(25–26), 3224–3234.

Kvien, T. K., Mowinckel, P., Heiberg, T., Dammann, K. L., Dale, Ø., Aanerud, G. J., … Uhlig, T. (2005). Performance of health status measures with a pen based personal digital assistant. *Annals of the Rheumatic Diseases*, *64*(10), 1480–1484.

Lamoureux, E. L., Hassell, J. B., & Keeffe, J. E. (2004). The determinants of participation in activities of daily living in people with impaired vision. *American Journal of Ophthalmology*, *137*(2), 265–270.

Land, M., Mennie, N., & Rusted, J. (1999). The roles of vision and eye movements in the control of activities of daily living. *Perception*, *28*(11), 1311–1328.

Lane, A. R., Smith, D. T., Ellison, A., & Schenk, T. (2010). Visual exploration training is no better than attention training for treating hemianopia. *Brain*, *133*(6), 1717-1728.

Lane, A. R., Smith, D. T., & Schenk, T. (2008). Clinical treatment options for patients with homonymous visual field defects. *Clinical Ophthalmology*, *2*(1), 93.

Langhorne, P., Coupar, F., & Pollock, A. (2009). Motor recovery after stroke: a systematic review. *The Lancet Neurology*, *8*(8), 741–754.

Latham, K., Baranian, M., Timmis, M. A., Fisher, A., & Pardhan, S. (2017). Relative Difficulties of Daily Living Tasks with Retinitis Pigmentosa. *Optometry and Vision Science*, *94*(3), 317–328.

Law, K.-Y., & Law, E.-M. (1998). Pituitary adenoma presenting with visual complications. *Clinical and Experimental Optometry*, *81*, 267–271.

Leat, S. J., & Lovie-Kitchin, J. (2006). Visual impairment and the useful field of vision. *Ophthalmic and Physiological Optics*, *26*(4), 392–403.

Lee, S. J., Kavanaugh, A., & Lenert, L. (2007). Electronic and computer-generated patient questionnaires in standard care. *Best Practice & Research. Clinical Rheumatology*, *21*(4), 637–647.

Leff, A. (2004). A historical review of the representation of the visual field in primary visual cortex with special reference to the neural mechanisms underlying macular sparing. *Brain and Language*, *88*(3), 268–278.

Leff, A., & Starrfelt, R. (2014). Hemianopic Alexia. *Alexia*, 31–69.

Legge, G. E., Pelli, D. G., Rubin, G. S., & Schleske, M. M. (1985). Psychophysics of reading I. Normal vision. *Vision Research*, *25*(2), 239–252.

Legge, G. E., Cheung, S. H., Yu, D., Chung, S. T., Lee, H. W., & Owens, D. P. (2007). The case for the visual span as a sensory bottleneck in reading. *Journal of Vision*, *7*(2), 9-9.

Lennerstrand, G., & Ahlström, C. (1989). Contrast sensitivity in macular degeneration and the relation to subjective visual impairment. *Acta Ophthalmologica*, *67*(3), 225–233.

Leonards, U., Rettenbach, R., Nase, G., & Sireteanu, R. (2002). Perceptual learning of highly demanding visual search tasks. *Vision Research*, *42*(18), 2193–2204.

Lévy-Bencheton, D., Pélisson, D., Prost, M., Jacquin-Courtois, S., Salemme, R., Pisella, L., & Tilikete, C. (2016). The effects of short-lasting anti-saccade training in homonymous hemianopia with and without saccadic adaptation. *Frontiers in Behavioral Neuroscience*, *9*, 332.

Lindberg, C. R., Fishman, G. A., Anderson, R. J., & Vasquez, V. (1981). Contrast sensitivity in retinitis pigmentosa. *British Journal of Ophthalmology*, *65*(12), 855 LP-858.

Liu, L., Kuyk, T., & Fuhr, P. (2007). Visual search training in subjects with severe to profound low vision. *Vision Research*, *47*(20), 2627–2636.

Lohmann, C. P., Köhler, M., & Ullirich, O.-W. (2000). Incomplete bitemporal hemianopia without headache: An unusual case of pituitary apoplexy. *Eye*, *14*, 116.

Loshin, D. S., & White, J. (1984). Contrast sensitivity: The visual rehabilitation of the patient with macular degeneration. *Archives of Ophthalmology*, *102*(9), 1303–1306.

Lovie-Kitchen, J., & Whittaker, S. (1998). Relative-size Magnification versus Relative-distance Magnification: Effect on the Reading Performance of Adults with Normal and Low Vision. *Journal of Visual Impairment & Blindness*, *92*(7), 433–446.

Lovie-Kitchin, J., Mainstone, J., Robinson, J., & Brown, B. (1990). What areas of of the visual field are important for mobility in low vision patients. *Clinical Vision Sciences*, *5*(3), 249–263.

Lovie-Kitchin, J., & Whittaker, S. G. (1999). Prescribing near magnification for low vision patients. *Clinical and Experimental Optometry*, *82*(6), 214–224.

Lowe, J., & Drasdo, N. (1992). Patients' responses to retinitis pigmentosa. *Optometry and Vision Science*, *69*(3), 182–185.

Luo, G., Satgunam, P., & Peli, E. (2012). Visual search performance of patients with vision impairment: effect of JPEG image enhancement. *Ophthalmic and Physiological Optics*, *32*(5), 421–8.

MacIntosh, C. (2003). Review articles-Stroke re-visited: Visual problems following stroke and their effect on rehabilitation. *British Orthoptic Journal*, (60), 10–14.

Mackenzie, P. J., Chang, T. S., Scott, I. U., Linder, M., Hay, D., Feuer, W. J., & Chambers, K. (2002). Assessment of vision-related function in patients with age-related macular degeneration. *Ophthalmology*, *109*(4), 720–729.

Mannan, S. K., Pambakian, A. L. M., & Kennard, C. (2010). Compensatory strategies following visual search training in patients with homonymous hemianopia: an eye movement study. *Journal of Neurology*, *257*(11), 1812–1821.

Markoff, J. I. (1972). Target recognition performance with chromatic and achromatic displays. Honeywell. *Inc. SRM-148, January*.

Markowitz, S. N. (2006). Principles of modern low vision rehabilitation. *Canadian Journal of Ophthalmology*, *41*(3), 289–312.

McCabe, P., Nason, F., Demers Turco, P., Friedman, D., & Seddon, J. M. (2000). Evaluating the effectiveness of a vision rehabilitation intervention using an objective and subjective measure of functional performance. *Ophthalmic Epidemiology*, *7*(4), 259–270.

McCreadie, C., & Tinker, A. (2005). The acceptability of assistive technology to older people. *Ageing and Society*, *25*(1), 91–110.

McDonald, S. A., Spitzyna, G., Shillcock, R. C., Wise, R. J. S., & Leff, A. P. (2006). Patients with hemianopic alexia adopt an inefficient eye movement strategy when reading text. *Brain*, *129*(1), 158–167.

McFadzean, R., Brosnahan, D., Hadley, D., & Mutlukan, E. (1994). Representation of the visual field in the occipital striate cortex. *The British Journal of Ophthalmology*, *78*(3), 185–190.

McFadzean, R. M., Doyle, D., Rampling, R., Teasdale, E., & Teasdale, G. (1991). Pituitary apoplexy and its effect on vision. *Neurosurgery*, *29*(5), 669–675.

McIlwaine, G. G., Carrim, Z. I., Lueck, C. J., & Chrisp, T. M. (2005). A mechanical theory to account for bitemporal hemianopia from chiasmal compression. *Journal of Neuro-Ophthalmology*, *25*(1), 40–43.

McMahon, T. T., Hansen, M., & Viana, M. (1991). Fixation characteristics in macular disease. Relationship between saccadic frequency, sequencing, and reading rate. *Investigative Ophthalmology and Visual Science*, *32*(3), 567–574.

Meads, C., & Hyde, C. (2003). What is the cost of blindness? *British Journal of Ophthalmology*, *87*(10), 1201–1204.

Meienberg, O., Zangemeister, W. H., Rosenberg, M., Hoyt, W. F., & Stark, L. (1981). Saccadic eye movement strategies in patients with homonymous hemianopia. *Annals of Neurology*, *9*(6), 537–544.

Miller, N. R., Walsh, F. B., & Hoyt, W. F. (Eds.). (2005). *Walsh and Hoyt's clinical neuro-ophthalmology* (Vol. 2). Lippincott Williams & Wilkins.

Mödden, C., Behrens, M., Damke, I., Eilers, N., Kastrup, A., & Hildebrandt, H. (2012). A randomized controlled trial comparing 2 interventions for visual field loss with standard occupational therapy during inpatient stroke rehabilitation. *Neurorehabilitation and Neural Repair*, *26*(5), 463–469.

Mosa, A. S. M., Yoo, I., & Sheets, L. (2012). A systematic review of healthcare applications for smartphones. *BMC Medical Informatics and Decision Making*, *12*(1), 67.

Nagy, A. L., & Sanchez, R. R. (1990). Critical color differences determined with a visual search task. *Journal of the Optical Society of America. A, Optics and Image Science*, *7*(7), 1209–1217.

Naidoo, K., Govender, P., & Holden, B. (2015). The uncorrected refractive error challenge. *Community Eye Health Journal*.

NCCMH (2004). Depression: Management of Depression in Primary and Secondary Care. British Psychological Society and Royal College of Psychiatrists: Leicester and London

Nelles, G., Esser, J., Eckstein, A., Tiede, A., Gerhard, H., & Diener, H. C. (2001). Compensatory visual field training for patients with hemianopia after stroke. *Neuroscience Letters*, *306*(3), 189–192.

Nemshick, L. A., McCay, V., & Ludman, F. (1986). The impact of retinitis pigmentosa on young adults: Psychological, educational, vocational and social considerations. *Journal of Visual Impairment & Blindness*, *80*(7), 859–862.

Newall, N. E., Chipperfield, J. G., Clifton, R. A., Perry, R. P., Swift, A. U., & Ruthig, J. C. (2009). Causal beliefs, social participation, and loneliness among older adults: A longitudinal study. *Journal of Social and Personal Relationships*, *26*(2–3), 273–290.

Nguyen, N. X., Stockum, A., Hahn, G. A., & Trauzettel-Klosinski, S. (2011). Training to improve reading speed in patients with juvenile macular dystrophy: a randomized study comparing two training methods. *Acta Ophthalmologica*, *89*(1), e82–e88.

Niekel, M. C., Lindenhovius, A. L. C., Watson, J. B., Vranceanu, A.-M., & Ring, D. (2009). Correlation of DASH and QuickDASH with measures of psychological distress. *The Journal of Hand Surgery*, *34*(8), 1499–1505.

Nilsson, U. L., Frennesson, C., & Nilsson, S. E. G. (2003). Patients with AMD and a large absolute central scotoma can be trained successfully to use eccentric viewing, as demonstrated in a scanning laser ophthalmoscope. *Vision Research*, *43*(16), 1777–1787.

Nouri, F. M., & Lincoln, N. B. (1987). An extended activities of daily living scale for stroke patients. *Clinical Rehabilitation*, *1*(4), 301–305.

Nys, G. M. S., Van Zandvoort, M. J. E., Van Der Worp, H. B., De Haan, E. H. F., De Kort, P. L. M., Jansen, B. P. W., & Kappelle, L. J. (2006). Early cognitive impairment predicts long-term depressive symptoms and quality of life after stroke. *Journal of the Neurological Sciences*, *247*(2), 149–156.

O'Neill, C., Jamison, J., McCulloch, D., & Smith, D. (2001). Age-Related Macular Degeneration. *Drugs & Aging*, *18*(4), 233–241.

Oduntan, a O. (2005). Prevalence and Causes of Low Vision and Blindness Worldwide. *South African Optometrist*, *64*(2), 44–54.

Ogra, S., Nichols, A. D., Stylli, S., Kaye, A. H., Savino, P. J., & Danesh-Meyer, H. V. (2014). Visual acuity and pattern of visual field loss at presentation in pituitary adenoma. *Journal of Clinical Neuroscience*, *21*(5), 735–740.

Ong, Y., Brown, M. M., Robinson, P., Plant, G. T., Husain, M., & Leff, A. P. (2012). Read-Right: a "web app" that improves reading speeds in patients with hemianopia. *Journal of Neurology*, *259*(12), 2611–2615.

Ong, Y., Jacquin-Courtois, S., Gorgoraptis, N., Bays, P. M., Husain, M., & Leff, A. P. (2015). Eye-Search: A web-based therapy that improves visual search in hemianopia. *Annals of Clinical and Translational Neurology*, *2*(1), 74–78.

Oomachi, K., Ogata, K., Sugawara, T., Hagiwara, A., Hata, A., Yamamoto, S., … Dandona, R. (1986). Contrast sensitivity versus visual acuity in retinal disease. *The British Journal of Ophthalmology*, *70*(7), 553–559.

Owsley, C. (2003). Contrast sensitivity. *Ophthalmology Clinics of North America*, *16*(2), 171–177.

Pambakian, A., & Kennard, C. (1997). Can visual function be restored in patients with homonymous hemianopia? *British Journal of Ophthalmology*, *81*(4), 324–328.

Pambakian, A., Mannan, S. K., Hodgson, T. L., & Kennard, C. (2004). Saccadic visual search training: a treatment for patients with homonymous hemianopia. *Journal of Neurology, Neurosurgery & Psychiatry*, *75*(10), 1443–1448.

Pambakian, A., Wooding, D., Patel, N., Morland, A., Kennard, C., & Mannan, S. (2000). Scanning the visual world: a study of patients with homonymous hemianopia. *Journal of Neurology, Neurosurgery, and Psychiatry*, *69*(6), 751–759.

Papageorgiou, E., Hardiess, G., Mallot, H. A., & Schiefer, U. (2012). Gaze patterns predicting successful collision avoidance in patients with homonymous visual field defects. *Vision Research*, *65*, 25–37.

Papageorgiou, E., Hardiess, G., Schaeffel, F., Wiethoelter, H., Karnath, H. O., Mallot, H., … Schiefer, U. (2007). Assessment of vision-related quality of life in patients with homonymous visual field defects. *Graefe's Archive for Clinical and Experimental Ophthalmology*, *245*(12), 1749–1758.

Papageorgiou, E., & Tsironi-Malizou, E. (2017). Neuro-Ophthalmological Examination in Homonymous Visual Field Defects. In *Homonymous Visual Field Defects*, 43–64.

Parmeggiani, F., Sato, G., De Nadai, K., Romano, M. R., Binotto, A., & Costagliola, C. (2011). Clinical and Rehabilitative Management of Retinitis Pigmentosa: Up-to-Date. *Current Genomics*, *12*(4), 250–259.

Pascolini, D., & Mariotti, S. P. (2012). Global estimates of visual impairment: 2010. *British Journal of Ophthalmology*, *96*(5), 614–618.

Passamonti, C., Bertini, C., & Làdavas, E. (2009). Audio-visual stimulation improves oculomotor patterns in patients with hemianopia. *Neuropsychologia*, *47*(2), 546–555.

Patel, A. T., Duncan, P. W., Lai, S.-M., & Studenski, S. (2000). The relation between impairments and functional outcomes poststroke. *Archives of Physical Medicine and Rehabilitation*, *81*(10), 1357–1363.

Perez, C., & Chokron, S. (2014). Rehabilitation of homonymous hemianopia: insight into blindsight. *Frontiers in Integrative Neuroscience*, *8*.

Pijnacker, J., Verstraten, P., van Damme, W., Vandermeulen, J., & Steenbergen, B. (2011). Rehabilitation of reading in older individuals with macular degeneration: a review of effective training programs. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition*, *18*(6), 708–732.

Plank, T., Rosengarth, K., Schmalhofer, C., Goldhacker, M., Brandl-Rühle, S., & Greenlee, M. W. (2014). Perceptual learning in patients with macular degeneration. *Frontiers in Psychology*, 5, 1189.

Pohjasvaara, T., Leppävuori, A., Siira, I., Vataja, R., Kaste, M., & Erkinjuntti, T. (1998). Frequency and clinical determinants of poststroke depression. *Stroke*, *29*(11), 2311–2317.

Pollock, A., Hazelton, C., Henderson, C. A., Angilley, J., Dhillon, B., Langhorne, P., … Rowe, F. J. (2011). Interventions for visual field defects in patients with stroke. *The Cochrane Library*, CD008388.

Poon, A., McNeill, P., Harper, A., & O'Day, J. (1995). Patterns of visual loss associated with pituitary macroadenomas. *Clinical and Experimental Ophthalmology*, *23*(2), 107–115.

Puchta, A. E. (2008). Why am I so tired after my stroke? *Journal of Vascular and Interventional Neurology*, *1*(2), 63.

Quinn, G. E., Miller, D. L., Evans, J. A., Tasman, W. E., McNamara, J. A., & Schaffer, D. B. (1996). Measurement of Goldmann visual fields in older children who received cryotherapy as infants for threshold retinopathy of prematurity. *Archives of Ophthalmology*, *114*(4), 425–428.

Rand, D., Schejter-Margalit, T., Dudkiewicz, I., Kizony, R., & Zeilig, G. (2013, August). The use of the iPad for poststroke hand rehabilitation; a pilot study. *Virtual Rehabilitation*, 109-113.

Reding, M. J., & Potes, E. (1988). Rehabilitation outcome following initial unilateral hemispheric stroke. Life table analysis approach. *Stroke*, *19*(11), 1354–1358.

Reinhard, J. I., Damm, I., Ivanov, I. V, & Trauzettel-Klosinski, S. (2014). Eye movements during saccadic and fixation tasks in patients with homonymous hemianopia. *Journal of Neuro-Ophthalmology*, *34*(4), 354–361.

Renninger, L., Dang, L., Verghese, P., & Fletcher, D. (2008). Effect of central scotoma on eye movement behavior. *Journal of Vision*, *8*(6), 641.

Riley, M., Kelly, K., Martin, T., Hayhoe, M., & Huxlin, K. (2007). Homonymous hemianopia alters distribution of visual fixations in 3-dimensional virtual environments. *Journal of Vision*, *7*(9), 289.

Rosengarth, K., Keck, I., Brandl-Rühle, S., Frolo, J., Hufendiek, K., Greenlee, M. W., & Plank, T. (2013). Functional and structural brain modifications induced by oculomotor training in patients with age-related macular degeneration. *Frontiers in Psychology*, *4*, 428.

Ross, J. E., Bron, A. J., & Clarke, D. D. (1984). Contrast sensitivity and visual disability in chronic simple glaucoma. *British Journal of Ophthalmology*, *68*(11), 821–827.

Roth, T., Sokolov, A. N., Messias, A., Roth, P., Weller, M., & Trauzettel-Klosinski, S. (2009). Comparing explorative saccade and flicker training in hemianopia A randomized controlled study. *Neurology*, *72*(4), 324–331.

Rovner, B. W., & Casten, R. J. (2002). Activity loss and depression in age-related macular degeneration. *The American Journal of Geriatric Psychiatry*, *10*(3), 305–310.

Rovner, B. W., Zisselman, P. M., & Shmuely-Dulitzki, Y. (1996). Depression and disability in older people with impaired vision: a follow-up study. *Journal of the American Geriatrics Society*, *44*(2), 181–184.

Rovner, B. W., & Casten, R. J. (2002). Activity loss and depression in age-related macular degeneration. *The American Journal of Geriatric Psychiatry*, *10*(3), 305–310.

Rowe, F., Brand, D., Jackson, C. A., Price, A., Walker, L., Harrison, S., … Freeman, C. (2009). Visual impairment following stroke: do stroke patients require vision assessment? *Age and Ageing*, *38*(2), 188–193.

Rowe, F., Conroy, E. J., Bedson, E., Cwiklinski, E., Drummond, A., García-Fiñana, M., … Sackley, C. (2017). A pilot randomized controlled trial comparing effectiveness of prism glasses, visual search training and standard care in hemianopia. *Acta Neurologica Scandinavica*, *136*(4), 310–321.

Rowe, F., Wright, D., Brand, D., Jackson, C., Harrison, S., Maan, T., … Akerman, N. (2013). A prospective profile of visual field loss following stroke: prevalence, type, rehabilitation, and outcome. *BioMed Research International*, *2013*.

Rowe, F., Walker, M., Rockliffe, J., Pollock, A., Noonan, C., Howard, C., & Currie, J. (2016). Delivery of high quality stroke and vision care: experiences of UK services. *Disability and Rehabilitation*, *38*(8), 813–817.

Rubin, G. S., & Feely, M. (2009). The Role of Eye Movements During Reading in Patients with Age-Related Macular Degeneration (AMD). *Neuro-Ophthalmology*, *33*(3), 120–126.

Rubin, G. S., West, S. K., Munoz, B., Bandeen-Roche, K., Zeger, S., Schein, O., & Fried, L. P. (1997). A comprehensive assessment of visual impairment in a population of older Americans. The SEE Study. Salisbury Eye Evaluation Project. *Investigative Ophthalmology & Visual Science*, *38*(3), 557–568.

Russell, W., Harper, R., Reeves, B., Waterman, H., Henson, D., & McLeod, D. (2001). Randomised controlled trial of an integrated versus an optometric low vision rehabilitation service for patients with age-related macular degeneration: study design and methodology. *Ophthalmic and Physiological Optics*, *21*(1), 36–44.

Sabel, B. A., & Trauzettel-Klosinksi, S. (2005). Improving vision in a patient with homonymous hemianopia. *Journal of Neuro-Ophthalmology*, *25*(2), 143–149.

Sahraie, A., Smania, N., & Zihl, J. (2016). Use of NeuroEyeCoach™ to Improve Eye Movement Efficacy in Patients with Homonymous Visual Field Loss. *BioMed Research International*, *2016*, 5186461-5186461.

Saltapidas, H., & Ponsford, J. (2007). The influence of cultural background on motivation for and participation in rehabilitation and outcome following traumatic brain injury. *J Head Trauma Rehabilitation*, *22*(2), 132–139.

Sandberg, M. A., & Gaudio, A. R. (2006). Reading speed of patients with advanced retinitis pigmentosa or choroideremia. *Retina (Philadelphia, Pa.)*, *26*(1), 80–88.

Saposnik, G., Chow, C.-M., Gladstone, D., Cheung, D., Brawer, E., Thorpe, K. E., … Schweizer, T. A. (2014). iPad technology for home rehabilitation after stroke (iHOME): a proof-of-concept randomized trial. *International Journal of Stroke*, *9*(7), 956–962.

Satgunam, P., Woods, R. L., Luo, G., Bronstad, P. M., Reynolds, Z., Ramachandra, C., … Peli, E. (2012). Effects of contour enhancement on low-vision preference and visual search. *Optometry and Vision Science*, *89*(9), E1364.

Schatz, H., & McDonald, H. R. (1989). Atrophic macular degeneration: rate of spread of geographic atrophy anti visual loss. *Ophthalmology*, *96*(10), 1541–1551.

Schuett, S. (2009). The rehabilitation of hemianopic dyslexia. *Nature Reviews Neurology*, *5*(8), 427–437.

Schuett, S., Heywood, C. A., Kentridge, R. W., Dauner, R., & Zihl, J. (2012). Rehabilitation of reading and visual exploration in visual field disorders: transfer or specificity? *Brain*, *135*(3), 912–921.

Schuett, S., Heywood, C. A., Kentridge, R. W., & Zihl, J. (2008a). Rehabilitation of hemianopic dyslexia: are words necessary for re-learning oculomotor control? *Brain*, *131*(12), 3156–3168.

Schuett, S., Heywood, C. A., Kentridge, R. W., & Zihl, J. (2008b). The significance of visual information processing in reading: Insights from hemianopic dyslexia. *Neuropsychologia*, *46*(10), 2445–2462.

Schuett, S., Kentridge, R. W., Zihl, J., & Heywood, C. A. (2009). Adaptation of eye-movements to simulated hemianopia in reading and visual exploration: Transfer or specificity? *Neuropsychologia*, *47*(7), 1712–1720.

Schuett, S., & Zihl, J. (2013). Does age matter? Age and rehabilitation of visual field disorders after brain injury. *Cortex*, *49*(4), 1001–1012.

Schuster, D., Rivera, J., Sellers, B. C., Fiore, S. M., & Jentsch, F. (2013). Perceptual training for visual search. *Ergonomics*, *56*(7), 1101–1115.

Schwartz, R., & Loewenstein, A. (2015). Early detection of age related macular degeneration: current status. *International Journal of Retina and Vitreous*, *1*(1), 20.

Scialfa, C. T., Jenkins, L., Hamaluk, E., & Skaloud, P. (2000). Aging and the development of automaticity in conjunction search. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *55*(1), 27-46.

Scialfa, C. T., & Joffe, K. M. (1998). Response times and eye movements in feature and conjunction search as a function of target eccentricity. *Perception & Psychophysics*, *60*(6), 1067–1082.

Seiple, W., Grant, P., & Szlyk, J. P. (2011). Reading rehabilitation of individuals with AMD: relative effectiveness of training approaches. *Investigative Ophthalmology & Visual Science*, *52*(6), 2938–2944.

Seiple, W., Szlyk, J. P., McMahon, T., Pulido, J., & Fishman, G. A. (2005). Eye-movement training for reading in patients with age-related macular degeneration. *Investigative Ophthalmology & Visual Science*, *46*(8), 2886–2896.

Senger, C., Margarido, M. R. R. A., De Moraes, C. G., De Fendi, L. I., Messias, A., & Paula, J. S. (2017). Visual Search Performance in Patients with Vision Impairment: A Systematic Review. *Current Eye Research*, *42*(11), 1561–1571.

Shervin, N., Dorrwachter, J., Bragdon, C. R., Shervin, D., Zurakowski, D., & Malchau, H. (2011). Comparison of paper and computer-based questionnaire modes for measuring health outcomes in patients undergoing total hip arthroplasty. *The Journal of Bone and Joint Surgery*, 93(3), 285–293.

Shingleton, B. J., & O'Donoghue, M. W. (2000). Blurred vision. *New England Journal of Medicine*, *343*(8), 556–562.

Shuttleworth, G. N., Dunlop, A., Collins, J. K., & James, C. R. (1995). How effective is an integrated approach to low vision rehabilitation? Two year follow up results from south Devon. *British Journal of Ophthalmology*, *79*(8), 719–723.

Silva, M., Nobre, M., Carvalho, K., & Montilha, R. (2014). Visual impairment, rehabilitation and International Classification of Functioning, Disability and Health. *Revista Brasileira de Oftalmologia*, *73*(5), 291-301.

Simpson, S. A., Abegg, M., & Barton, J. J. S. (2010). Rapid adaptation of visual search in simulated hemianopia. *Cerebral Cortex*, *21*(7), 1593–1601.

Sireteanu, R., & Rettenbach, R. (1995). Perceptual learning in visual search: fast, enduring, but non-specific. *Vision Research*, *35*(14), 2037–2043.

Sireteanu, R., & Rettenbach, R. (2000). Perceptual learning in visual search generalizes over tasks, locations, and eyes. *Vision Research*, *40*(21), 2925–2949.

Skeel, R. L., Nagra, A., VanVoorst, W., & Olson, E. (2003). The relationship between performance-based visual acuity screening, self-reported visual acuity, and neuropsychological performance. *The Clinical Neuropsychologist*, *17*(2), 129–36.

Smiddy, W. E., & Fine, S. L. (2017). Prognosis of Patients with Bilateral Macular Drusen. *Ophthalmology*, *91*(3), 271–277.

Smith, C. (2011). Confrontation visual field testing: detecting gross visual field defects. *International Journal of Ophthalmic Practice*, *2*(5), 200–207.

Smith, M., Mole, C. D., Kountouriotis, G. K., Chisholm, C., Bhakta, B., & Wilkie, R. M. (2015). Driving with homonymous visual field loss: Does visual search performance predict hazard detection? *British Journal of Occupational Therapy*, *78*(2), 85–95.

Smith, N. D., Glen, F. C., & Crabb, D. P. (2012). Eye movements during visual search in patients with glaucoma. *BMC Ophthalmology*, *12*(1), 45.

Smith, N. D., Glen, F. C., Mönter, V. M., & Crabb, D. P. (2014). Using eye tracking to assess reading performance in patients with glaucoma: a within-person study. *Journal of Ophthalmology*, 2014, 120528

Solan, H. A., Feldman, J., & Tujak, L. (1995). Developing visual and reading efficiency in older adults. *Optometry and Vision Science*, *72*(2), 139–145.

Spitzyna, G. A., Wise, R. J. S., McDonald, S. A., Plant, G. T., Kidd, D., Crewes, H., & Leff, A. P. (2007). Optokinetic therapy improves text reading in patients with hemianopic alexia A controlled trial. *Neurology*, *68*(22), 1922–1930.

Spofforth, J., Codina, C., & Bjerre, A. (2017). Is the 'visual fields easy'application a useful tool to identify visual field defects in patients who have suffered a stroke?. *Ophthalmology Research*, 7(1), 1-10.

Staub, F., & Bogousslavsky, J. (2001). Fatigue after stroke: a major but neglected issue. *Cerebrovascular Diseases*, *12*(2), 75–81.

Stelmack, J. A., Rosenbloom, A. A., Brenneman, C. S., & Stelmack, T. R. (2003). Patients' perceptions of the need for low vision devices. *Journal of Visual Impairment and Blindness*, *97*(9), 521–535.

Sudano Jr, J. J., Kofford, B., & Wotman, S. (2005). Using tablet PC's in dental practice research: Technology, cost savings, and direct data entry" on the go." *Journal of Public Health Dentistry*, *65*(4), 244–245.

Sumi, I., Matsumoto, S., Okajima, O., & Shirato, S. (2000). The relationship between visual disability and visual scores in patients with retinitis pigmentosa. *Japanese Journal of Ophthalmology*, *44*(1), 82–87.

Sunness, J. S., Applegate, C. A., Haselwood, D., & Rubin, G. S. (1996). Fixation patterns and reading rates in eyes with central scotomas from advanced atrophic age-related macular degeneration and Stargardt disease. *Ophthalmology*, *103*(9), 1458–1466.

Sunness, J. S., Gonzalez-Baron, J., Applegate, C. A., Bressler, N. M., Tian, Y., Hawkins, B., … Bergman, A. (1999). Enlargement of atrophy and visual acuity loss in the geographic atrophy form of age-related macular degeneration. *Ophthalmology*, *106*(9), 1768–1779.

Sunness, J. S., Rubin, G. S., Applegate, C. A., Bressler, N. M., Marsh, M. J., Hawkins, B. S., & Haselwood, D. (1997). Visual function abnormalities and prognosis in eyes with age-related geographic atrophy of the macula and good visual acuity. *Ophthalmology*, *104*(10), 1677–1691.

Suter, P. S. (2016). Rehabilitation and management of visual dysfunction following traumatic brain injury. In *Traumatic brain injury* (pp. 323–370). CRC Press.

Symister, P., & Friend, R. (2003). The influence of social support and problematic support on optimism and depression in chronic illness: A prospective study evaluating self-esteem as a mediator. *Health Psychology*, *22*(2), 123.

Szlyk, J. P., Alexander, K. R., Severing, K., & Fishman, G. A. (1992). Assessment of driving performance in patients with retinitis pigmentosa. *Archives of Ophthalmology (Chicago, Ill. : 1960)*, *110*(12), 1709–1713.

Szlyk, J. P., Fishman, G. A., Alexander, K. R., Revelins, B. I., Derlacki, D. J., & Anderson, R. J. (1997). Relationship between difficulty in performing daily activities and clinical measures of visual function in patients with retinitis pigmentosa. *Archives of Ophthalmology*, *115*(1), 53–9.

Szlyk, J. P., Seiple, W., Fishman, G. A., Alexander, K. R., Grover, S., & Mahler, C. L. (2001). Perceived and actual performance of daily tasks: relationship to visual function tests in individuals with retinitis pigmentosa. *Ophthalmology*, *108*(1), 65–75.

Tadin, D., Nyquist, J. B., Lusk, K. E., Corn, A. L., & Lappin, J. S. (2012). Peripheral vision of youths with low vision: motion perception, crowding, and visual search. *Investigative Ophthalmology and Visual Science*, *53*(9), 5860–5868.

Tant, M., Cornelissen, F., Kooijman, A., & Brouwer, W. (2002). Hemianopic visual field defects elicit hemianopic scanning. *Vision Res*, *42*(10), 1339–1348.

Tant, M. (2002). Visual performance in homonymous hemianopia: assessment, training and driving (Doctoral dissertation).

Taylor, D. J., Hobby, A. E., Binns, A. M., & Crabb, D. P. (2016). How does age-related macular degeneration affect real-world visual ability and quality of life? A systematic review. *British Medical Journal open*, 6(12), e011504.

Taylor, D. J., Smith, N. D., & Crabb, D. P. (2017). Searching for Objects in Everyday Scenes: Measuring Performance in People With Dry Age-Related Macular Degeneration. *Investigative Ophthalmology and Visual Science*, *58*(3), 1887–1892.

Timberlake, G. T., Peli, E., Essock, E. A., & Augliere, R. A. (1987). Reading with a macular scotoma. II. Retinal locus for scanning text. *Investigative Ophthalmologyand& Visual Science*, *28*(8), 1268–1274.

Timmis, M. A., Allsop, J., Baranian, M., Baker, J., Basevitch, I., Latham, K., ... & van Paridon, K. N. (2017). Visual search behavior in individuals with retinitis pigmentosa during level walking and obstacle crossing. *Investigative Ophthalmology and Visual Science*, 58(11), 4737-4746.

Tinelli, F., Cioni, G., & Purpura, G. (2017). Development and Implementation of a New telerehabilitation system for Audiovisual stimulation training in Hemianopia. *Frontiers in Neurology*, 8, 621.

Townend, B. S., Sturm, J. W., Petsoglou, C., O'Leary, B., Whyte, S., & Crimmins, D. (2007). Perimetric homonymous visual field loss post-stroke. *Journal of Clinical Neuroscience*, *14*(8), 754–756.

Trauzettel-Klosinski, S. (1997). Eccentric fixation with hemianopic field defects: A valuable strategy to improve reading ability and an indication of cortical plasticity. *Neuro-Ophthalmology*, *18*(3), 117–131.

Trauzettel-Klosinski, S. (2017). Adaptation and Rehabilitation in Patients with Homonymous Visual Field Defects. In *Homonymous Visual Field Defects*, 161–173.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*(1), 97–136.

Tsai, S.-Y., Cheng, C.-Y., Hsu, W.-M., Su, T. P., Liu, J.-H., & Chou, P. (2003). Association between visual impairment and depression in the elderly. *Journal of the Formosan Medical Association*, *102*(2), 86–90.

Turano, K. A., Broman, A. T., Bandeen-Roche, K., Munoz, B., Rubin, G. S., West, S. K., & Team, S. E. E. P. (2004). Association of visual field loss and mobility performance in older adults: Salisbury Eye Evaluation Study. *Optometry and Vision Science*, *81*(5), 298–307.

Turano, K. A., Geruschat, D. R., Baker, F. H., Stahl, J. W., & Shapiro, M. D. (2001). Direction of gaze while walking a simple route: persons with normal vision and persons with retinitis pigmentosa. *Optometry and Vision Science*, 78(9), 667-675.

Turano, K. A., Geruschat, D. R., Stahl, J. W., & Massof, R. W. (1999). Perceived visual ability for independent mobility in persons with retinitis pigmentosa. *Investigative Ophthalmology and Visual Science*, *40*(5), 865–877.

Van der Stigchel, S., Bethlehem, R. A., Klein, B. P., Berendschot, T. T., Nijboer, T., & Dumoulin, S. O. (2013). Macular degeneration affects eye movement behavior during visual search. *Frontiers in Psychology*, 4, 579.

Vargas-Martin, F., & Peli, E. (2006). Eye movements of patients with tunnel vision while walking. *Investigative Ophthalmology and Visual Science*, *47*(12), 5295–5302.

Vashist, P., Senjam, S. S., Gupta, V., Gupta, N., & Kumar, A. (2017). Definition of blindness under National Programme for Control of Blindness: Do we need to revise it? *Indian Journal of Ophthalmology*, *65*(2), 92–96.

Veerbeek, J. M., van Wegen, E., van Peppen, R., van der Wees, P. J., Hendriks, E., Rietberg, M., & Kwakkel, G. (2014). What is the evidence for physical therapy poststroke? A systematic review and meta-analysis. *PloS one*, *9*(2), e87987.

Virgili, G., Pierrottet, C., Parmeggiani, F., Pennino, M., Giacomelli, G., Steindler, P., … Orzalesi, N. (2004). Reading Performance in Patients with Retinitis Pigmentosa: A Study Using the MNREAD Charts. *Investigative Ophthalmology and Visual Science*, *45*(10), 3418–3424.

Von Korff, M., Gruman, J., Schaefer, J., Curry, S. J., & Wagner, E. H. (1997). Collaborative management of chronic illness. *Annals of Internal Medicine*, *127*(12), 1097–1102.

Wade, D. T. (2009). Goal setting in rehabilitation: an overview of what, why and how. *Clinical rehabilitation*, 23(4), 291.

Walker, R., Mannan, S., Maurer, D., Pambakian, A. L. M., & Kennard, C. (2000). The oculomotor distractor effect in normal and hemianopic vision. *Proceedings of the Royal Society of London B: Biological Sciences*, 267(1442), 431-438.

Wang, Y.-P., & Gorenstein, C. (2013). Assessment of depression in medical patients: A systematic review of the utility of the Beck Depression Inventory-II. *Clinics*, *68*(9), 1274–1287.

Warren, M. (2009). Pilot study on activities of daily living limitations in adults with hemianopsia. *The American Journal of Occupational Therap*y, 63(5), 626.

Watson, G. R. (2001). Low vision in the geriatric population: rehabilitation and management. *Journal of the American Geriatrics Society*, *49*(3), 317–330.

Weale, R. A. (2003). Epidemiology of refractive errors and presbyopia. *Survey of ophthalmology*, 48(5), 515-543.

Weiskrantz, L. (2004). Roots of blindsight. *Progress in Brain Research*, *144*, 227–241.

Wheatley, C. M., Dickinson, J. L., Mackey, D. A., Craig, J. E., & Sale, M. M. (2002). Retinopathy of prematurity: recent advances in our understanding. *Archives of Disease in Childhood-Fetal and Neonatal Edition*, *87*(2), F78–F82.

White, J. M., & Bedell, H. E. (1990). The oculomotor reference in humans with bilateral macular disease. *Investigative Ophthalmology and Visual Science*, *31*(6), 1149–1161.

Whittaker, S. G., Cummings, R. W., & Swieson, L. R. (1991). Saccade control without a fovea. *Vision Research*, *31*(12), 2209–2218.

WHO World Health Organization. (2001). *International classification of functioning, disability and health: ICF*. Geneva: World Health Organization.

Wilkinson, J. M., Cozine, E. W., Khan, A. R., & Kahn, A. R. (2017). Refractive Eye Surgery: Helping Patients Make Informed Decisions About LASIK. *American Family Physician*, *95*(10).

Williams, R. A., Brody, B. L., Thomas, R. G., Kaplan, R. M., & Brown, S. I. (1998). The psychosocial impact of macular degeneration. *Archives of Ophthalmology*, *116*(4), 514–520.

Wolfe, J. M., Alvarez, G. A., Rosenholtz, R., Kuzmova, Y. I., & Sherman, A. M. (2011). Visual search for arbitrary objects in real scenes. *Attention, Perception & Psychophysics*, *73*(6), 1650–1671.

Wolff, J. L., Starfield, B., & Anderson, G. (2002). Prevalence, expenditures, and complications of multiple chronic conditions in the elderly. *Archives of Internal Medicine*, *162*(20), 2269–2276.

Wolffsohn, J. S., & Eperjesi, F. (2004). Predicting prescribed magnification. *Ophthalmic and Physiological Optics*, *24*(4), 334-338.

Wolffsohn, J. S., & Eperjesi, F. (2005). The effect of relative distance enlargement on visual acuity in the visually impaired. *Clinical and Experimental Optometry*, *88*(2), 97–102.

Wong, W. L., Su, X., Li, X., Cheung, C. M. G., Klein, R., Cheng, C.-Y., & Wong, T. Y. (2014). Global prevalence of age-related macular degeneration and disease burden projection for 2020 and 2040: a systematic review and meta-analysis. *The Lancet Global Health*, *2*(2), e106–e116.

Woodhead, Z. V. J., Ong, Y. H., & Leff, A. P. (2015). Web-based therapy for hemianopic alexia is syndrome-specific. *British Medical Journal Innovations*, 1(3), 88-95.

Wressle, E., Eeg-Olofsson, A.-M., Marcusson, J., & Henriksson, C. (2002). Improved client participation in the rehabilitation process using a client-centred goal formulation structure. *Journal of Rehabilitation Medicine*, *34*(1), 5–11.

Wurm, L. H., Legge, G. E., Isenberg, L. M., & Luebker, A. (1993). Color improves object recognition in normal and low vision. *Journal of Experimental Psychology: Human Perception and Performance*, *19*(4), 899.

Ylvisaker, M., Mcpherson, K., Kayes, N., & Pellett, E. (2008). Metaphoric identity mapping: Facilitating goal setting and engagement in rehabilitation after traumatic brain injury. *Neuropsychological Rehabilitation*, *18*(5–6), 713–741.

Yoshida, M., Origuchi, M., Urayama, S. I., Takatsuki, A., Kan, S., Aso, T., ... & Seiyama, A. (2014). fMRI evidence of improved visual function in patients with progressive retinitis pigmentosa by eye-movement training. *NeuroImage: Clinical*, 5, 161-168.

Zhang, X., Kedar, S., Lynn, M. J., Newman, N. J., & Biousse, V. (2006). Natural history of homonymous hemianopia. *Neurology*, *66*(6), 901–905.

Zihl, J. (1995a). Eye movement patterns in hemianopic dyslexia. *Brain*, *118*(4), 891–912.

Zihl, J. (1995b). Visual scanning behavior in patients with homonymous hemianopia. *Neuropsychologia*, *33*(3), 287–303.

Zihl, J. (2010). *Rehabilitation of visual disorders after brain injury*. Psychology Press.

Zihl, J., & Von Cramon, D. (1985). Visual field recovery from scotoma in patients with postgeniculate damage. *Brain*, *108*(2), 335–365.

Appendix A: NHS Ethical Approval

NHS
Health Research Authority
NRES Committee North East - Newcastle & North Tyneside 1
Jarrow Business Centre
Jarrow REC Centre
Room 001
Rolling Mill Road
Jarrow
NE32 3DT

Telephone: 0191 428 3565

9 December 2015

Mr Azuwan Musa
PhD Student
Cognitive Neuroscience Research Unit
Wolfson Research Institute
Durham University Queen's Campus
Durham University
Stockton-on-Tees
TS17 6BH

Dear Mr Musa

Study title:	**Efficacy of visuomotor training for individuals with visual field defects**
REC reference:	**15/NE/0351**
Protocol number:	**N/A**
IRAS project ID:	**188218**

Thank you for your letter of 1 December 2015, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details. Publication will be no earlier than three months from the date of this opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to make a request to postpone publication, please contact the REC Manager, Ms Gillian Mayer, nrescommittee.northeast-newcastleandnorthtyneside1@nhs.net.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a **Favourable** ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

Conditions of the favourable opinion

The REC favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements. Each NHS organisation must confirm through the signing of agreements and/or other documents that it has given permission for the research to proceed (except where explicitly specified otherwise).

Guidance on applying for NHS permission for research is available in the Integrated Research Application System, www.hra.nhs.uk or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of management permissions from host organisations

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database within 6 weeks of recruitment of the first participant (for medical device studies, within the timeline determined by the current registration and publication trees).

There is no requirement to separately notify the REC but you should do so at the earliest opportunity, e.g. when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non-clinical trials this is not currently mandatory.

If a sponsor wishes to contest the need for registration they should contact Catherine Blewett (catherineblewett@nhs.net), the HRA does not, however, expect exceptions to be made. Guidance on where to register is provided within IRAS.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Ethical review of research sites

NHS sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Non-NHS sites

The Committee has not yet completed any site-specific assessment (SSA) for the non-NHS research site(s) taking part in this study. The favourable opinion does not therefore apply to any non-NHS site at present. We will write to you again as soon as an SSA application(s) has been reviewed. In the meantime no study procedures should be initiated at non-NHS sites.

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	*Version*	*Date*
Covering letter on headed paper [Cover Letter and Response to Previous Unfavourable Opinion Version 2]	2	30 September 2015
Evidence of Sponsor insurance or indemnity (non-NHS Sponsors only) [Durham Professional Indemnity]	1	20 July 2015
GP/consultant information sheets or letters [GP Information Sheet_V2]	2	01 August 2015
Letter from funder [Letter from Funder]	1	24 November 2014
Letter from sponsor [Letter from Sponsor]	1	02 June 2015
Letter from statistician [Letter from Statistician]	1	06 August 2015
Letters of invitation to participant [Participant Invitation Letter_V3]	3	23 November 2015
Other [CV Amanda Ellison]	1	26 February 2015
Other [CV Neil Archibald]	1	20 June 2015
Other [Motivation Questionnaire]		
Other [Visual Impairment Questionnaire]		
Other [Self-ability and Attitude Questionnaire]		
Other [15-NE-0240 Unfavourable Opinion Letter]		28 July 2015
Other [Protocol for Management of Suicide Risk_V1]	1	23 November 2015
Other [Covering Letter_V3 – Response Letter]	3	01 December 2015
Participant consent form [Participant Consent Form_V3]	3	23 November 2015
Participant information sheet (PIS) [Participant Information Sheet_V3]	3	23 November 2015
REC Application Form [REC_Form_28092015]		28 September 2015
Referee's report or other scientific critique report [Departmental Ethics Letter]	1	21 May 2015
Research protocol or project proposal [Research Protocol_V2]	2	01 August 2015
Summary CV for Chief Investigator (CI) [CV Azuwan Musa]	1	26 February 2015
Summary CV for supervisor (student research) [CV Alison Lane]	1	07 March 2015
Summary, synopsis or diagram (flowchart) of protocol in non-technical language [Flowchart of DREX Protocol_V2]	2	01 August 2015
Validated questionnaire [Beck Depression Inventory II]		

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document *"After ethical review – guidance for researchers"* gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The HRA website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

User Feedback

The Health Research Authority is continually striving to provide a high quality service to all applicants and sponsors. You are invited to give your view of the service you have received and the application procedure. If you wish to make your views known please use the feedback form available on the HRA website: http://www.hra.nhs.uk/about-the-hra/governance/quality-assurance/

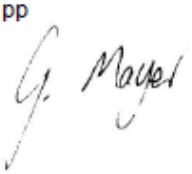
HRA Training

We are pleased to welcome researchers and R&D staff at our training days – see details at http://www.hra.nhs.uk/hra-training/

15/NE/0351	**Please quote this number on all correspondence**

With the Committee's best wishes for the success of this project.

Yours sincerely
pp



Professor Philip Preshaw
Chair

Email: nrescommittee.northeast-newcastleandnorthtyneside1@nhs.net

Enclosures: 'After ethical review – guidance for researchers'

Copy to: Dr Alison Lane - Cognitive Neuroscience Research Unit, Wolfson Research Institute, Durham University

Mr Jon Davidson – R&D Dept, Durham University

Appendix B: Participant Invitation Letter

Date: ……..

Dear ……,

Participant Invitation Letter: Visuomotor training for Hemianopia

I am writing with regards to a research project that is being conducted at Durham University into a training programme for people with visual field defects. The chief investigator is Mr Azuwan Musa. Enclosed with this letter is a Participant Information Sheet from him that explains about the research and what your participation would involve.

Briefly, throughout the study you will be asked to complete four assessment sessions. The first three of these will be approximately 6 weeks apart, and the final one 3 months later. Depending on the group to which you are allocated you may be asked to complete exploration and then reading training over the course of 12 weeks between the first three assessment sessions. The training is done using either a computer or a touchscreen device, and the relevant device can be provided. All assessments and the training can be done conveniently at your home.

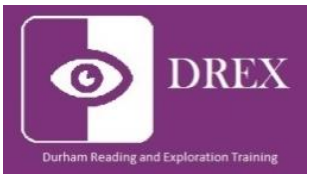
I hope that you find the Participant Information Sheet useful. If you require the information sheet in larger print or a different format, or would like to talk to someone about the research, then please do not hesitate to contact either myself, Mr Musa, or any of the researchers involved. Contact details are provided in the Participant Information Sheet.

If you would like to be contacted to discuss the research further, please complete the attached **Reply Slip** and then return this to Mr Musa using the stamped addressed envelope provided. Once your reply slip is received the investigators will contact you to arrange an appointment. Alternatively, you may phone Mr Musa and register your interest or ask questions directly via 0191 334 0588.

Thank you very much for your time.
Yours sincerely,

……
Name:

REPLY SLIP



Dear Mr. Azuwan Musa,

I hereby agree to be contacted to discuss the research project entitled 'Visuomotor training for Hemianopia'. You may contact me via the details below.

Thank you.

Name:

_____

Address:

_____

_____

_____

Postcode: _____

Contact no.: _____

Signature:

Date: _____

Please send this reply slip to:

Mr. Azuwan Musa
Cognitive Neuroscience Research Unit,
Wolfson Research Institute,
Durham University Queen's Campus,
Stockton-on-Tees, TS17 6BH
Tel: 0191 3340588 / 07481157071

Appendix C: Participant Information Sheet

Cognitive Neuroscience Research Unit
Wolfson Research Institute
Durham University Queen's Campus
Stockton-on-Tees
TS17 6BH

Version 3 – 23/11/2015

PARTICIPANT INFORMATION SHEET

Title of Project: ***Visuomotor Training for Hemianopia***

Name of Researcher: Mr Azuwan Musa; Dr Alison Lane;

Dr Amanda Ellison; Dr Neil Archibald

Thank you for taking the time to read this information sheet. We are pleased to invite you to participate in this research project. Outlined below are details about the project that will help you to decide whether to take part or not. Please ask the researcher if you have any questions or require further information.

What is the purpose of the study?

We are developing a new training program that can help people who have partial blindness. The aim of the training is to encourage people to maximize the use of their remaining sight using a touchscreen or computer-based training. If successful, then the training will provide a quick and user-friendly tool that can improve peoples' searching and reading skills.

Why have I been chosen?

You are at least 18 years old and have partial blindness as a result of brain injury or stroke which affects your ability to read or explore your surroundings.

Do I have to take part?

No, it is up to you to decide if you want to take part. If you do, you will be asked to sign a consent form. You are still free to withdraw at any

time. You do not have to give any reason for withdrawing and doing so will not affect your care in any way.

What are the possible disadvantages and risks of taking part?

You will be asked to do a number of assessment tests and to take part in a training program. Although some of the assessment tests and the training might be a bit tiring, they are neither painful nor harmful and therefore do not pose a risk. We can do the assessment tests in your home if that is most convenient. If you would prefer to do these at the University (Wolfson Research Institute in Stockton-on-Tees), then this can be arranged and any transport costs would be reimbursed. The assessment tests should last for no more than 2 hours.

The training program would require you to complete approximately 35 hours of training at home over the course of 12 weeks. Half of the training (6 weeks) is an exploration training. The other half (6 weeks) is a reading training. The training would be done using either a computer or touchscreen device, and this will be provided if you do not have one. Half way through the training and then again at the end of the training, we would repeat the assessment tests either in your home or at the University. This is necessary for us to determine if the training is successful. You will be invited to complete the assessment tests one further time, 3 months after the end of the training, so that any longer term benefits can be measured.

What are the possible benefits of taking part?

We hope the training program will improve your ability to cope better in tasks where sight is important (e.g. reading, finding your way around). If the training is successful, it could possibly benefit many others who suffer from partial blindness. You should be aware that this training is not meant to restore your lost sight, but it is designed to make better use of your remaining sight.

What will happen to me if I take part?

With your approval, we will consult your medical records for information about your current medical condition and brain damage. The first thing we will ask you to complete is a set of assessment tests that will tell us how your brain damage has affected your sight and how well you are coping with the partial blindness.

The assessment tests are:

1. Near vision test – A test of your vision at near distance.
2. Perimetry (Visual field test) – Two short tests of your ability to see spots of light. These are used to find the areas of partial blindness.
3. Reading – You will be asked to read two short passages (one on paper and one on a computer screen or touchscreen device). We will record the reading speed and accuracy.
4. Visual search – The three tasks will be presented on a computer screen or touchscreen device. You will have to find a specific number or item on the screen. Your speed and accuracy will be recorded.
5. Short term memory – A test of your ability to remember information like identical numbers.
6. Questionnaires – There are 5 questionnaires relating to your motivation, mood and sight loss. One will be conducted on a touchscreen device and the others done on paper.

After the assessment tests, you will be randomly assigned to one of three groups:

1. Standard care group – Participants in this group will continue with any present treatment given by their doctor.

2. Visuomotor training group – Participants in this group will do the visual exploration training followed by the reading training on a touchscreen device. The training will be done at home. Both training tasks require participants to make decisions based on what they see or read (e.g., pictures, numbers or words). Training difficulty will increase depending on individual achievement. The touchscreen device will store information about program use and training performance for monitoring purposes.

3. Computer training group – Participants in this group will do the same training as the visuomotor training group, but the training is completed using a computer or laptop.

The visuomotor and computer training groups will be invited to repeat the assessment tests after they have completed the visual exploration training, and then again after the reading training. A final assessment will be 3 months after the end of the training. The standard care group will also be invited for these assessment tests. They will be called 6 weeks after the first assessment tests, then again after the following

6 weeks, and finally for a 3 month follow-up. The standard care group will be offered the training program after they have finished the final assessment tests.

Will my taking part in this study be kept confidential?

All information that is collected about you during the course of this study will be kept confidential. Your documents and records will be stored securely and only accessed by authorised personnel. Any information that we publish will have your name and address removed so that you cannot be recognised from it. With your approval we will inform your GP about your participation in this study, and where information collected is relevant to your medical care we will inform either your consultant or GP.

What will happen to the results of the study?

The results of the research may be published. However, you will not be identified in any report. If you want to have a copy of the published report then you may do so and the researchers will ask you about this.

What if there is a problem?

The research involves non-invasive tasks and so we do not anticipate anything going wrong. However, in the unlikely event that your health and wellbeing are affected you will be referred immediately to your referring consultant or GP for appropriate care. The research is also fully covered by insurance provided by Durham University.

Who is organising and funding this study?

The research is organised by Durham University and is funded by the Ministry of Education, Malaysia (KPT(BS)870404115795). The research is being undertaken as part of fulfillment of a PhD project by Mr Musa.

Does this study have NHS Research Ethics Committee approval?

Yes, this project has been approved by Newcastle and North Tyneside 1 NHS Research Ethics Committee. The reference number is 15/NE/0351

What should I do if I am interested in participating in this study?

You need to complete the Reply Form attached in the participant invitation letter and send it to Mr Azuwan Musa using the stamped addressed envelope provided. He will contact you once the Reply Form is received for an appointment and to answer any questions. Alternatively, you may phone Azuwan Musa to register your interest or ask questions directly via 0191 334 0588 / 07481157071.

More Information and Contact Details

1) DREX Team

Please feel free to contact Mr. Azuwan Musa (Research Postgraduate) at Durham University. His contact details are:

Cognitive Neuroscience Research Unit,
Wolfson Research Institute,
Durham University
TS17 6BH
Tel: 0191 3340588 / 07481157071.
Email: azuwan.musa@durham.ac.uk

You may also contact his supervisors:

Dr. Alison Lane
Lecturer
Cognitive Neuroscience Research Unit,
Wolfson Research Institute,
Durham University
TS17 6BH
Tel: 0191 3340431
Email: a.r.lane@durham.ac.uk

Dr. Amanda Ellison
Reader
Cognitive Neuroscience Research Unit,
Wolfson Research Institute,
Durham University
TS17 6BH
Tel: 0191 3340430
Email: amanda.ellison@durham.ac.uk

Dr. Neil Archibald
Clinical Supervisor; Neurology Consultant
Department of Neurology,
The James Cook University Hospital, Marton Road,
Middleborough
TS4 3BW
Tel: 01642 854060
Email: neil.archibald@stees.nhs.uk

2) NHS Patient Advice & Liaison Service (PALS)

The Patient Advice and Liaison Service (PALS) provides confidential advice and support about NHS services including your participation in this study. You can find officers from PALS in your local hospital. You can search for your nearest PALS via www.nhs.uk/Service-Search/Patient-advice-and-liaison-services-(PALS)/LocationSearch/363. Simply type your postcode into the space provided. Alternatively you can call **111** for assistance. The officer will help you with your queries.

3) NHS Complaints page

If you have any issue that cannot be solved informally such as by discussing it with your doctor or a member of staff, you may also make a formal complaint through the NHS Complaints page. A simple step-by-step procedure is available from the link below:

http://www.nhs.uk/choiceinthenhs/rightsandpledges/complaints/pages/nhscomplaints.aspx

Appendix D: Participant Consent Form

Cognitive Neuroscience Research Unit
Wolfson Research Institute
Durham University Queen's Campus
Stockton-on-Tees
TS17 6BH

Version 3 – 23/11/2015

PARTICIPANT CONSENT FORM

Title of Project: ***Visuomotor Training for Hemianopia***

Name of Researcher: **Mr Azuwan Musa; Dr Alison Lane; Dr Amanda Ellison; Dr Neil Archibald**

Please initial box

1. I confirm that I have read and understood the information sheet dated ..... 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 and without my medical care or legal rights being affected. ☐
3. I understand that sections of my medical notes may be looked at by responsible individuals from Durham University where it is relevant to my taking part in the research. I give permission for these individuals to have access to relevant sections of my medical records. ☐
4. I understand that my GP will be informed about my participation in this study. ☐
5. I agree that where information is collected during the research which is relevant to my medical care that this information can be provided to either the referring consultant or my GP. ☐
6. I understand that my personal information will be kept confidential and that in any publication of results I would not be identifiable. ☐
7. I agree to be responsible in taking care of the University laptop or touchscreen device provided throughout the research, if applicable. ☐
8. I would like to receive the results of the research study when available. ☐
9. I agree to take part in the above research study. ☐

_____	_____	_____
Name of Patient	Date	Signature
_____	_____	_____
Researcher	Date	Signature

Appendix E: Paper-based reading task

Reading 1

Participant ID :
Assessment no. :
Date of assessment :

There is one great mystery in life which is taken completely for granted. Everyone has a share in it but very few ever give it a thought. Most people just accept it and never worry their heads about it. This mystery is time. There are calendars and clocks which measure it, but they mean little or nothing because everyone knows that an hour sometimes seems an eternity while at other times it passes in a flash, depending on what happens during that hour. Time is life itself; and life dwells in the heart. Nobody knew that better than the grey gentlemen. Nobody had as firm a grasp of the value of life down to the last hour or minute or even second as they did. True, they had their own way of grasping it, rather as a leech might be said to grasp the victim from whom it sucks blood.
They had plans for making use of the time which men spent, far-reaching and carefully prepared plans, and it was vital that no one should be aware of their activities. Step by step, without a single soul being aware of it, they progressed daily and were gradually taking over mankind.

Reading 2

Participant ID :
Assessment no. :
Date of assessment :

How odd the big city looked now! On the roadways stood row upon row of cars, the drivers sitting motionless behind their steering-wheels, a hand on the gear-lever or the horn. There were cyclists with arm outstretched, signalling that they were about to turn. On the pavements stood all the pedestrians; men, women and children, dogs and cats, completely still and rigid. Even the smoke from the exhaust pipes hung motionless. Policemen stood at the cross-roads in the act of beckoning on the traffic. A flock of pigeons hovered immobile in the air above the square. High above all was an aeroplane as if painted in the sky. The water in the fountains looked like ice. Leaves falling from a tree were suspended in mid air. A small dog in the act of lifting his leg at a lamp-post stood as still as if he had been stuffed. Through the centre of the city as lifeless as a photograph the grey gentlemen ran headlong, with her always behind them, though always taking care not to be seen by the time thieves. In point of fact, they no longer noticed anything, for their flight was proving ever more difficult and exhausting.

Reading 3

Participant ID :
Assessment no. :
Date of assessment :

Amphitheatres looked like a circus looks today, except that they were made entirely of blocks of stone. The rows of seats for the spectators were ranged in tiers, often in a wide semicircle. Some of them were as big as a football stadium, others were smaller and could hold only a couple of hundred spectators. Some were magnificent, ornamented with pillars and statues, others were simple and plain. These amphitheatres had no roof, and everything took place in the open air. Hence, in the magnificent ones, gold-embroidered tapestries were stretched above the seats so as to protect the public from the heat of the sun or from sudden storms. In the plainer ones, matting of rush or straw served the same purpose. Plays were such as the local people could stage. They felt as if the mock life there was in some mysterious way more real than their own everyday life. And they loved to listen to this other reality. Thousands of years have passed since then. The noble cities of those days have crumbled, the palaces have fallen, wind and rain, heat and cold have worn away and hollowed out the stones. Of the great theatres only ruins remain.

Reading 4

Participant ID :
Assessment no. :
Date of assessment :

The room was bigger than the most enormous church or the very biggest railway station. Mighty pillars supported a lofty ceiling, guessed at rather than seen in the half-dark. There were no windows. The golden light which shimmered in this vast room came from innumerable candles which were standing everywhere, their flames burning as steadily as if they had been painted in luminous colours and needed no wax in order to burn. The myriad whirring, ticking, chiming and buzzing which she had heard as she entered came from countless clocks of every shape and size. They were standing or lying on long tables, in glass cases, on golden console tables and on endless rows of shelves. There were dainty, bejewelled pocket-watches, tin alarm clocks, musical clocks with little dancing dolls on them, wooden clocks, marble clocks, glass clocks and clocks that were driven by a jet of water. On the walls hung all sorts of cuckoo clocks, clocks with weights and clocks with swinging pendulums, some moving in a slow and stately manner, others with tiny little pendulums that wagged busily to and fro. At first floor height a balcony, reached by a spiral staircase, ran right round the room.

Appendix F: Visual Impairment Questionnaire (VIQ)

Name:

Visual Impairments Questionnaire.

Five point-scale:
0 – no problem
1 – rare problem
2 – occasional problem
3 – frequent problem
4 – very frequent problem

Using this five-point scale, to what extent do you experience problems with the following?

1) Seeing objects	0	1	2	3	4
2) Bumping into obstacles	0	1	2	3	4
3) Losing your way	0	1	2	3	4
4) Findings objects on a table	0	1	2	3	4
5) Finding objects in a room	0	1	2	3	4
6) Finding objects in a supermarket	0	1	2	3	4
7) Using public transport	0	1	2	3	4
8) Finding way at home	0	1	2	3	4
9) Crossing the street	0	1	2	3	4
10) Reading	0	1	2	3	4

Appendix G: Motivation for Rehabilitation Traumatic Brain Injury Rehabilitation (MOT-Q)

MOT-Q

Motivation for Traumatic Brain Injury Rehabilitation Questionnaire

Defense and Veterans Head Injury Progaram, Walter Reed Army Medical Center, Bldg. 7, Rm. 224, Washington, D.C. 20307
(202) 782-7281, FAX (202) 782-4400

Name (Last, First, MI) _____

Today'sDate (Mo/Day/Yr) ____/____/____

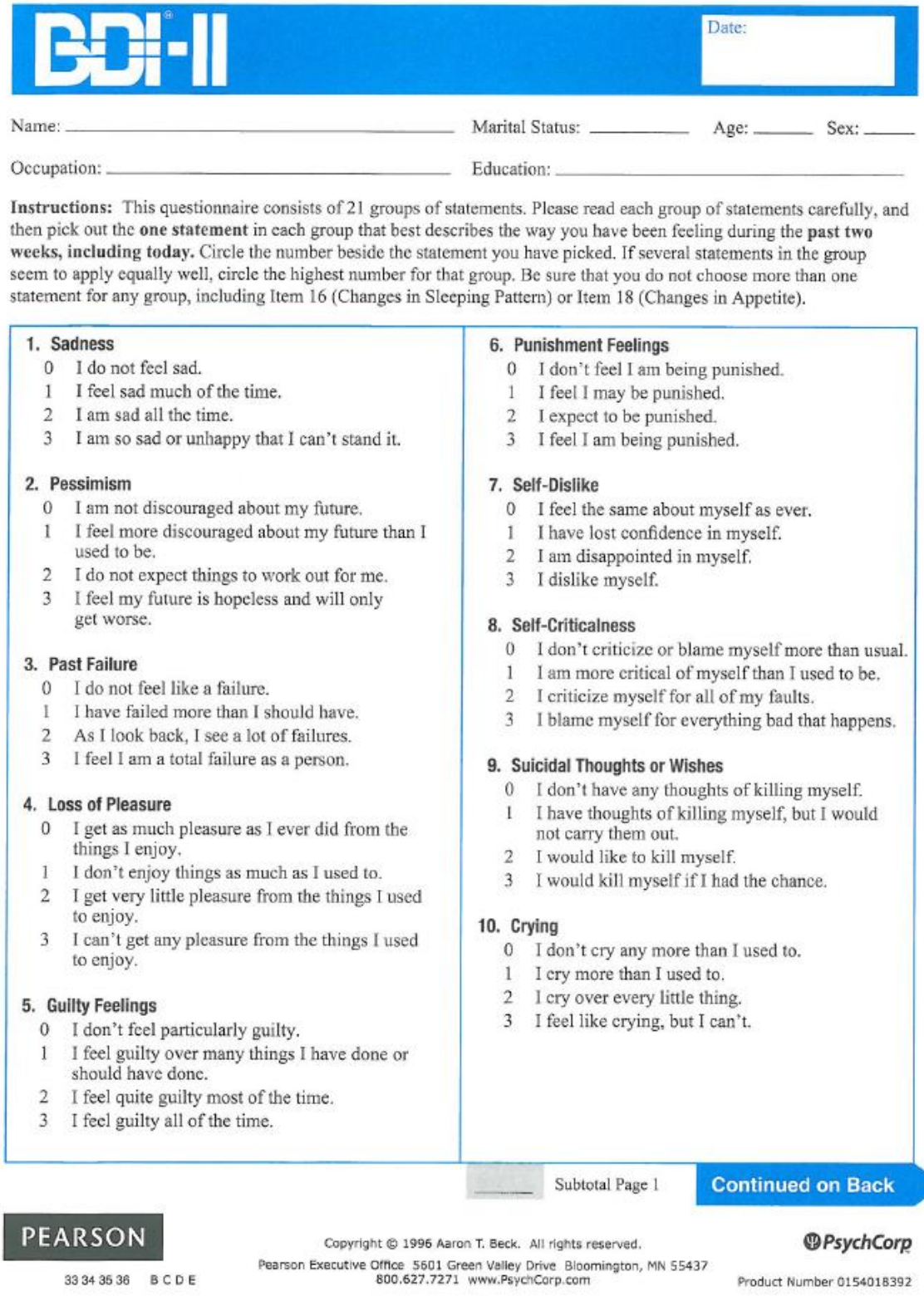
Please rate your agreement with the following statements by placing an X in an appropriate square.

Rehabilitation programs are designed to help injured persons recover from their illness. Rehabilitation includes: physical therapy, speech therapy, counseling or psychotherapy, occupational therapy, vocational services, and cognitive therapy.

		Strongly Disagree	Disagree Somewhat	Undecided	Agree Somewhat	Strongly Agree	For Office Use Only LD	IR	LA	RH
1	If it was recommended, I would see a rehabilitation therapist.	-2	-1	0	1	2				
2	Given a choice I would spend more time in therapy.	-2	-1	0	1	2				
3	Rehabilitation will probably help me.	-2	-1	0	1	2				
4	Rehabilitation is very useful.	-2	-1	0	1	2				
5	At first I had some problems, but I'm fine now.	2	1	0	-1	-2				
6	I'm better now than I ever was.	2	1	0	-1	-2				
7	Rehabilitation therapists can't help me with my problems.	2	1	0	-1	-2				
8	Rehabilitation has nothing to do with my needs.	2	1	0	-1	-2				
9	I have always had the problems I'm having now.	2	1	0	-1	-2				
10	I have some problems, but I'm doing fine.	2	1	0	-1	-2				
11	Rehabilitation therapists would probably treat me like a child.	2	1	0	-1	-2				
12	I'm very excited about getting treatment as soon as possible.	-2	-1	0	1	2				
13	There is nothing wrong with me.	2	1	0	-1	-2				
14	I'll be the same if I get treatment or not.	2	1	0	-1	-2				
15	Therapists would have me do things that are irrelevant.	2	1	0	-1	-2				
16	The head injury had minimal effect on my abilities.	2	1	0	-1	-2				
17	Rehabilitation is useful, but I don't think I need it.	2	1	0	-1	-2				
For Office Use Only						Subtotal Page 1				

		Strongly Disagree	Disagree Somewhat	Undecided	Agree Somewhat	Strongly Agree	For Office Use Only LD	IR	LA	RH
18	I rely on doctors to help me with my problems.	-2	-1	0	1	2				
19	I don't have any problems worth mentioning.	2	1	0	-1	-2				
20	I'd ask my therapists to do extra therapy tasks.	-2	-1	0	1	2				
21	I always follow medical orders because I think they'll help me.	-2	-1	0	1	2				
22	Doctors know what I need and I'll do what they say.	-2	-1	0	1	2				
23	I'd do what a therapist tells me even if it doesn't make sense.	-2	-1	0	1	2				
24	I'm very interested in rehabilitation, but it's not for me.	2	1	0	-1	-2				
25	I don't have time for rehab.	2	1	0	-1	-2				
26	It's fine to see a rehabilitation therapist.	-2	-1	0	1	2				
27	My problems are my own business.	2	1	0	-1	-2				
28	I don't like people prying too deeply.	2	1	0	-1	-2				
29	Therapists would waste my time.	2	1	0	-1	-2				
30	Going through rehabilitation will help me get (or keep) a job.	-2	-1	0	1	2				
31	Doctors shouldn't say I have problems without knowing how I was before my injury.	2	1	0	-1	-2				
For Office Use Only						Subtotal Page 2				
						Subtotal Page 1				
						Total				

Appendix H: Beck Depression Inventory II



BDI-II

Date:

Name: _____ Marital Status: _____ Age: _____ Sex: _____

Occupation: _____ Education: _____

Instructions: This questionnaire consists of 21 groups of statements. Please read each group of statements carefully, and then pick out the **one statement** in each group that best describes the way you have been feeling during the **past two weeks, including today.** Circle the number beside the statement you have picked. If several statements in the group seem to apply equally well, circle the highest number for that group. Be sure that you do not choose more than one statement for any group, including Item 16 (Changes in Sleeping Pattern) or Item 18 (Changes in Appetite).

1. Sadness
0 I do not feel sad.
1 I feel sad much of the time.
2 I am sad all the time.
3 I am so sad or unhappy that I can't stand it.

2. Pessimism
0 I am not discouraged about my future.
1 I feel more discouraged about my future than I used to be.
2 I do not expect things to work out for me.
3 I feel my future is hopeless and will only get worse.

3. Past Failure
0 I do not feel like a failure.
1 I have failed more than I should have.
2 As I look back, I see a lot of failures.
3 I feel I am a total failure as a person.

4. Loss of Pleasure
0 I get as much pleasure as I ever did from the things I enjoy.
1 I don't enjoy things as much as I used to.
2 I get very little pleasure from the things I used to enjoy.
3 I can't get any pleasure from the things I used to enjoy.

5. Guilty Feelings
0 I don't feel particularly guilty.
1 I feel guilty over many things I have done or should have done.
2 I feel quite guilty most of the time.
3 I feel guilty all of the time.

6. Punishment Feelings
0 I don't feel I am being punished.
1 I feel I may be punished.
2 I expect to be punished.
3 I feel I am being punished.

7. Self-Dislike
0 I feel the same about myself as ever.
1 I have lost confidence in myself.
2 I am disappointed in myself.
3 I dislike myself.

8. Self-Criticalness
0 I don't criticize or blame myself more than usual.
1 I am more critical of myself than I used to be.
2 I criticize myself for all of my faults.
3 I blame myself for everything bad that happens.

9. Suicidal Thoughts or Wishes
0 I don't have any thoughts of killing myself.
1 I have thoughts of killing myself, but I would not carry them out.
2 I would like to kill myself.
3 I would kill myself if I had the chance.

10. Crying
0 I don't cry any more than I used to.
1 I cry more than I used to.
2 I cry over every little thing.
3 I feel like crying, but I can't.

_____ Subtotal Page 1 Continued on Back

PEARSON

33 34 35 36 B C D E

Pearson Executive Office 5601 Green Valley Drive Bloomington, MN 55437
800.627.7271 www.PsychCorp.com

PsychCorp

Product Number 0154018392

11. Agitation

0 I am no more restless or wound up than usual.
1 I feel more restless or wound up than usual.
2 I am so restless or agitated that it's hard to stay still.
3 I am so restless or agitated that I have to keep moving or doing something.

12. Loss of Interest

0 I have not lost interest in other people or activities.
1 I am less interested in other people or things than before.
2 I have lost most of my interest in other people or things.
3 It's hard to get interested in anything.

13. Indecisiveness

0 I make decisions about as well as ever.
1 I find it more difficult to make decisions than usual.
2 I have much greater difficulty in making decisions than I used to.
3 I have trouble making any decisions.

14. Worthlessness

0 I do not feel I am worthless.
1 I don't consider myself as worthwhile and useful as I used to.
2 I feel more worthless as compared to other people.
3 I feel utterly worthless.

15. Loss of Energy

0 I have as much energy as ever.
1 I have less energy than I used to have.
2 I don't have enough energy to do very much.
3 I don't have enough energy to do anything.

16. Changes in Sleeping Pattern

0 I have not experienced any change in my sleeping pattern.

1a I sleep somewhat more than usual.
1b I sleep somewhat less than usual.

2a I sleep a lot more than usual.
2b I sleep a lot less than usual.

3a I sleep most of the day.
3b I wake up 1–2 hours early and can't get back to sleep.

17. Irritability

0 I am no more irritable than usual.
1 I am more irritable than usual.
2 I am much more irritable than usual.
3 I am irritable all the time.

18. Changes in Appetite

0 I have not experienced any change in my appetite.

1a My appetite is somewhat less than usual.
1b My appetite is somewhat greater than usual.

2a My appetite is much less than before.
2b My appetite is much greater than usual.

3a I have no appetite at all.
3b I crave food all the time.

19. Concentration Difficulty

0 I can concentrate as well as ever.
1 I can't concentrate as well as usual.
2 It's hard to keep my mind on anything for very long.
3 I find I can't concentrate on anything.

20. Tiredness or Fatigue

0 I am no more tired or fatigued than usual.
1 I get more tired or fatigued more easily than usual.
2 I am too tired or fatigued to do a lot of the things I used to do.
3 I am too tired or fatigued to do most of the things I used to do.

21. Loss of Interest in Sex

0 I have not noticed any recent change in my interest in sex.
1 I am less interested in sex than I used to be.
2 I am much less interested in sex now.
3 I have lost interest in sex completely.

_____ Subtotal Page 2

_____ Subtotal Page 1

_____ Total Score

281253-2 9878

Appendix I: Self-ability and Attitude Questionnaire

Self-Ability and Attitude Questionnaire

These questions are about your confidence, hope, recovery attitude, and optimism.

Please rate how much you agree with each one of the following statements, from 1 (strongly disagree) to 5 (strongly agree).

	(strongly disagree)				(strongly agree)
1. I am confident walking outside on my own	1	2	3	4	5
2. I am confident using technology					
i) computer	1	2	3	4	5
ii) touchscreen tablet (e.g., I-Pad)	1	2	3	4	5
3. I am confident using computer/mobile apps such as games	1	2	3	4	5
4. There a lots of ways around any problem	1	2	3	4	5
5. I always pursue my goals	1	2	3	4	5
6. People who are in recovery need the support of others	1	2	3	4	5
7. I cannot afford to pay for rehabilitation costs	1	2	3	4	5
8. I find that home-training is very convenient	1	2	3	4	5

Please TICK ☑ all that apply

9. Which of these activities would you like to improve?

A. Reading ☐
B. Shopping ☐
C. Going out (e.g. cinema, party) ☐
D. Driving ☐
E. Taking part in sports ☐
(please state:……..)

F. Visiting people ☐
G. Grooming (shaving, putting on makeup) ☐
H. Enjoying TV programs ☐
I. Others ☐
(please state:……..
……)

10. Which activity in **Question 9** is your main goal? Please state your choice **(A to I)** in this box. ☐