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Clinical evaluation of behavioural interventions for patients with homonymous visual field defects.

Alison R. Lane

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Thesis submitted for the degree of Doctor of Philosophy

Durham University, Psychology Department

2009

0 9 FEB 2009

Declaration

I confirm that no part of the material offered has previously been submitted by me for a degree in this or in any other University. If material has been generated through joint work, my independent contribution has been clearly indicated. In all other cases material from the work of others has been acknowledged and quotations and paraphrases suitably indicated.

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Abstract

Rehabilitation for patients with homonymous visual field defects (HVFDs) is important for helping to improve their quality of life. Various therapies have been developed, most notably vision restoration training (VRT), optical aids and compensatory training. Studies utilising modern optical aids have reported promising results but the extent to which these aids can reliably reduce the patients' visual disability has yet to be confirmed. Restorative approaches are the most ambitious and controversial, aiming to restore vision to portions of the lost visual field. Whilst early studies suggested that VRT could reduce the visual field defect, recent studies using more reliable methods to monitor the patients' fixation could not confirm this effect. A recent study proposed the possibility that extending the patient's arm into their blind hemifield could enhance visual detection in this location. Chapter 5 of this thesis examined this possibility and concluded that this is unlikely to be a successful rehabilitation approach for the majority of patients with HVFDs. Consequently restoration of the visual field should not be considered a realistic rehabilitation outcome.

Whilst compensatory exploration training exists which teaches patients how to more effectively scan the visual scene, and for which behavioural improvements have been previously demonstrated, there are some issues which required further evaluation. Three main evaluative criteria were examined in this thesis, including the generalisation of the therapeutic benefits (Chapter 2), the stability of the gains over a six month period without further intervention (Chapter 3), and the relative efficacy as compared to a placebo condition (Chapter 4). Using a repeated-measures design these criteria were used to evaluate the efficacy of a compensatory exploration training which used small display visual search tasks. Overall the results

revealed that the training did improve the searching skills of patients with HVFDs, and that these benefits transferred to various tasks requiring exploration, although did not lead to improvements in reading. Furthermore, the post-training improvements were generally found to be stable. However, for many of the tasks, except that most similar to the training, the effects of the exploration training were found to be no greater than obtained following a placebo therapy which trained attention in the absence of exploration. Thus, on the basis of such findings it can be concluded that behavioural intervention may lead to functional improvements, yet the contribution of visual attention to the rehabilitation of HVFDs may previously have been underestimated.

Acknowledgements

I wish to thank my primary supervisor Thomas Schenk, whose enthusiasm, knowledge and expertise has been very valuable for shaping my own research abilities as well as this thesis. I am fortunate and thankful for his expert guidance, support and encouragement. These thanks also extend to my research collaborator, Dan Smith, who has helped at all stages of the project from recruitment and design, through testing and analysis and also writing up. I am indebted to him for his continued intellectual advice and assistance. It has been a pleasure to work alongside both of you.

I would like to thank the Economic and Social Research Council and the Medical Research Council who provided the funding which enabled me to conduct this research: I really appreciate the opportunities that you have provided. I am also thankful for the assistance provided by my secondary supervisor Professor David Mendelow and many of his colleagues working in local NHS settings, especially Alison Jones. The experiences provided by such collaborators have helped to improve my confidence and practical skills, and their input certainly aided with the recruitment of suitable participants. My gratitude extends to all of the patients involved in the studies, without whom this research would most definitely not have been possible, and also would not have been as rewarding or enjoyable. Furthermore, I wish to thank Dr Adam Galpin (University of Salford) who kindly provided the pictures that were used to create the displays for the comparative search tasks, and Susanne Schuett who helped to generate the material for the reading tasks, in addition to her general friendly support.

I am very pleased to have found so many colleagues who have also become such good friends, and have enjoyed the numerous discussions with you all (some more intellectual than others). Special thanks go to Gill for allowing me to pester her continually and helping me to come up with solutions to many of my problems. I couldn't have wished for a better office buddy; your constant positivism, cheeriness and friendship have helped make the PhD experience much more enjoyable.

I could never have done this without the love and support from good friends and family: Mum, Dad, Natty and Paul – I love you all. Having you in my lives has helped me to keep everything in perspective, which undoubtedly contributed to making the whole experience much more pleasant and less stressful than I had ever imagined. Finally I would like to give a big hug to my bunnies, Miffy and Floyd, for providing much comfort and sanity.

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Chapter 5

Chapter 1: General introduction[1]

1.1 Overview of the chapter

The primary aim of this thesis is to evaluate the clinical efficacy of behavioural interventions for patients with homonymous visual field defects (HVFDs). This chapter firstly explains what visual field defects are and then discusses the importance of rehabilitation for patients with such visual loss. This discussion will focus on both the disability which can result from HVFDs and the likelihood of meaningful spontaneous recovery, including not only visual restoration but also compensation. The various rehabilitation options are then examined focusing on the three main approaches: visual restoration, optical aids and compensatory therapy, with a consideration of the advantages and weaknesses of each therapeutic method. Following this is a discussion of some of the gaps in the current knowledge of HVFD rehabilitation, in which the primary aims of this thesis (and each of its constituent chapters) are also defined. The concluding section of this chapter outlines the remainder of the thesis.

1.2 Visual field defects

The visual field can be defined as the total area of space in which visual stimuli can be detected when the eyes are fixating centrally. If someone has a visual field defect (VFD) this means that they have lost the ability to perceive visual stimuli which are presented in one specific part of the visual field. With HVFDs the same part of the visual field is affected both for the right and the left eye. Various types of HVFD can be defined. Homonymous hemianopia (depicted in Figure 1.1) describes the disorder in which one half of the visual field is blind, and this occurs

[1] This chapter is based upon a published review article (Lane, Smith & Schenk, 2008) of which I was the first author.

in approximately 75% of cases (Zihl, 1995a). Homonymous quadrantanopia refers to visual loss which is restricted to one quarter of the visual field (left or right, superior or inferior), and a homonymous scotoma is an island of visual loss surrounded by relatively preserved vision.

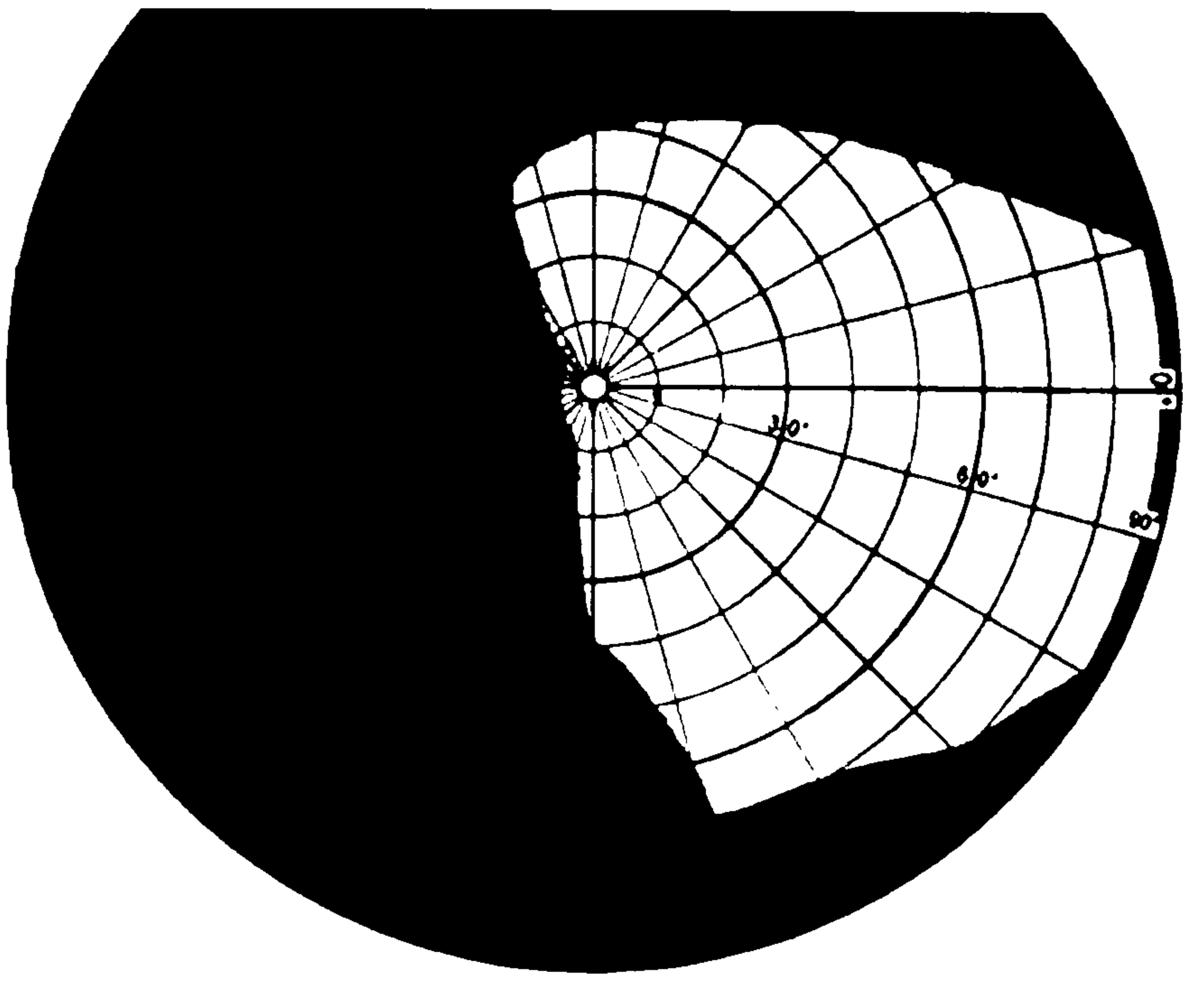

Figure 1.1: Binocular visual field plot representing a left-sided homonymous hemianopia (figure reproduced with permission from Lane, Smith & Schenk, 2008).

Due to the large proportion of the brain involved with visual processing, a deficit in this modality is a relatively common occurrence following brain damage. Approximately 50% of brain-injury patients suffer some visual impairment and lesion location determines the resulting deficit (Schlageter, Gray, Hall, Shaw & Sammet, 1993). Pre-chiasmatic lesions or lesions to the optic chiasm itself result in non-homonymous VFDs. HVFDs occur following post-chiasmatic lesions to the primary visual pathway because it is at the optic chiasm at which information from the nasal portions of each retina, which represent the temporal aspects of the visual field, cross over into the contralateral cerebral hemisphere, whilst the temporal retinal projections remain in the ipsilateral hemisphere (see Figure 1.2). Therefore posterior to the optic chiasm information from both eyes relating to the right visual field is processed in the left cerebral hemisphere, and vice versa. Consequently, damage to the visual processing areas (namely primary visual cortex) in one hemisphere results in a visual defect in the contralesional side of space.

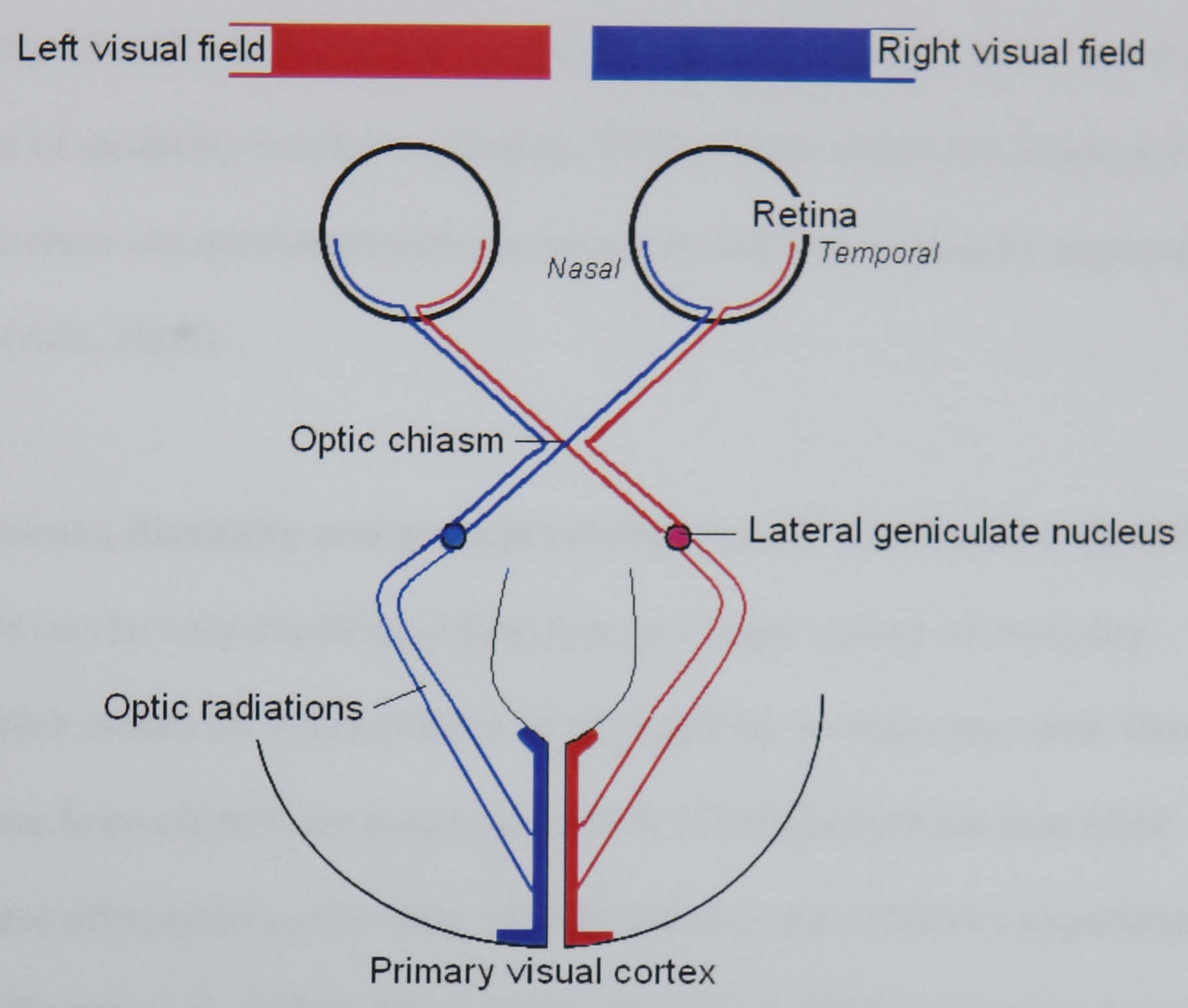

Figure 1.2: Diagram showing the visual pathways and their relation to visual field processing.

According to Zhang, Kedar, Lynn, Newman & Biousse (2006b) approximately 40% of HVFDs result from lesions involving the occipital lobe, with about 30% due to damage to the optic radiations. The remainder result from multiple location lesions, damage to the optic tract or lateral geniculate nucleus. HVFDs have been reported in approximately 20 to 30 percent of people with acquired brain injury in neurological rehabilitation units (Kasten et al., 1999), and in 0.8% of community dwelling older adults who were at least 49 years of age, for which there was an increased incidence with increasing age and history of stroke (Gilhotra, Mitchell, Healey, Cumming & Currie, 2002). Stroke is the most common aetiology associated with HVFDs, with approximately 70% of cases resulting from infarctions involving the posterior cerebral artery (Huber, 1992; Zhang et al., 2006b; Zihl, 2000). In a sample of 61 stroke patients, 16% were found to have a HVFD nine months post-stroke (Townend et al., 2007). Annually in the UK approximately 130,000 people suffer a stroke (Carroll & Majeed, 2001) and it is the largest cause of disability in adults (Hankey, 1999). Other relatively frequent causes of HVFDs include occipital haemorrhage, tumours and less frequently neurosurgery and trauma (Zihl, 2000).

1.3 Impairments, disability and perceptual experiences associated with HVFDs

HVFDs can be very disabling, impacting on a wide variety of everyday activities which makes the rehabilitation of such defects an important area. Reading problems have been objectively observed in 48% of hemianopic patients (Zihl, 1999a) and are often cited as the most relevant behavioural difficulty experienced by patients (Kasten et al., 1999). Hemianopic dyslexia is the term used to describe the particular pattern of reading problems that are associated with HVFDs, and the specific reading difficulties depend mainly on HVFD location (Trauzettel-Klosinski & Brendler, 1998). For example, in Western cultures where text is read from left to right, patients with right-sided field defects experience more severe problems since the parafoveal information to the right is crucial for guiding appropriate eye-movements during reading. Furthermore, reading is typically worse in patients who have less than 5° of visual sparing (Zihl, 1995b), therefore specifically patients with macular splitting or a central scotoma. However, such patients are the minority of cases (Leff, 2004). Analysis of patients' eye-movement data indicates that patients with HVFDs do not appear to compensate for their field loss when reading and show inefficient eye-movements (Trauzettel-Klosinski & Brendler, 1998; McDonald, Spitsyna, Shillcock, Wise & Leff, 2006), although this is not the case for all patients (Gassel & Williams, 1963). Gassel and Williams (1963) found that some patients with atypical eye-movements can still exhibit adequate reading speeds, demonstrating that such saccadic patterns do not necessarily lead to impaired reading ability. For a complete current review of hemianopic dyslexia see Schuett, Heywood, Kentridge & Zihl (2008a).

One of the main behavioural problems for patients with HVFDs is their inability to generate a complete visual overview (Zihl, 1995a), particularly in novel environments, thereby affecting the ability of the patient to interact effectively with their environment and find objects for example. This ability has been examined using visual search tasks, where the aim is to locate a target item which is presented amongst distracting elements in a visual display. Patients typically take longer than healthy individuals to complete such tasks (Chédru, Leblanc & Lhermitte, 1973; Zihl, 1995a), and can have similar difficulties performing other visual tasks such as identification and sorting (Zihl & Wohlfarth-Englert, 1986; Zihl, Roth, Kerkhoff & Heywood, 1988). Many patients with HVFDs execute abnormally short eye-movements when looking into the blind regions of their visual field and each movement is typically slower than that of a normally-sighted individual, a behaviour known as saccadic hypometria (Zihl, 2000). Several studies have demonstrated the abnormal searching eye-movement patterns of patients with HVFDs (Chédru et al., 1973; Meienberg, Zangemeister, Rosenberg, Hoyt & Stark, 1981; Pambakian et al., 2000; Zangemeister, Oechsner & Freksa, 1995; Zihl, 1995a, 1999b). Approximately 70% of patients show such disorganised searching strategies (Kerkhoff, 1999), which limits the ability of patients to effectively search their environment, contributing to their disorientation and obstacle avoidance problems. This sort of defective scanning pattern has also been found for neurologically healthy participants in whom hemianopia was simulated (Cornelissen, Bruin & Kooijman, 2005; Tant, Cornelissen, Kooijman & Brouwer, 2002) demonstrating that the behaviour is the product of the perceptual experience rather than a consequence of neurological damage.

Much enjoyment can be gained from reading and leisure activities that require visual search skills, and any impairment in these abilities has obvious consequences for the emotional well-being of the patient. Similarly, HVFDs can restrict many activities such as driving (Kooijman et al., 2004) as well as the ability to find employment (Kasten et al., 1999), which can lead to a loss of independence, thereby affecting social and emotional functioning. The fact that many patients can struggle to understand the nature of their visual loss and have particular difficulty explaining it to others can further increase their insecurity, isolation and depression (Zihl & Kennard, 1996). The primary cause of HVFD is stroke (Huber, 1992) and accordingly the majority of patients are elderly (Cairns, 2004). Therefore visual problems can increase the risk of accidents such as falls to which this age group are already prone (Anderson, 2002; Ramrattan et al., 2001). Visual loss is associated with poor quality of life, functional impairment and deficient performance on activities of daily living (ADLs) for patients with field defects due to ocular or cortical causes (Brown, Brown, Sharma & Busbee, 2003; Chia et al., 2004; Papageorgiou et al., 2007; Patel, Duncan, Lai & Studenski, 2000; Ramrattan et al., 2001; Sànchez-Blanco, Ochoa-Sangrador, López-Munaín, Izquierdo-Sánchez, & Fermoso-García, 1999; Stelmack, 2001; Reding & Potes, 1988). The fact that patients with ocular pathology show similar functional impairments indicates that this is due to the perceptual impairment rather than the neurological insult. However, the degree of visual loss which patients experience is not the only factor contributing to their level of functioning.

One other factor which affects functioning is awareness. Hemianopic anosagnosia is the term used to define the absence of awareness of perceptual impairment. Many patients are unaware of their visual field loss in the initial stages after the onset of their HVFD (Celesia, Brigell & Vaphiades, 1997; Townend et al., 2007), and although complete insight is typically gained within the first few months (Huber, 1992) this is not always the case, specifically if the visual loss has not been clinically identified. The visual field loss is not apparent to many patients whilst they simply view a scene for example, but rather patients become aware of their HVFD as a consequence of their behavioural failings (i.e. bumping into obstacles). Consequently the development of awareness takes time and is a result of a learning process. Awareness and insight into the HVFD is associated with functioning; increased awareness is related to better functional outcomes, including employment (Sherer et al., 1998; Williams & Gassel, 1962).

Another factor which can be related to the level of disability experienced by patients with HVFDs is disorder comorbidity. Comorbidities alongside HVFDs are common (Anderson & Rizzo, 1995) and patients with multiple difficulties are typically more functionally impaired than those with a single defect (Han, Law-Gibson & Reding, 2002; Patel et al., 2000; Sànchez-Blanco et al., 1999). One disorder which commonly co-occurs with HVFDs is hemispatial neglect (Halligan, 1999), which typically presents after right-hemispheric damage and leads to patients ignoring sensory information from the contralesional half of their body and surroundings. Not only does such co-morbidity impair functioning to a greater extent than a HVFD in isolation, but it is also associated with increased mortality (Cassidy, Bruce, Lewis & Gray, 1999), probably due to the more extensive neurological damage.

Not only do HVFDs create problems within the visual domain, but they may also reduce the efficacy of other rehabilitation procedures, for example those aimed at increasing the patient's mobility (i.e. physiotherapy). According to Riggs, Andrews, Roberts and Gilewski (2007) "visual problems in the rehabilitative process can reduce responsiveness to therapeutic programs and interfere with overall functional progress" (pp. 858). Therefore, not only is it the case that the HVFD can lead to impairment in its own right, but this can further impact on other areas of functioning which might appear, on the surface, to be unrelated to visual processing.

In addition to the negative symptom of HVFDs (absence of vision) they can also be associated with positive symptoms: experiences of visual pseudo-hallucinations. These are perceptions which occur without appropriate visual stimulation but which the person knows are not real. This sort of visual illusion has been reported in a prospective study by more than 50% of patients with HVFDs (Poggel et al., 2007) and more commonly occur in the acute stage. They are typically experienced in the blind hemifield only and can be classified as either simple (i.e. colours and abstract patterns) or complex, with the latter typically consisting of people and animals rather than scenes such as landscapes (Lance, 1976). A case-study reported visual illusions which persisted for in excess of two years post-HVFD onset (Cole, 1999). Pseudo-hallucinations associated with HVFDs have received relatively little consideration in research, yet they are worthy of investigation due to the fact that they appear somewhat common and are possibly permanent in some cases. It is possible that they could prove useful for predicting rehabilitation success, especially if they are associated with visual recovery as some researchers have suggested (Kölmel, 1985; Poggel et al., 2007; Tan, Sabel & Goh, 2006). Unfortunately accessing information on these sorts of visual experiences may not prove easy; many patients do not report experiencing pseudo-hallucinations because they are aware that the perceptions are not real, and are therefore worried about being labelled as insane (Menon, 2005, Zihl & von Cramon, 1986). It is therefore crucial that awareness of visual illusions associated with HVFDs be raised in order to remove any potential social stigma and increase understanding. Furthermore, identifying these illusions as pseudo-hallucinations is necessary to avoid costly and unnecessary neuroimaging and psychiatric evaluation (Teunisse, Cruysberg, Hoefnagels, Verbeek & Zitman, 1996). The clinician should provide patients with an explanation for their hallucinations and give them reassurance that they are not a sign of insanity (Anderson & Rizzo, 1995; Teunisse et al., 1996).

Blindsight is another interesting phenomenon relating to patients with HVFDs. The term blindsight (coined by Weiskrantz, Warrington, Sanders & Marshall, 1974) refers to the ability which some patients possess to locate or discriminate between visual stimuli presented in the blind hemifield (with accuracy which significantly exceeds chance), despite having no conscious visual perception of the stimuli. Numerous different blindsight abilities have been reported including localising targets with hand- or eye-movements (Kentridge, Heywood & Weiskrantz, 1997; Perenin & Jeannerod, 1978; Weiskrantz et al., 1974), wavelength discrimination (Stoerig & Cowey, 1989), motion detection and discrimination (Barbur, Ruddock & Waterfield, 1980; Blythe, Kennard & Ruddock, 1987; Stoerig & Cowey, 1997), semantic priming (Marcel, 1998) and emotional conditioning (Hamm et al., 2003). It is estimated that 15-20% of patients with HVFDs demonstrate some blindsight abilities (Blythe et al., 1987; Walker, Mannan, Maurer, Pambakian, & Kennard, 2000; Wüst, Kasten, & Sabel, 2002), although it is currently unknown if the ability is associated with rehabilitative success.

It has been suggested that training patients to be aware of their blindsight could be a useful rehabilitation strategy since functional benefits are found for children who possess such capabilities (Boyle, Jones, Hamilton, Spowart & Dutton, 2005) and repeated blindsight testing can improve detection sensitivity (Cowey & Stoerig, 1991). Also, many everyday tasks are performed implicitly and therefore it might be possible to improve functioning by enhancing blindsight. Training patients to discriminate the position of targets within the blind field does lead to improvements in saccadic localisation to such stimuli (Zihl, 1980), however the effect that such blindsight training might have on everyday functioning for patients with HVFDs remains unclear since additional behavioural outcomes have not been examined. Furthermore, the training also encourages patients to shift their gaze towards the blind hemifield and thus any benefits may not be a direct consequence of enhanced blindsight capacities, but instead might reflect alternative compensatory mechanisms. If this is the case, then explicitly orienting patients towards the blind hemifield would presumably be as advantageous, if not more so.

Several mechanisms have been proposed to explain blindsight. The two main theories are that islands of spared striate cortex within the damaged hemisphere may underlie the effects (Fendrich, Wessinger & Gazzaniga, 1992), and the second is that multiple visual pathways which do not require striate cortex to be intact mediate the blindsight capabilities (Cowey & Stoerig, 1991). Understanding the mechanisms of blindsight might prove useful with regards to further identifying possible mechanisms of HVFD rehabilitation and also helping to elucidate the nature of consciousness. Therefore continued research in this field may prove beneficial in understanding the recovery of such patients.

1.4 Spontaneous recovery of HVFDs

When considering the rehabilitation of HVFDs it is firstly important to consider whether or not intervention is necessary, or if natural recovery is possible. Furthermore, knowing the likely pattern of natural recovery is important for assessment and rehabilitation, and is useful for determining the time at which training will be maximally effective. Some spontaneous visual field restoration is widely accepted to occur for patients with HVFDs. However, the number of patients who experience any restoration is undetermined, with reports ranging from 7 to 85% of cases (Kasten et al., 1999). The amount of field recovery that an individual can experience is similarly variable (Zihl and Kennard, 1996). In an extensive review of spontaneous recovery, Zhang, Kedar, Lynn, Newman & Biousse (2006a) observed that the degree of natural recovery decreased as the amount of time since the onset of the HVFD increased. The approximate maximal period of spontaneous recovery is typically three months (Huber, 1992; Pambakian and Kennard, 1997). In summary, spontaneous visual field recovery does not occur in all patients and complete recovery is rare. Therefore many patients are left with chronic and disabling HVFDs and rehabilitation for such patients is important.

Patients may also try to adapt to their visual loss. Papageorgiou et al. (2007) found that the level of ability reported by patients was not simply related to the extent of their visual field loss. This may indicate that some patients compensate, and therefore do not experience the same level of impairment or disability as might be expected based on their visual loss, whilst others do not demonstrate such compensation. Ishiai, Furukawa, and Tsukagoshi (1987) reported that patients spent more time looking into their blind hemifield than they did the seeing field, possibly in an attempt to compensate. Making larger and more frequent eye-movements, specifically into the blind areas, might seem the most obvious way of compensating for HVFDs, yet unfortunately not all patients adopt this strategy (Kerkhoff, 1999). Rather, several researchers have shown that the eye-movements of many HVFD patients are very small and their scan-paths (the pattern of eye-movements used to scan a complex visual representation) are disorganised (Chédru et al., 1973; Meienberg et al., 1981; Pambakian et al., 2000; Zihl, 1995a, 1999b). Patients who have a chronic HVFD show more organised scanning strategies than those patients whose difficulties are a recent occurrence (Pambakian et al., 2000; Zihl, 1995a), however, many patients' eye-movements are still disorganised 14 months after the onset of the HVFD (Kerkhoff, 1999).

There are two reasons why patients may fail to effectively compensate for their visual loss spontaneously. Firstly patients must be aware of their need to compensate. As such, insight into the presence of the HVFD would appear crucial for spontaneous compensation to occur. However, many patients are often unaware of their visual loss, especially in the early stages after onset (Celesia et al., 1997; Townend et al., 2007). Since patients have no direct sensation of visual loss they often only become aware of their defect as a consequence of behavioural impairments (i.e. bumping into unseen obstacles), and therefore awareness will depend upon cognitive capacities such as memory. Consequently it appears likely that the process of compensation is acquired with time, conscious effort and the necessary cognitive skills and knowledge. Secondly, compensation via oculomotor modification (altering the exploratory eye-movement strategies) requires the patient to consciously override the saccades which are most likely to be elicited by the visual sensation. When viewing a visual display containing an array of items eye-movements are quite often directed towards those items which are close to the current point of fixation (Motter & Belky, 1998a, 1998b). For patients with HVFDs it can be assumed that the saccades will be directed towards the items closest to fixation which can be perceived, which will be those items appearing in the intact hemifield of vision. Subsequently saccades will tend to be directed into the sighted field, and therefore the patient is required to consciously produce eye-movements in the opposite direction in order to compensate effectively.

Patients may also use other forms of behavioural compensation. One method is the use of eccentric fixation; the eye is rotated slightly towards the blind hemifield rather than straight ahead (Gassel and Williams, 1963). This means that the centre of the observed image does not fall exactly on the fovea, but instead the image falls further into the seeing field at a marginally eccentric position. The spontaneous use of such a technique is described in a personal account by Kolb (1990):

"In spite of the absence of a reduction in the objective size of the scotoma beyond 2 months poststroke, there is little doubt that my visual abilities continued to improve for some time. It seems likely that a major reason for this is the shift in the point of fixation" (pp. 145).

This eccentric fixation strategy is found in approximately 30% of cases and can increase reading speed (Trauzettel-Klosinski, 1997), although the impact of such a strategy on other activities has not been clearly determined. It is a strategy which may be of use for patients with little central vision, for example those with a HVFD with macular splitting or a scotoma which involves the fovea (Nilsson, Frennesson & Nilsson, 2003), although this is the minority of HVFD patients (Leff, 2004). However, eccentric fixation is unlikely to be a useful strategy for patients with an intact fovea. Another strategy witnessed in children involves forward and backward rocking motions to bring greater portions of the visual field into view (Boyle, Jones, Hamilton, Spowart & Dutton, 2005). Such a method has not been reported in adults.

In summary, HVFDs are debilitating and the sensory loss is exacerbated by the adoption of slow and inefficient search strategies when exploring the blind hemifield. The prognosis for spontaneous recovery appears poor, and although adaptation is possible many patients do not develop effective ways of compensating for their deficits. For these patients specific intervention is required and the following section addresses some of the main rehabilitation approaches.

1.5 Rehabilitation of HVFDs

HVFDs are a relatively common consequence of brain injury and the chance of spontaneous recovery which would allow the patient to function adequately is rare, meaning that many patients experience chronic disability as a result of their visual field loss. HVFDs have traditionally been considered untreatable (Zihl, 2000), however, recent advances in our understanding of the neural capacities for functional reorganisation within the visual system have led to an upsurge of attempts to achieve a reduction of the field loss through training. At the same time, new rehabilitation procedures have been developed which might allow patients to perceive the whole visual world more effectively and to improve reading performance despite persistent HVFDs. These procedures have been reviewed previously (Kerkhoff, 2000; Pambakian, Currie & Kennard, 2005; Pelak, Dubin & Whitney, 2007; Lane et al., 2008), including a recent systematic review (Bouwmeester, Heutink & Lucas, 2007), and it was concluded that compensatory rehabilitation procedures can improve the visual search skills and reading performance of patients with HVFDs. Despite these encouraging results patients often do not receive specific rehabilitation for their HVFDs (Kerkhoff, 1999; Pambakian et al., 2005).

Most research has focused on three treatment approaches: restorative training, optical aids and compensatory training. The restorative approach is the most ambitious. It works at the level of impairment and aims to reduce the visual field loss through prolonged training. The other two main methods work on the level of disability. The second approach uses optical aids to artificially expand the patient's visual field, such that parts of the visual world which would otherwise fall into the blind field now appear in the seeing field. The third approach is compensatory training. This therapy is based on the assumption that the visual field defect cannot be changed significantly, and therefore attempts to alleviate the resulting disability by teaching patients to make more efficient eye-movements. Each of these rehabilitation strategies are discussed separately below.

1.5.1 Restorative training

Restorative training aims to restore vision (at least in part) to the blind visual field, based on evidence which supports plasticity in the visual system of both animals (Cowey and Weiskrantz, 1963; Cowey, 1967; Mohler and Wurtz, 1977; Eysel and Schwiegart, 1999) and humans (Donoghue, 1997). For a review of evidence relating to visual system plasticity see Karmarkar and Dan (2006). There was early promise for the potential of such training which involved repeated visual stimulation and detection (Zihl and von Cramon, 1979) or saccadic localisation of light stimuli which were presented within the blind hemifield (Zihl, 1981; Zihl & von Cramon, 1985). However, some dismissed the approach as ineffective, with any supposed field increase being regarded as the product of eye-movements (Balliet, Blood & Bach-y-Rita, 1985).

Restorative training was later revived by Kasten, Sabel and colleagues who introduced a computerised therapy called vision restoration therapy (VRT; Kasten and Sabel, 1995; Kasten, Strasburger & Sabel, 1997). During VRT patients fixate a central point whilst visual stimuli are repeatedly presented in the border region between the blind and seeing field (the transition zone). The training is typically conducted in daily one hour sessions for six months. Placebo controlled studies have suggested that VRT leads to significant increases in the visual field of approximately 5° (Kasten, Wüst, Behrens-Baumann & Sabel, 1998; Kasten, Müller-Oehring, & Sabel, 2001), although more so for patients with optic tract damage as opposed to cortical damage. The post-VRT field increases have been found to be preserved at least six months after the cessation of the treatment (Kasten and Sabel, 1995; Kasten et al., 2001). Schmielau and Wong (2007) developed a similar training technique which uses automatic visual stimulation within a perimeter rather than using a computer screen and found significant field increases, although this was in a non-controlled study.

However, despite the apparent success of VRT critics have challenged the claim that it is an effective treatment for patients with post-chiasmatic HVFDs (Horton, 2005; McFadzean, 2006; Plant, 2005). Firstly, if one accepts the increase in the visual field of approximately 5°, then the question arises of the clinical significance of this. Such an increase is only useful if it occurs within 15° of the fovea and yet the results reported in relation to VRT do not specify the location within the visual field at which the change occurs. The relevance of these visual field increases cannot be ascertained since improved functioning (in reading or visual search for example) has not been objectively established. Secondly, critics of VRT also question whether or not the visual restoration is real. This is because the claims of significant field increases found in the VRT studies mentioned above were based on a questionable method of assessing the visual field. The field was measured using high-resolution perimetry (HRP) which is computer-based and incorporated into the VRT training device, and does not allow a reliable way of controlling the patients' fixation. Standard non-HRP perimetric methods, such as Tübingen automated perimetry (TAP), have resulted in contradictory findings (Kasten et al., 1998; Mueller, Mast & Sabel, 2007; Sabel, Kenkel & Kasten, 2004; Schreiber et al., 2006). However, techniques do exist with which to monitor fixation very reliably. This includes scanning laser ophthalmoscope (SLO) combined with microperimetry, which allows the researcher to monitor fixation directly by viewing the stimuli presented on the retina in real time (Jamara, van de Velde & Peli, 2003). In studies whereby VRT has been re-evaluated, and fixation reliably monitored using SLO during visual field assessment, no significant visual field increases were obtained (Reinhard et al., 2005; Sabel et al., 2004).

Recently, Kasten, Bunzenthal and Sabel (2006) responded to this challenge by publishing a study in which they used a video-based system to monitor the fixation of their patients and found a significant, but somewhat modest, field increase of 1.8°. This finding is insufficient to re-establish the therapeutic value of VRT for two reasons. Firstly, because the employed fixation control technique is inferior to that used by other studies which did not find significant field increases. Secondly, even if we accept the reported field increase, such an increase of 1.8 degrees is clearly not enough to convey a clinically significant benefit to patients who have endured three months of daily training and invested a considerable amount of money. In this context it is important to note that this treatment is available in the United States of America and that the expenses are currently not covered by medical insurance companies (Pelak et al., 2007).

The main aim of any therapeutic intervention is to improve functioning. Even if the claim that VRT produces a clinically relevant field increase is dismissed, the widespread subjective improvements reported by many participants after this training cannot be disregarded (Mueller, Poggel, Kenkel, Kasten & Sabel, 2003; Reinhard et al., 2005; Sabel et al., 2004). The fact that improvements are sometimes reported by patients in the absence of any training induced field recovery (Mueller et al., 2003; Reinhard et al., 2005) raises an interesting question: why do patients report that subsequent to the training they find it easier to find objects and avoid obstacles, if their visual field is unchanged? It might be the case that these reports simply reflect the desire of patients to justify a training in which they have invested a lot of time, effort and money: "patients will clamour for a treatment they believe works, even if it is humbug" (Horton, 2005, pp. 793).

However, it is also possible that VRT leads to behavioural improvements. For example, it is possible that VRT cues patients to allocate more attention into their blind hemifield. Zihl and von Cramon (1979) suggested that the field increase observed after restorative training may be partly influenced by selective attention forcing the patient to use the blind hemifield. Furthermore, attentional cueing can improve target detection of stimuli presented in the blind areas of the visual field (Poggel, Kasten, Müller-Oehring, Bunzenthal & Sabel, 2006). Although visual co-stimulation (in which two stimulus probes are presented simultaneously and close to one another in visual space) was found to be no more effective than single stimulus

VRT at expanding the visual field, VRT was observed to have beneficial effects on attention and the increased attention was associated with the supposed visual restoration (Kasten, Bunzenthal, Müller-Oehring, Mueller & Sabel, 2007). Marshall et al. (2008) reported no increase in the visual field after one month of VRT but did observe altered neural activity. However, it is not known what caused the change in brain activity and it could possibly be associated with shifting attention from the seeing hemifield to the transition zone. Further research into the role of attention for visual field restoration is required. In addition to possible effects on attention, VRT could also inadvertently lead to eye-movements being more frequently directed into the blind field, although this explanation is denied by Kasten et al. (2006).

Restorative training has been shown to induce changes in cortical activity as reported by several small-sample (n=1-5) imaging and electrophysiological studies (Julkunen, Tenovuo, Jääskeläinen & Hämäläinen, 2003; Julkunen et al., 2006; Pleger et al., 2003). Such studies have revealed widespread changes in neural activity after VRT, and these alterations in cortical activity have been interpreted as evidence for the training-induced brain plasticity underlying the recovery of visual field loss. However, in the absence of reliable evidence for such visual field recovery this interpretation appears unlikely, and simply because a change occurs on the neuronal level does not provide any indication as to the mechanism which may underlie the effect. As such, this evidence is not sufficient to establish the value of VRT at present.

More encouraging results have been obtained with children. Werth and colleagues presented findings from randomised placebo-controlled trials with a restorative training used with children aged between one and fifteen years (Werth and Moehrenschlager, 1999; Werth and Seelos, 2005). In some cases the visual field defect disappeared completely, and the mean increase was 65°. Such dramatic increases coincide with evidence suggesting that there is greater potential for recovery from damage sustained early in life (Payne, Lomber, Macneil & Cornwell, 1996; Boyle et al., 2005), possibly because child and adult cases typically differ with regards to aetiology and lesion location (Kedar, Zhang, Lynn, Newman & Biousse, 2006), or perhaps due to greater neuronal plasticity more generally in children. However, due to the age of these patients conventional perimetry could not be performed and instead the researchers had to rely on observed changes in target-directed eye-movements to estimate the extent of visual field recovery. Accordingly the visual field measurements and reported field increases are difficult to interpret and could reflect compensatory mechanisms rather than restorative ones. Given the large improvements which appear possible, this training would seem to be worthwhile pursuing with children who have HVFDs regardless of the underlying mechanism.

Given some of the controversy which surrounds the use of VRT, alternative methods of attenuating the visual loss and alleviating some of the disability resulting from HVFDs would be desirable. Schendel and Robertson (2004) found in a case study that extending a patient's arm into his blind hemifield could increase conscious detection of stimuli visually presented in this location. Using such a simple manipulation to modify the visual field and increase the visual perceptual abilities of patients provides an exciting possible new avenue for HVFD rehabilitation. This method would certainly be preferable to costly and time consuming VRT. However, unfortunately so far, the results have not been replicated with a larger sample, and there are additional methodological flaws with the study which make it difficult to interpret the result reliably. These include a failure to adequately control for guessing or criterion-shifts, as well as not monitoring fixation reliably during the assessment of visual detection abilities. Despite this, the observation that arm manipulation could influence conscious visual detection does require further study to examine its potential efficacy as a new HVFD rehabilitation approach.

In conclusion, restorative training in adults has failed to fulfil its early promise. Whilst VRT can occasionally produce large restoration of the visual field in single cases, recent studies suggest that VRT does not lead to significant increases in visual field size but does consistently yield subjective improvements. The basis of these subjective improvements is still unclear but it is possible that VRT leads to compensatory changes in behaviour which are as yet unconfirmed. However, even if we were to assume that VRT leads to significant behavioural improvements it would still be inferior to other forms of compensatory training (see below) which appear to produce effective behavioural compensation with significantly less effort, cost and time. VRT would also be inferior to a restorative approach based on the manipulation of arm position if it could be established that this method increases visual detection reliably.

1.5.2 Optical aids

Optical aids are used with patients with HVFDs in order to reduce the apparent visual field loss by shifting visual stimuli from the blind field into the patient's seeing field, or by expanding the perceptual visual field. Such optical devices include prisms (Gottlieb, Furh, Hatch & Wright, 1998), telescopes (Lowe & Rubinstein, 2000) and head-mounted closed circuit television systems (Luo & Peli, 2006), with prisms proving to be the most widely accepted optical aid.

Optical prisms are fitted to spectacles and can be fitted to just one eye (monocular) or both eyes (binocular). Typically the prism is restricted to just one half of the spectacle lens (on the side of the blind field), which is known as a partial or sector prism. Fitting prisms across the full lens in both eyes (binocular full prisms) can shift the whole visual field towards the intact hemifield, thereby bringing portions of the blind hemifield into view. However, binocular full prisms have not been investigated with regards to HVFD rehabilitation. Whilst sector prisms appear to enhance visual functioning (Gottlieb et al., 1998; Lee & Perez, 1999; Szlyk, Seiple, Stelmack & McMahon, 2005) they do have their limitations. Monocular sector prisms provide an expansion of the visual field but at the cost of creating central double-vision (diplopia) which patients experience as unpleasant. Binocular sector prisms lead to field relocation rather than field expansion. Furthermore, such prisms are only useful when gaze is directed into the prisms. Such limitations of the techniques as these probably explain why so far these optical aids have proved only moderately successful in HVFD rehabilitation.

Peli (2000, 2001) introduced a new set of spectacles with monocularly fitted sector prisms which extend across the width of the spectacle lens, but which spare the central aspect. This is known as vision multiplexing and using this technique field expansion is achieved without central diplopia. Peli (2000) reported field expansion of about 20° and noted on the basis of subjective reports that patients seemed to benefit from the spectacles. Recently, Bowers, Keeney and Peli (2008) found that nearly 50% of patients in a sample of 43 continued to wear such prisms after 12 months, indicating that at least some patients do experience a benefit of them in everyday life. They further observed that patients reported improvements in their obstacle avoidance capabilities in various everyday situations. Vision multiplexing seems promising but randomised controlled trials using objective measures of functional improvement are required to evaluate the clinical potential of such a technique.

1.5.3 Compensatory training

Even if training cannot achieve a significant reduction in the visual field loss and thus visual impairment remains, it might still be possible to help patients to cope more effectively with their HVFD. One of the most frequently reported problems experienced by patients with HVFDs is difficulty in perceiving and exploring a visual scene (Zihl, 1995a), and even simulated HVFDs affect the ability of participants to produce effective exploratory eye-movements (Cornelissen et al., 2005; Tant et al., 2002). Scanning the visual world systematically with large sweeping eye-movements would appear to be the most obvious form of compensation, however many patients do not spontaneously adopt this strategy (Kerkhoff, 1999). Since compensation involves patients knowing how to compensate (Zihl, 2000) it might be possible to teach people this knowledge if they do not possess it implicitly. In order to improve the ability of patients to compensate for their visual loss, several researchers have developed training schemes designed to teach patients more efficient strategies for visual scanning. The training programs are based on the evidence which has revealed that many patients with HVFDs exhibit disorganised and inefficient oculomotor behaviour, including numerous fixations and refixations, hypometric saccades and repetitions of the scan-path (Chédru et al., 1973; Meienberg et al., 1981; Pambakian et al., 2000; Zihl, 1995a, 1999b). Thus with respect to HVFDs, compensation focuses on the use of intentional eye-movements as a replacement for the lost vision and training aims to facilitate this process of oculomotor modification.

The compensatory training approaches typically progress gradually from simple to more complex tasks. Specific target localisation tasks are used to train patients to make overtly large amplitude eye-movements and can be done using either a perimeter (Zihl, 1995a) or a computer monitor (Kerkhoff, Münßinger, Haaf, Eberle-Strauss & Stögerer, 1992b; Kerkhoff, Münßinger & Meier, 1994; Pommerenke & Markowitsch, 1989). Such saccadic localisation formed the basis for the training used by Pommerenke & Markowitsch (1989) and was the first stage of the therapy assessed by both Zihl (1995a) and Kerkhoff et al. (1992b, 1994).

Increasingly more complex visual search tasks are used to teach patients to use systematic scanning strategies when exploring their visual world. These have been employed as the second phase of therapy by some researchers (Zihl, 1995a; Kerkhoff et al., 1992b, 1994) but have also been used as a therapy on its own (Nelles et al., 2001; Pambakian, Mannan, Hodgson & Kennard, 2004). The search displays have been limited to the central horizontal 25° of the visual field in some instances (Pambakian et al., 2004), whilst Nelles et al. (2001) used a display which extended across the whole visual field. In some instances patients were provided with instructions for how to scan the visual scenes, for example to employ systematic row-by-row or column-by-column searching saccades (Nelles et al., 2001; Kerkhoff et al., 1992b, 1994; Zihl, 1995a), whilst Pambakian et al. (2004) allowed patients to develop their own strategies whilst completing the visual search tasks. Visual search not only involves visual processing and exploration but also visuo-spatial attention. As such the task can also be assumed to enhance attention and may help patients to orient attention to the blind hemifield. A final stage of training sometimes included in the program helps the patient to utilise the newly acquired saccadic strategies in everyday situations requiring visual search, such as crossing the street, finding objects around the home or simulated driving (Kerkhoff et al., 1992b, 1994; Kooijman et al., 2004). Kerkhoff and colleagues trained patients in the situations which were identified by individual patients to be the most problematic for them. Compensatory strategies can be effectively acquired following daily one hour training sessions for about four to six weeks, making it much less demanding than VRT.

Compensatory training in general leads to improved visual search performance and efficiency such as increased search speed and an approximate 30° enlargement of the search field, which is the area of visual space in which stimuli can be detected using eye-movements (Kerkhoff et al., 1992b, 1994; Nelles et al., 2001; Pambakian et al., 2004; Pommerenke & Markowitsch, 1989; Verlohr and Dannheim, 2007; Zihl, 1995a). Such benefits can be observed following visual search training in which the patients receive no direct instructions for how to search. Two studies confirmed that the reduction in search time obtained after training was significantly greater than that observed during untrained periods and the benefit is thus training-specific (Kerkoff et al., 1994; Pambakian et al., 2004). Furthermore, it was found that the post-training search improvements could be maintained for at least one month, and in some cases up to 22 months (Kerkhoff et al., 1992b). Zihl (1995a) found a small but significant increase in the mean saccadic amplitude (~1°) after training, as well as fewer saccades and refixations which subsequently reduced the length of the scan-path. This indicates that the training does lead to more systematic saccadic strategies being employed. Unfortunately, only those patients with impaired scanning prior to training were included in this study and therefore it is not known if all patients, regardless of their oculomotor behaviour, can improve their scanning as a consequence of the training.

Not only does it appear from these studies that compensatory training can significantly improve search, but it is possible that it may actually increase the visual field itself (Kerkhoff et al., 1992b; Kerkhoff et al., 1994). However, not all studies have found significant visual field increases after compensatory training (Nelles et al., 2001; Pambakian et al., 2004; Pommerenke & Markowitsch, 1989; Zihl, 1995a). Caution is required when interpreting these findings as the same limitations relating to fixation control during perimetry are present as in studies examining restorative approaches.

Alterations in neural activity have been observed in patients with HVFDs when stimuli are presented to the blind hemified, notably improved activation of ipsilateral extrastriate visual cortex (Nelles, de Greiff, Pscherer, Forsting, Gerhard et al., 2007). Whilst this indicates changes in cortical activity associated with

HVFDs, the cause of this alteration cannot be inferred. Nelles, de Greiff, Pscherer, Stude, Forsting et al. (2007) found altered activity in the frontoparietal neural network when patients made saccades relative to the activation observed in neurologically healthy controls. The authors interpreted this as evidence for a neurological substrate of a compensatory mechanism. However, the frontoparietal network has also been found to be involved with attention processes (Corbetta, 1998; Corbetta & Shulman, 2002) and it is possible that such differences in brain activity could also be associated with alterations in attention. The evidence shows that brain activity can be altered in patients with HVFDs, although the mechanism for this change is currently unknown.

The reading performance of patients with HVFDs is also often impaired (Leff et al., 2001). Consequently, specific compensatory reading training procedures have been developed to directly address this deficit (Han, Ciuffreda & Kapoor, 2004; Kerkhoff, Münßinger, Eberle-Strauss, & Stögerer, 1992a; Spitzyna et al., 2007; Zihl, 1995b). Zihl (1995b) found that such training can improve reading accuracy and speed, although unfortunately there was no control group and so it is not known to what extent the effects were due to the training provided. In contrast, a recent study by Spitzyna et al. (2007) included a placebo condition to assess the specific effects of reading training for patients with hemianopic dyslexia. They tested 19 patients with right-sided hemianopia and divided them into two groups. The group 1 patients received reading training for two four week blocks. During this training, patients practiced reading moving text which scrolled from right to left. The patients in group 2 received a four week block of placebo training and a four week block of reading training. In the placebo training patients were presented with pairs of pictures which differed only in a number of minor features and they had to detect these differences. The reading training but not the placebo training induced significant improvements in reading speed.

The results surrounding compensatory training indicate the promise which such an approach holds for helping patients to adapt to their visual loss, and whilst controversy continues to surround the use of VRT, compensation would appear to be a viable rehabilitation option for many patients with HVFDs. However, it is important to note that for most compensatory training regimes a placebo controlled study examining their efficacy is still missing.

There is a dearth of research investigating HVFD rehabilitation in the UK, and subsequently patients do not have access to treatments which could potentially improve their quality of life. Only one recent study has attempted to address the problem of patient access by designing computer based training that can be completed in the patient's own home (Pambakian et al., 2004). The study reported significant improvements in visual search performance after training, which they claim transferred to ADLs. However, the conclusions of this study should be treated with caution, as they did not provide an adequate control for their patient group.

1.6 Open research questions

The clinical efficacy has not yet been unequivocally established for any of the described rehabilitation procedures. However, compensatory approaches have come further towards the aim of establishing their clinical value than the other approaches. The compensatory training approach is the only one for which behavioural improvements in the form of improved search times, increased reading speed and more efficient searching eye-movements have been reliably demonstrated. In fact, for one form of compensatory reading training its superiority over placebo training has already been established (Spitzyna et al., 2007). However, attention will now be turned to those aspects of behavioural interventions which require further research for clinical efficacy to be established.

1.6.1 The transfer and generalisation of compensatory training benefits

One aspect which is crucial to the clinical evaluation of any rehabilitation procedure is whether or not the achieved training gains also lead to relevant improvements in other tasks, especially ADL ones. Unfortunately the issue of the transferability of compensatory training has received relatively little consideration previously, with most studies which have examined the training either not assessing its impact on ADL tasks or relying upon subjective reports. Zihl (1995a) found that all patients reported severe everyday problems prior to the training and afterwards all patients had improved: 79% reported either no or mild difficulties, whilst 21% reported moderate problems. Using a standardised and validated questionnaire, several studies found that patients reported significant functional improvements after compensatory training for an assortment of activities which are known to be impaired for this clinical group. However, whilst Kerkhoff et al. (1994) and Nelles et al. (2001) found significant improvements for all of the items which they assessed, Pambakian et al. (2004) noted significant improvements for only three items: 'finding objects on a table', 'finding objects in a room', and 'crossing the street'. Kerkhoff and colleagues (1992b, 1994) and Nelles et al. (2001) instructed patients how to move their eyes during training, whilst Pambakian et al. (2001) did not. It is possible that such additional researcher input influenced the amount of subjective improvement reported by the patients. It is worth noting that a large discrepancy can exist between objective and subjective measures, with subjective report typically overestimating the level of improvement (Pambakian et al., 2004), highlighting the need to interpret self-report data with caution. It is therefore important to establish using behavioural measures the functional benefits of the training, since subjective gains can be unreliable indicators of rehabilitation success.

Several studies which noted improved performance on visual search tasks after the compensatory training assessed this behaviour using the same stimuli as used for the training (Nelles et al., 2001; Pambakian et al., 2004; Zihl, 1995a). This makes it difficult to interpret the generalisation of this search improvement, since it is possible that the benefit may be limited to those specific stimulus examples rather than reflecting a general improvement in visual scanning. Other researchers have demonstrated search improvements which do transfer to comparable non-directly trained exploration situations (Kerkhoff et al., 1992b, 1994; Pommerenke & Markowitsch, 1989), and future research should try to ensure that various visual stimuli are used to avoid such confounds.

There are a few studies which have used objective measures to assess the transfer of training benefits to other tasks. Kerkhoff et al. (1994) demonstrated that combined compensatory search training (i.e. training which combines saccadic localisation, search tasks and exercises such as finding objects around the home) can yield improved search performance in more naturalistic forms of visual search. For example, following training the patients in this study showed a 50% reduction in search time on the table test in which they had to search for real items amongst distractors displayed atop a table. Further to this, Kerkhoff et al. also reported that 91% of the sample returned to some sort of part-time work after the training. Pambakian et al. (2004) reported training related improvements in performance on activities which they claimed represented ADL tasks, such as searching for and threading beads onto string in a sequential order. Whilst this does indicate the successful transfer of the training benefits to visually-guided search behaviours, there is a question of how much such tasks actually tell us about improvements in more common-place everyday activities. Research is needed which examines the efficacy of the training in relation to more relevant examples of ADLs.

Driving is a major activity for which transfer of training gains would be beneficial since it is prohibited for the majority of patients with HVFDs. Kooijman et al. (2004) found that only 2 out of the 17 homonymous hemianopic patients who failed a test of practical driving fitness passed this test after a form of compensatory therapy which trained visual exploration during driving. Given the social and emotional impact that the loss of driving has on patients with HVFDs the effect that compensatory training has on driving ability should be further examined. It is worth noting that patients with HVFDs may be able to drive as adequately as neurologically healthy individuals (Schulte, Strasburger, Muller-Oehring, Kasten & Sabel, 1999), and therefore, perhaps driving guidelines should be modified such that an HVFD is not an automatic cause for license revocation. Of course, given the safety issues surrounding driving, assessing this as an outcome may be practically difficult.

Nelles et al. (2001) reported that patients' subjective impression of their reading ability had improved after the compensatory search training. Audio-visual stimulation training has been found to enhance reading ability (Bolognini, Rasi, Coccia & Làdavas, 2005), although reading performance has not been objectively measured following compensatory visual search training. Therefore, it is not possible to conclude if there is transfer from visual search training to reading tasks. Again reading is an activity which many patients report having difficulties with, and which can severely impact on their quality of life, and as such, should be considered an important outcome measure.

Currently there is insufficient information about how the gains achieved with compensatory training transfer to other relevant activities like driving, reading, visuomotor control, and visual search in natural surroundings. Furthermore, it is currently unclear whether some tasks benefit more from training than others. If it is confirmed that some everyday tasks do not benefit sufficiently from compensatory training then additional training which addresses the specific requirements of those tasks will be needed. It is the primary aim of the following chapter to examine the issue of the extent to which compensatory training leads to benefits in various transfer tasks.

1.6.2 The stability of the benefits of compensatory training

A second important issue to consider when examining the efficacy of a therapy is the stability of the improvements. It is clearly preferable that the benefits of a therapy should last for as long as possible in order to avoid the patient having to receive ongoing intervention or to revert to a more impaired state. Improved search abilities (decreased visual search time and an increase in the search field) have been reported following compensatory exploration training, and these improvements have also been found to be maintained over a follow-up period of at least one month (Kerkhoff et al., 1992b, 1994; Nelles et al., 2001; Pambakian et al., 2004; Zihl, 2000), suggesting that the searching benefits extend beyond the duration of compensatory training. However, since transfer of the training benefits has not been unequivocally demonstrated (as described above) then the issue of whether or not transferable benefits are maintained is of course still unknown at present. The aim of Chapter 3 is to address this issue of stability and since search improvements appear to be maintained over a follow-up period, it could perhaps be predicted that other benefits would be retained also.

1.6.3 The relative efficacy of compensatory training versus a placebo

It is generally accepted that currently compensatory training offers the best rehabilitation approach to HVFDs (Lane et al., 2008). However the approach has been criticised for the absence of randomised controlled trials which are essential for determining the relative value of a therapeutic intervention compared to no treatment and to rule out possible placebo effects. Compensatory reading training has been examined in a placebo controlled trial (Spitzyna et al., 2007) and the results revealed improvements in reading performance which were specific to the reading training. However, the efficacy of compensatory exploration training has not been demonstrated in a similar way.

Both Kerkhoff et al. (1994) and Pambakian et al. (2004) included repeated baseline measures (non-training periods) in order to determine if the compensatory exploration training produced greater improvement than could be expected spontaneously or as a result of repeated testing. These studies did reveal the exploration training to be more beneficial at improving visual search performance than no intervention at all. However, the extent to which this type of training is more beneficial than a placebo condition has yet to be established, an aspect which is important in order to convince clinicians and patients of the value of such an approach to HVFD rehabilitation. The main aim of Chapter 4 is to examine this issue by comparing the effects of the compensatory exploration training to a placebo condition.

1.6.4 The contribution of visual attention

Compensatory training based on visual search was developed in order to improve the oculomotor behaviour of patients with HVFDs which had been found to be deficient. However, exploration training necessarily also involves components of visual attention processing. Therefore, compensation via oculomotor modification involves not only altering the scanning eye-movements with respect to the blind hemifield, but also enhancing and reinforcing attention to this location. During compensatory exploration training patients are required to voluntarily maintain their attention to the blind region in order to explore it effectively and also to selectively attend to specific target features. Zihl (2000) proposed that the additional element of spatial attention involved in visual search would be beneficial for helping to improve the oculomotor strategies acquired during training which involves exploration. However, since both attention and exploration are implicated in the visual search training it is currently not possible to determine whether or not exploration, attention or a combination of both are required to produce the functional improvements in search behaviour. The fact that selective attention may contribute to visual restoration has been known for many years (Zihl and von Cramon, 1979) and it is possible that such visual attention plays a far larger role in HVFD rehabilitation than has been credited in the past. The placebo therapy utilised in the study reported in Chapter 4 of this thesis involves training attention in the absence of exploration, and therefore also aims to address the question of the extent to which attention plays a role in the compensatory rehabilitation of HVFDs.

1.6.5 The restorative effects of behavioural interventions

In the case of restorative training the early claims of increased visual field size following training have not been confirmed by studies using more reliable means of assessing the visual field size, and there is currently no evidence that the reported subjective improvements correspond to measurable behavioural improvements. Restoration of vision and thus amelioration of the perceptual impairment is clearly preferable to compensation, and yet does not seem a particularly likely outcome for the majority of patients with HVFDs. Given the associated cost and time of VRT this approach does not seem worthwhile pursuing. However, an alternative approach exists, as was proposed by Schendel and Robertson (2004). It is possible that extending the contralesional arm can increase visual detection in the blind hemifield of patients with HVFDs, thus essentially restoring portions of lost vision. It may be possible to perceive this as a compensatory strategy rather than a restorative one however, since the visual improvement is achieved using an adaptive manipulation of the body, and the effect appears to be lost once the manipulation is reversed (placing the arm in the lap). If manipulating arm position can ameliorate the visual loss of patients with HVFDs then this could potentially provide a simple and cost-effective therapeutic approach, thereby radically altering the rehabilitation of HVFDs. However, the result of Schendel and Robertson was based on a case study using inadequate fixation control during the assessment of the visual detection capabilities, and so further investigation is required. One of the aims of the research contained herein (Chapter 5) is therefore to examine whether or not this behavioural intervention does influence visual perception.

What's more, some researchers have suggested that a side effect of compensatory exploration training may be restoration of part of the blind hemifield (Kerkhoff et al., 1992b, 1994), although this proposal is controversial and has not been supported by all studies (Nelles et al., 2001; Pambakian et al., 2004; Pommerenke & Markowitsch, 1989; Zihl, 1995a). This leaves the question as to whether or not compensatory training can induce restoration currently unanswered. However, when considering this issue the same caveats and limitations apply as when evaluating the findings of restorative approaches such as VRT. One additional aim of this thesis (within Chapter 2) is to examine the impact of compensatory exploration training on the visual field, addressing both the issue of the control of fixation during perimetry and the possible impact of factors such as attention. This issue is then further examined in Chapter 4 in order to examine the relative impact of the placebo condition as compared to the exploration training in order to further address the issue of whether any effects may be associated with the specificity of the training.

1.7 Outline of the forthcoming chapters

The following chapter focuses on the issue of the transfer and generalisation of the compensatory exploration training benefits. Since Pambakian et al. (2004) had observed that improvements were possible using a portable visual search-based training system this was the method assessed in this study. As discussed above the exploration training appears to be the HVFD rehabilitation approach for which there is the most promising evidence, although currently there is relatively little evidence relating to the extent to which the benefits can generalise across tasks. This is an important question for clinicians since an intervention is of most value if it can improve performance on a variety of tasks. Two other important evaluative criteria with respect to compensatory training are the stability of the therapeutic improvements, including the stability of the benefits for transfer tasks, and the relative clinical efficacy of the training as compared to a placebo condition. These two criteria are assessed in Chapters 3 and 4 respectively.

In addition to the compensatory exploration training this thesis also addresses the efficacy of using arm extension as a method of reducing visual loss for patients with HVFDs, as previously proposed by Schendel and Robertson (2004). Chapter 5 describes an experimental study which examines the effect of manipulating the arm position of patients with HVFDs on their detection and localisation of visual stimuli presented in the blind hemifield.

The final chapter (Chapter 6) is the general discussion in which the conclusions from each of the experimental chapters are summarised. The implications of the research findings for HVFD rehabilitation are further discussed and some suggestions are made for future research within this final chapter also.

Chapter 2: Do the benefits of compensatory exploration training transfer across tasks and lead to visual restoration?

2.1 Introduction

2.1.1 Overview of the chapter

The primary aim of this chapter is to examine the extent to which compensatory exploration training leads to improvements in the visual search ability of patients with homonymous visual field defects (HVFDs), and also whether or not these improvements transfer to a variety of tasks and visual stimuli. The introduction firstly considers the importance of assessing transfer and then explains the choice of the training parameters and the assessment measures used in this study. The exploration training (both method and results) is described, followed by independent reports for each of the measures of transfer.

A secondary concern of the chapter is to address the issue of whether or not the compensatory training can enhance visual detection within the blind hemifield. The chapter examines this issue taking into account the resolution of the perimetric measurement and considers changes in the visual field outside of the blind hemifield in order to examine if factors other than restoration could influence the outcome. The issue of visual restoration is examined after that of training transferability.

2.1.2 The importance of the transfer of therapeutic benefits

The problems resulting from visual field loss are extensive and debilitating, impairing a variety of everyday behaviours such as exploration, navigation, reading and driving. These behavioural inabilities can further negatively affect social and emotional functioning and the outcome with regards to functional independence for patients with HVFDs is poor (Reding & Potes, 1988). Clearly it is an important part of rehabilitation that the findings from the laboratory should extend to situations and activities which are not explicitly trained, since the aim of rehabilitation is "to improve the person's ability to function in all aspects of family and community life" (Aetna: Cognitive Rehabilitation, 1998; pp. 2). Given the diverse impairments which can result from an HVFD it is essential that a rehabilitative approach attempts to alleviate as many of these deficits as possible, and therefore generalisation of the training benefits is paramount.

The question of transfer is also important because it determines not only the effectiveness of the training, but also the training design. In the case of perfect transfer between the oculomotor domain and visually-guided manual movements (*visuomotor* domain) a general training in visual exploration would be sufficient to achieve a general reduction in disability. Otherwise, if a procedure only benefits the task which it directly trains then this means that each individual task which is impaired will have to be trained separately. It is a well-established fact in the field of neurorehabilitation that many behavioural interventions which produce significant improvements in the training task produce significantly less of an effect in the transfer tasks, and even less or no improvement for the patients' performance in everyday activities (Sohlberg & Mateer, 2001). Examining the transferability of training is therefore a crucial aspect of the evaluation of any rehabilitation procedure, and only if the training leads to benefits in other activities will it be acceptable to both patients and clinicians. Currently there has been little uptake of the rehabilitative methods available for patients with HVFDs, and perhaps a lack of confidence in the transferability of the benefits is a contributing factor for this.

2.1.3 The structure and parameters of the exploration training

Various types of compensatory training for HVFDs have been examined in the past, which have used a range of tasks as well as different display sizes, instructions and training durations. Pommerenke and Markowitsch (1989) used saccadic localisation tasks aimed at increasing the amplitude and accuracy of eye-movements into the blind hemifield. Others have started with saccadic localisation and followed with visual search tasks to encourage improvements in search efficiency (Kerkhoff et al., 1992b, 1994; Zihl, 1995a), and Kerkhoff and colleagues then taught patients to incorporate the newly acquired search strategies into everyday situations. However, other researchers have used visual search on its own to encourage improvements in search behaviour with positive outcomes (Nelles et al., 2001; Pambakian et al., 2004). Given that improvements have been obtained using the practical visual search-based tasks in isolation, this method of exploration training has therefore been chosen for this study.

The majority of researchers have made the exploratory strategies to be employed by patients during training very explicit, for example by informing them to use row-by-row, or column-by-column, searching eye-movements (Kerkhoff et al., 1992b, 1994; Nelles et al., 2001; Zihl, 1995a). However, Pambakian et al. (2004) did not instruct participants on how to move their eyes, and instead allowed patients to develop their own searching strategies during the training. Since they observed significant improvements in visual search performance this implies that saccadic instructions are not an integral part of the therapy. This minimises the role of the researcher/therapist thereby reducing possible experimenter effects, as well as making the training easier to conduct. Consequently the decision was made not to include saccadic instructions in this study.

In previous studies the training has been conducted using variable display sizes. Pambakian et al. (2004) displayed visual search tasks using a 21-inch monitor which trained the central 25° of the horizontal visual field, and extended 10° vertically. Others have trained visual search using displays which subtended between 40° and 52° of the horizontal visual field (Kerkhoff et al., 1992b, 1994;

Zihl, 1995a), whilst Nelles et al. (2001) used a display which extended across the entire visual field. It is more practical to train only a small visual field since this means that the training can be performed using a portable system, and since such a method has been used successfully in one previous study (Pambakian et al., 2004) it has been selected to be used here also.

Different training durations have been utilised as well. However, many studies have found positive improvements in search behaviour using daily training sessions for approximately 30 to 60 minutes, with an average of four to six weeks of training (Kerkhoff et al., 1992b, 1994; Nelles et al., 2001; Pambakian et al., 2004; Zihl, 1995a). In this study the patients received 15 sessions of training, each of which took approximately 45 minutes to complete. This is similar to the duration of the visual search training employed by Zihl (16 sessions, each 30 minutes in duration).

2.1.4 The assessment measures used to assess the transfer of the training benefits

As already mentioned, the transferability of training benefits is an important criterion to consider when evaluating the efficacy of a therapy, and yet this issue has received relatively little consideration to date with regards to compensatory training for patients with HVFDs. Research has revealed post-training improvements in visual search performance, although some of these findings need to be interpreted with caution since the same stimuli were used for both training and assessment (Nelles et al., 2001; Pambakian et al., 2004; Zihl, 1995a). This limits the extent to which these findings represent transferable gains, since they do not reliably demonstrate an improvement in exploration as opposed to an enhancement of the recognition of specific, highly practiced stimuli for example. Demonstrating transfer to visual search with novel displays is required for this, as found by Pommerenke and Markowitsch (1989) and Kerkhoff et al. (1994). The fact that

Pommerenke and Markowitsch (1989) trained patients to make large amplitude saccades along one axis into the blind hemifield (typically the horizontal midline) and yet observed improved search on a display which extended along all meridians, indicates that the training benefits can generalise to situations requiring different search strategies to those taught during a training program. An improvement in exploration also appears the more likely explanation than enhanced recognition, since oculomotor behaviour improves after the training (Zihl, 1995a). It is important to examine transfer to visual stimuli which have not been explicitly practiced in order to evaluate this ability for the specific method of training used (i.e. small display and no saccadic instructions during visual search).

One of the main elements of transfer to consider in this chapter is whether the improvements in search are limited by the size of the display. Since the method of training chosen to use in this study trains only a small visual field (~30° of the horizontal visual field) it is therefore important to examine whether improvements in visual search can generalise to more of the visual field than is directly trained. When looking for something in a natural environment, the object of interest may not lie within the central 30° of the visual field and therefore finding objects further into the periphery of the visual field is a valuable and relevant practical skill. If transfer across the visual field is observed then it means that meaningful generalisation could be achieved by training search strategies using a portable small display system. Generalisation has been observed following small-display training (~25°) for tasks involving objects positioned across a table in a display extending 1m by 0.5m (Pambakian et al., 2004). This suggests that search does improve across more of the visual field than has been trained, although this cannot be confirmed since the viewing distance for these tasks was not reported. The issue of transfer of visual search improvements across the visual field has not been directly addressed previously, and therefore is examined in this study.

Although visual search performance has been repeatedly found to improve post-training (Nelles et al., 2001; Pambakian et al., 2004; Pommerenke & Markowitsch, 1989; Zihl, 1995a) the responses used in the tasks (a button-press or using a pointer to localise targets) have little ecological validity. In everyday situations when people are looking for a specific item they typically intend to make a purposeful movement in relation to this. For example, when someone is trying to find their keys they pick them up once they have located them, which indicates that everyday search tasks often require more than just the visual modality. Pambakian et al. (2004) found that performance on activities such as searching for and threading beads in a sequential order was significantly improved after visual search training, a benefit which could not be explained via general motor improvements. Although they referred to these tasks as representing activities of daily living (ADLs) they are very dissimilar to those activities which are commonly encountered in everyday situations. Kerkhoff et al. (1994) reported that patients showed significant improvements in ecologically valid forms of visual search, which included searching for and identifying a target object from a table displaying an array of real objects. Unfortunately, in the paper the researchers did not detail the response which was required by the patients for this task, and therefore it is not known if visuomotor output was needed (i.e. picking up the item). The improvements with regards to visuomotor behaviour have yet to be replicated and it is important to establish whether or not the training can improve performance using a more naturalistic behavioural response.

Examining ADLs is clearly necessary when considering the clinical efficacy of a therapy since it is important that the benefits do transfer to the everyday situations which the patient is exposed to. ADL tasks that have been identified as important to patients with HVFDs include driving, reading and obstacle avoidance (Kasten et al., 1999; Weih, Hassell & Keeffe, 2002; Zihl, 2000). As mentioned above, Pambakian et al. (2004) examined the improvement in tasks such as sequentially threading beads which were designed to represent ADLs, yet the relevance to everyday life of such tasks is questionable. A specific form of compensatory therapy which has involved training patients to use specific saccadic strategies during driving was found to improve the driving performance of two out of seventeen patients with HVFDs (Kooijman et al., 2004). Since this training was tailored to this activity it can perhaps be assumed that a more general search training would be of no greater benefit to this ADL task. Combined with the additional resources required to assess driving, this behaviour has not been selected to be assessed in this study. A practical ADL task to assess is reading, which is examined herein, and the effect of compensatory training on reading ability has been little reported previously. Bolognini et al. (2005) found improved reading speed after a training which combined auditory stimulation with a saccadic localisation task. This indicates that training does not need to be content specific (i.e. the use of reading material is not required) in order for improvements in reading ability to be obtained. Nelles et al. (2001) reported a significant reduction in the reading impairment as reported by the patients post-training. However, the impact of exploration training on objective reading ability has not been described. The efficacy of a training specifically designed to help patients to compensate for their reading impairments has been established (Spitzyna et al., 2007), but as mentioned above it would be useful if one type of training could benefit all tasks. Therefore, it is necessary to examine the transfer of exploration training to reading.

Additionally, subjective measures of ADLs and quality of life will be included in this study, and several studies have already found patient-reported improvements after compensatory exploration training (Kerkhoff et al., 1992b, 1994; Nelles et al., 2001; Pambakian et al., 2004; Zihl, 1995a). Knowing how patients perceive their improvement is an important outcome for a therapy since part of the aim of rehabilitation is to improve subjective quality of life. However, discrepancy can often exist between subjective and objective measures (Pambakian et al., 2004) and therefore it is important to consider the reliability of patient reports. In order to address this issue this study will not only examine subjective ADL but also relate this to the objective ADL performance (i.e. reading speed).

2.1.5 The restorative effects of compensatory exploration training

Although the primary aim of compensatory training is not visual restoration, it is possible that the training may produce some restorative effects, and the secondary aim of this chapter is to examine this possibility. One of the elements of compensatory exploration training is encouraging patients to make large amplitude saccades, which has its basis in visual restoration training using saccadic localisation. Using this restorative localisation training two studies revealed significant increases in the visual field (Zihl, 1981; Zihl & von Cramon, 1985), although this finding was not confirmed by a third study (Balliet et al., 1985). Balliet et al. (1985) observed eye-movements post-training, indicating that compensatory rather than restorative mechanisms may account for the supposed visual field increase. Using a similar technique, Pommerenke and Markowitsch (1989) confirmed the compensatory effects, but also failed to observe a significant visual field increase.

Kerkhoff and colleagues (1992b, 1994) found that approximately 50% of patients showed an increase in their visual field after compensatory exploration training. Whilst the improvement found ranged from 1° to 30° the mean change was approximately 5° for these patients, which is comparable to the reported increases after visual restoration training (VRT; Kasten et al., 1998). The restorative effects noted by Kerkhoff and colleagues did not correlate with the magnitude of the improvements found in the visual search field. This indicates that any increase in the visual field is not sufficient to overcome the visual impairment and that compensatory saccades are producing an additive enhancement. Other researchers have failed to observe any significant increase in the visual field after exploration training (Nelles et al., 2001; Pambakian et al., 2004; Zihl, 1995a) and these inconsistent findings reveal that the effect of compensatory training on the visual field has yet to be reliably established.

Part of the problem in trying to establish whether or not compensatory therapies can lead to restorative outcomes is that the same caveats apply as to the restorative approaches. Namely the field assessment needs to be reliable by adequately monitoring fixation during perimetry, and there are other factors (for example attention) which can influence the visual field and therefore need to be considered. In this study the restorative effects of exploration training are assessed and these factors are taken into consideration. A manual Tübinger perimeter (a conventional method) is used to assess the visual field which allows the researcher to monitor the participant's fixation via a telescope, and therefore the eccentricities of visual perception are only recorded when fixation is maintained. Furthermore, the resolution of the technique is assessed in order to determine how accurately saccades made by the participant can be observed by the researcher, and whether or not this is sufficient to exclude the possibility of fixation bias from explaining any field increases. Changes are also examined not only in the blind hemifield but also in the seeing hemifield in order to investigate the possible contribution of other factors.

2.2 Overview of the aims and design of the study

Within this chapter the training and each of the assessment tasks will be considered independently. Consequently the method and results for each of these are reported in the individual task sections. Therefore, information which is relevant to the whole study (aims, design and sample) is firstly described in this section.

2.2.1 Study aims

This study aims to address the clinical issue of the transferability of compensatory training benefits for patients with HVFDs. Firstly, transfer is examined to visual search involving displays which contain non-trained visual stimuli. Secondly, the training is limited to a small portion of the visual field and therefore it is important to establish whether or not the improvement in search generalises across the visual field. Other transfer tasks which are examined include search involving a different response modality, reading (which is an example of an ADL task) and also subjective improvements in ADLs. These outcome measures all address different aspects of transferability.

The secondary aim of this chapter is to address the issue of visual restoration as a side effect of compensatory exploration training. The previous results have been contradictory, and the same limitations apply when considering changes in the visual field as an outcome measure as those for restorative techniques. This study examines the impact of exploration training on the blind visual hemifield whilst considering both the resolution of the perimetric measurement and the impact of the training on the seeing hemifield, in order to address some of the problems surrounding the issue of visual restoration.

2.2.2 Design

This was a within-subjects repeated-measures study in which the sample of patients (for whom details are provided in the section below) completed a series of tasks in a pre-training assessment session, before performing the exploration training and then repeating the same assessment tasks in a post-training session. The assessment tasks included various visual search tasks involving non-practiced visual stimuli, a 'projected search' task involving visual search using a larger display size than had been used during training, and a 'visuomotor search' task which required a different behavioural response to that used during the training. At each session the patients also completed reading tasks and self-report questionnaires designed to assess certain ADL abilities. A group of neurologically healthy control participants also completed the transfer tasks in order to examine relative impairment and improvement of the patients' performance. As well as these outcome measures, perimetry was performed with the patients at each session to examine any possible restoration of the visual field.

2.2.3 Sample

All participants gave informed consent to partake in the study in accordance with the Declaration of Helsinki (International Committee of Medical Journal Editors, 1991). Approval for the study was obtained from the departmental ethics committee at Durham University and from the NHS multi-centre research ethics committee.

2.2.3.1 Patients with HVFDs

Participants were recruited from those patients referred to the study from local hospitals or who referred themselves. Patients with visual field loss due to pre-chiasmatic or chiasmatic damage were excluded. Patients with additional eye-movement disorders, photosensitive epilepsy, progressive neurological disorders or insufficient speech, language, cognition or mobility to be able to complete the tasks were also excluded from the sample. Participants had to be at least 18 years of age, although there was no upper age-limit.

A total of 23 patients with HVFDs participated in the study, and the individual characteristics of these patients are outlined in Table 2.1. Of these participants, 18 were male and 5 were female, 22 were right-handed and 1 was left-handed, and all had either normal or corrected-to-normal visual acuity. The mean age of the patients was 64.0 years (range: 33 to 79 years). The aetiologies underlying the HVFDs included ischaemic stroke (n = 16), cerebral haemorrhage (n = 6) and trauma (n = 1). Six of the patients (26%) had a right-hemifield HVFD and the remaining 17 (74%) had a left-hemifield HVFD, and the mean amount of visual sparing was 3.6° (range: 0° to 12°). The mean time since the onset of field loss was 23.9 months (range: 3 to 276 months), and the minimum amount of time that had elapsed since onset was three months in order to minimise the likelihood of the results being confounded by spontaneous recovery of vision (Pambakian & Kennard, 1997).

Two of the patients had a comorbid neglect as assessed using the star cancellation task (Halligan, Cockburn & Wilson, 1991), and confirmed using medical records. The decision to include patients with additional neglect was based on the findings of Kerkhoff et al. (1992b) that such patients could benefit from exploration training. Some patients had additional difficulties including hemiplegia or hemiparesis (n = 5), memory impairments (n = 1), aphasia (n = 1) and diplopia (n = 1), although none of these were sufficient to prevent participation.

2.2.3.2 Dropouts

Of the 23 patients who participated in the study, 21 completed the training and attended the post-training assessment session. Both of the non-completers dropped out after the initial assessment session, one due to personal choice and the other died.

Table 2.1

Characteristics of the patients and their visual field defects. Details include gender, age, handedness, type and location of HVFD, presence of neglect, visual field sparing, aetiology, and HVFD duration.

Participant	Gender	Age (yrs)	Handedness	HVFD[a]	Neglect	Sparing (°)	Aetiology	Duration (m)
1	Male	65	Right	RH	No	0	Ischaemic stroke	34
2	Male	73	Right	LIQ	No	2	Ischaemic stroke	16
3	Male	57	Right	LH	No	2	Trauma	276
4	Male	62	Right	LH	No	0	Ischaemic stroke	32
5	Male	60	Right	LIQ	No	3	Ischaemic stroke	6
6	Female	61	Right	LH	No	12	Ischaemic stroke	9
7	Male	62	Right	LH	No	4	Haemorrhage	11
8	Male	78	Right	RH	No	2	Ischaemic stroke	3.5
9	Male	71	Right	LH	Yes	0	Ischaemic stroke	11
10	Female	71	Right	RH	No	0	Haemorrhage	4.5
11	Male	68	Right	LSQ	No	12	Ischaemic stroke	3.5
12	Male	78	Right	LH	No	2	Ischaemic stroke	3.5
13	Male	75	Right	LS	No	0	Ischaemic stroke	4
14	Male	78	Right	RH	No	0	Ischaemic stroke	12
15	Female	33	Right	LIQ	No	10	Haemorrhage	16.5

Participant	Gender	Age (yrs)	Handedness	HVFD	Neglect	Sparing (°)	Aetiology	Duration (m)
16	Male	50	Right	LSQ	No	4	Haemorrhage	10
17	Female	69	Right	LH	No	8	Ischaemic stroke	3
18	Male	55	Right	LH	No	0	Ischaemic stroke	3
19	Male	79	Right	LS	No	6	Ischaemic stroke	6.5
20	Male	66	Right	LH	Yes	2	Ischaemic stroke	10
21	Male	46	Right	RIQ	No	4	Haemorrhage	13.5
22	Male	44	Left	RH	No	5	Haemorrhage	58
23	Female	70	Right	LSQ	No	4	Ischaemic stroke	4

Note: [a] RH: right hemianopia; LH: left hemianopia; LIQ: left inferior quadrantanopia; LSQ: left superior quadrantanopia; LS: left scotoma; RIQ: right inferior quadrantanopia.

2.2.3.3 Control participants

The sample also included a group of 23 healthy control participants who were neurologically intact, and who were matched to the patient group with regards to age and gender. These participants had a mean age of 66.0 years (range: 41 to 76 years), which was not significantly different to that of the patient group ($U = 244$, $p = 0.652$, $r = 0.07$). Of the control sample, 18 were male and 5 were female (which was the same proportion as the patient sample), 20 were right-handed and 3 were left-handed, and all had either normal or corrected-to-normal visual acuity.

2.3 Compensatory exploration training

2.3.1 Method

2.3.1.1 Tasks and stimuli

The training consisted of 15 sessions which were separated into three blocks of five sessions. Each session involved nine tasks which are outlined in Table 2.2. The first three of the tasks in each session were feature visual searches, whereby the pre-defined target could be differentiated from the distractors by colour, size (large letter) or form (specific letter). Participants had to decide if the target was present or absent on each trial and on half of the trials the target was present. For the feature search tasks there were always eight randomly presented distractors and difficulty was modified across the sessions by reducing the stimulus presentation time. The trial duration was modified for each session and for each participant individually, and was determined so that accuracy levels always exceeded 80%.

Table 2.2

Details of the visual search tasks used in each session of the exploration training. The details include the defining characteristics of the target, the number of distractors in the display (for each block of training separately) and the minimum and maximum display duration (in seconds).

Task type	Target	Number of distractors			Display (s)	
		Block 1	*Block 2*	*Block 3*	*Max*	*Min*
Feature	Colour	8	8	8	12	0.5
Feature	Size	8	8	8	12	0.5
Feature	Form	8	8	8	12	0.5
Easy Conjunction	Colour & Form	8	10-13	12-17	15	3
Hard Conjunction	Colour & Form	8	10-13	12-17	15	3
Easy Conjunction	Size & Form	8	10-13	12-17	15	3
Hard Conjunction	Size & Form	8	10-13	12-17	15	3
Easy Comparative	Missing object	3	3 or 6[a]	3, 6, or 9[a]	10	10
Hard Comparative	Replaced object	3	3 or 6[a]	3, 6, or 9[a]	10	10

Note: [a] The number of items in the display would increase to the next number only if the patient had successfully completed trials using the lower number of items.

The feature tasks were followed by four conjunction visual searches, which again required patients to decide upon the presence or absence of a pre-specified target which was present on half of the trials. In conjunction searches the target is defined by two characteristics. The first of these tasks involved a target which was defined by colour and form (*easy colour-form conjunction*). In the following task the target remained the same but the level of difficulty increased; the distracting items were made more visually similar to the target letter (*hard colour-form conjunction*). In the third conjunction search the target was defined by size and form (*easy size-form conjunction*), and in the final task of this type the target was the same as in the third, but again the distracting items were made more similar to the target (*hard size-form conjunction*). The difficulty of the conjunction searches was modified by adding more distractors (which gradually increased as the blocks progressed) and reducing the display presentation time, which was modified in the same manner as for the feature searches.

The final two tasks of each session were comparative searches, in which patients had to decide if two pictures (one on the left and one on the right side of the screen) were the same or different. Both of the pictures contained a series of objects (i.e. butterflies and dolls) which were in the same location in each image. In the first of the comparative searches one of the objects was missing from one of the pictures in half of the trials (*easy comparative*). In the final task, one of the objects was replaced using a within-category item for half of the trials (*hard comparative*), and an example of this task can be seen in Figure 2.1.

Figure 2.1: An example of the display used in the hard comparative search task (not to scale). In each picture the items are located in the same positions. In this example the snowglobes in the two pictures are different.

2.3.1.2 Apparatus

The training program was created using E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA), and was performed using a laptop computer. The screen of the laptop computer was viewed binocularly at an approximate distance of 57cm, which meant that the display subtended approximately 30° horizontally (15° in each hemifield) and 21° vertically.

2.3.1.3 Procedure

The training was performed in the participants' homes, in a dimly-lit room with few distractions. Participants sat comfortably such that they were centrally-aligned with the computer and with their hands resting on the keyboard. Each trial of each of the tasks began with a central fixation cross which was presented for one second. The visual search display was then presented until the participant made a response, which they did using an appropriate key-press ('B' for present/the same or 'N' for absent/different). If a response was not made before the pre-determined trial duration was reached then a blank, black screen was presented for two seconds within which time patients were encouraged to provide a response. After the patient's response, feedback regarding trial accuracy ('[illegible]' or 'incorrect') was presented for 500ms.

Patients had to complete 32 trials for each task in every session, and overall feedback (accuracy in percent and mean search time in seconds) was given at the end of each task. The next task within the session began when the patient indicated that they were ready to continue. Where appropriate, verbal feedback and encouragement was also provided by the researcher, and participants were instructed to perform the tasks as quickly and as accurately as possible. However, specific instructions for how participants should move their eyes were not provided. The mean duration of the training was 3.9 weeks (range: 2 to 9 weeks).

2.3.2 Results and discussion

The data analysis was performed using SPSS 14.0 (SPSS Inc, Chicago, IL), statistical tests were always two-tailed and the alpha-level was set at 0.05. Wilcoxon signed ranks tests were performed for the analyses of the dependent data. These analyses were based on the means for individual patients, and the analysis of search time was based on only the correct trials. Effect sizes were calculated using the following formula: $r = z / \sqrt{N}$, where N was the number of observations used to calculate z. An effect size less than 0.3 was classed as small, 0.3 to 0.49 as medium, and anything which was 0.5 or greater was interpreted as large (Cohen, 1988).

Due to time constraints one of the patients (14) completed only the first ten training sessions and consequently this patient's data was excluded from the analyses. Feature search was selected as the task type used to examine the change in performance across training. This was chosen in preference to conjunction or comparative search tasks since the number of distractors remained constant across each of the sessions for the feature tasks, making it easier to compare performance across these. Blocks of training were selected as the independent variable rather than individual sessions, since across one block there were different colours and shapes used for the five sessions, but these were then repeated across each block of training.

The data was collapsed across the three different feature tasks (colour, form and size). Technical problems meant that data from some patients was missing for some of the sessions (7.3% of values, for further details see Appendix 1), and these missing values were replaced using the mean for the session. The mean value for each training block was calculated based on the results from each of the five sessions which it was comprised of.

The results described are for the target-present condition (the target-absent results are described in Appendix 2). The mean search time gradually decreased across the three training blocks (see Figure 2.2). The decrease in search time in block 3 relative to the first training block was 621.40ms, meaning that the slope of improvement was 310.70ms/block. This represents a significant overall improvement across the training of 33.7% ($z = -3.88$, $p < 0.001$) and the training had a large effect on search time ($r = 0.61$).

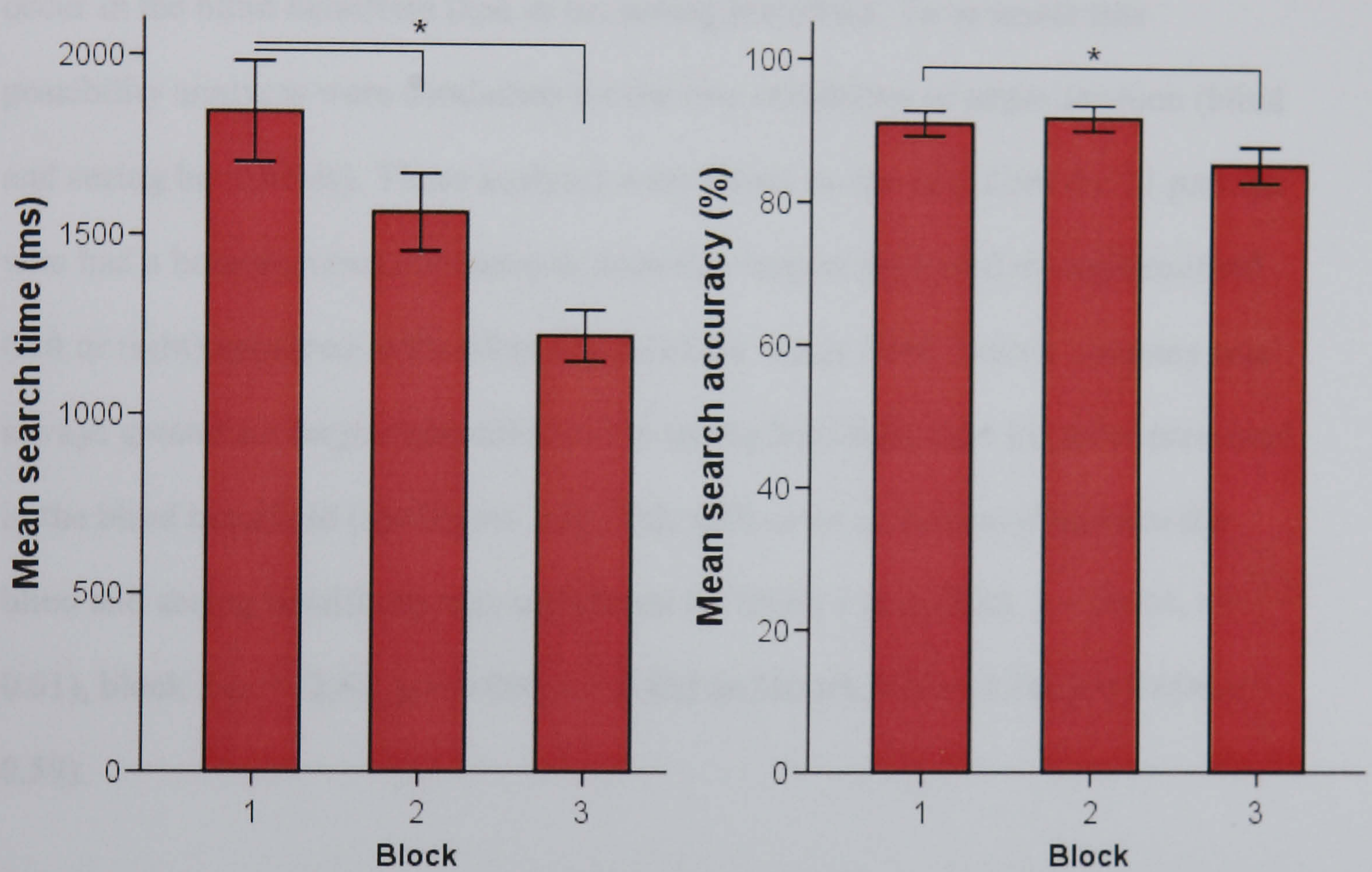

Figure 2.2: Graphs to show the mean search time (in milliseconds) and accuracy (in percent) for each of the training blocks for the target-present condition. The error bars represent the standard error of the mean and '*' represents a significant difference.

However, Figure 2.2 also shows that search accuracy declined in block 3 of the training. The overall decrease in accuracy across the training (block 3 versus block 1) was 5.55%, and this was significant ($z = -2.88$, $p = 0.004$, $r = 0.46$) indicating a speed-accuracy trade-off effect.

In order to further examine the interaction between speed and accuracy, blocks 1 and 2 of the training were compared. There was a significant decrease in search time in block 2 as compared to the first block ($z = -3.14$, $p = 0.002$, $r = 0.50$), whilst there was no significant difference in accuracy between these two blocks of training (z = -0.88, p = 0.378, r = 0.14). This indicates that the improvement in training performance cannot be entirely explained as the result of a speed-accuracy trade-off effect.

The aim of the training was to improve visual search, specifically of the blind areas. If the training is specific then a greater effect would be expected to occur in the blind hemifield than in the seeing hemifield. To examine this possibility analyses were conducted for the two conditions of target location (blind and seeing hemifields). These analyses were based on the data from the 11 patients who had a homonymous hemianopia, such that targets presented in one hemifield (left or right) appeared in the blind region of the visual field. Search accuracy was always greater for targets presented in the seeing hemifield than for those presented in the blind hemifield (see Figure 2.3). This difference in accuracy between the blind and seeing hemifields was significant for block 1 (z = -2.85, p = 0.004, r = 0.61), block 2 (z = -2.81, p = 0.005, r = 0.60) and block 3 (z = -2.76, p = 0.006, r = 0.59).

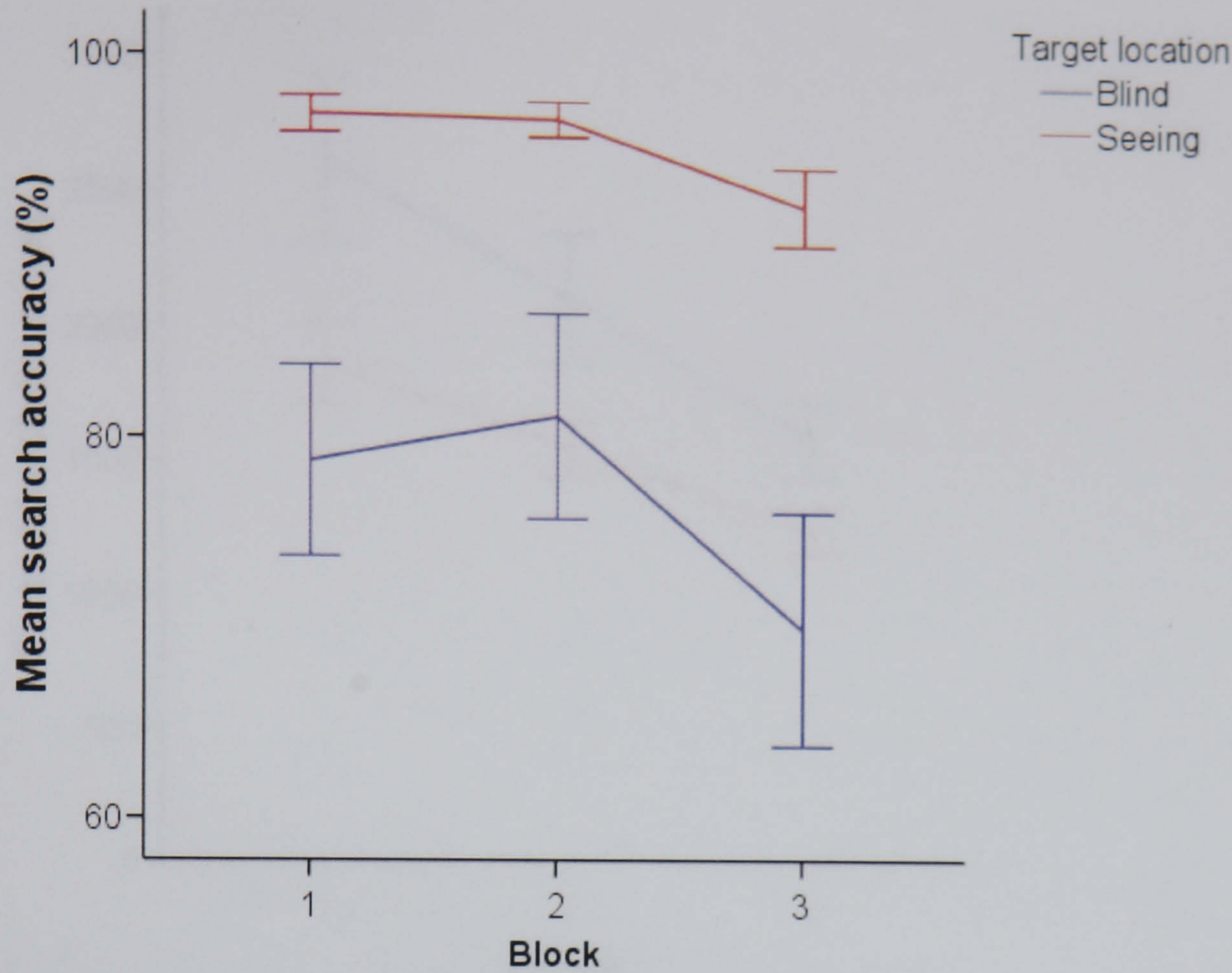

Figure 2.3: Graph showing the mean search accuracy (in percent) for the three training blocks, separately for the condition in which the target was presented in the seeing hemifield and the blind hemifield. The error bars represent the standard error of the mean.

The mean search time was always greater for targets presented in the blind hemifield than those in the seeing hemifield (see Figure 2.4). This difference in search time between the hemifields was significant for block 1 (z = -2.67, p = 0.008, r = 0.57), block 2 (z = -2.67, p = 0.008, r = 0.57) and block 3 (z = -2.76, p = 0.006, r = 0.59). In order to examine if there was any difference in the training benefit observed for the two hemifields the mean search slope was calculated for each. The mean search slope for targets in the seeing hemifield was -304.36ms/block (SD = 171.59) whilst for the blind hemifield it was -510.90ms/block (SD = 353.02). The difference between the slopes was significant (z = -2.58, p = 0.010, r = 0.55), which indicates that the improvement in search time was greater for those targets appearing in the blind hemifield than for those in the seeing hemifield.

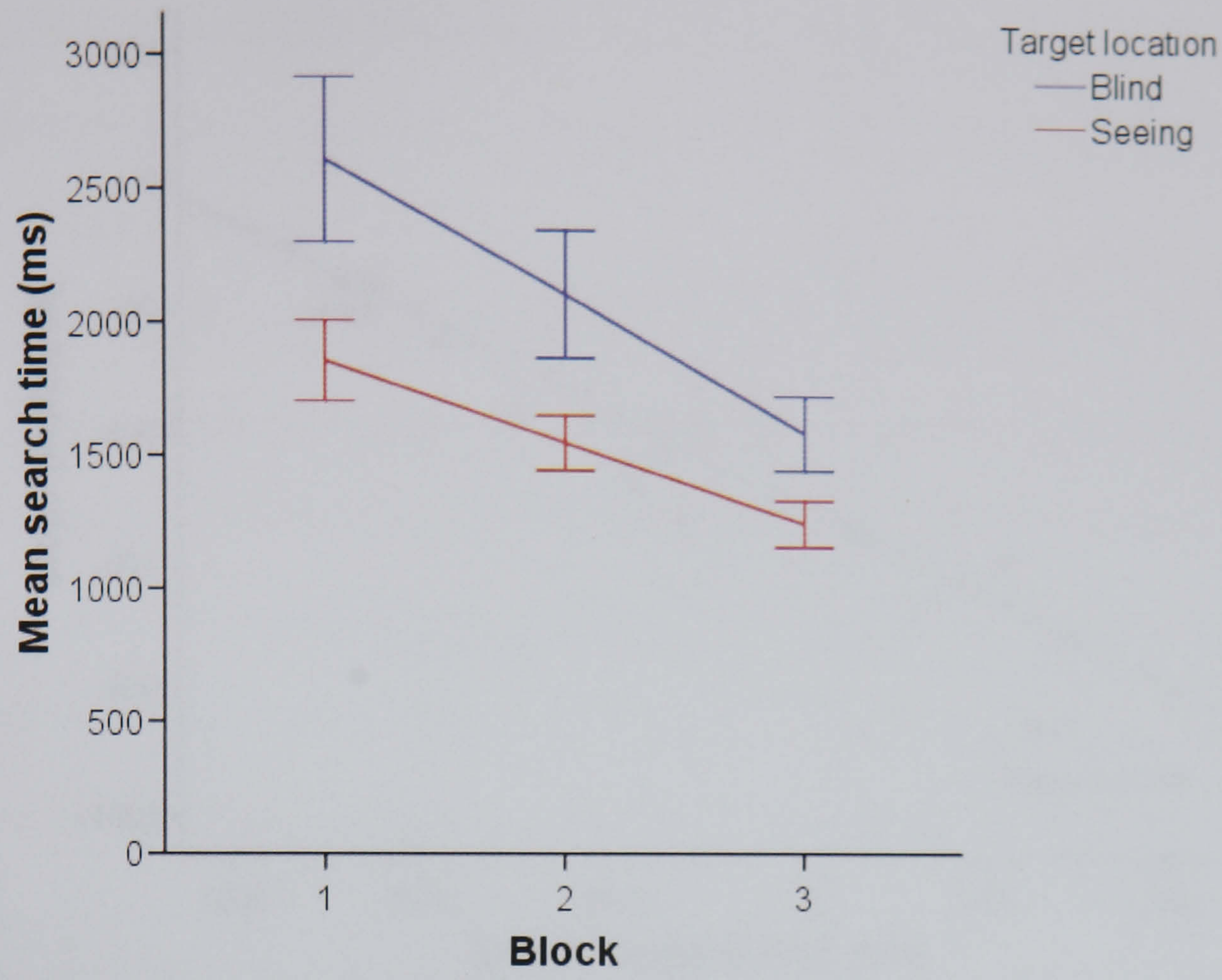

Figure 2.4: Graph showing the mean search time (in milliseconds) for the three training blocks, separately for the condition in which the target was presented in the seeing hemifield and the blind hemifield. The error bars represent the standard error of the mean.

The difference in the effect for the seeing and blind hemifields implies a specific training effect. However, performance in the seeing hemifield did improve and it is possible that the baseline performance limited the improvement possible for this condition (ceiling effect). To examine the possibility that baseline performance was related to improvement, the target-present search slope was calculated for each individual, and this was then plotted against the individual search time for block 1 of the training (see Figure 2.5).

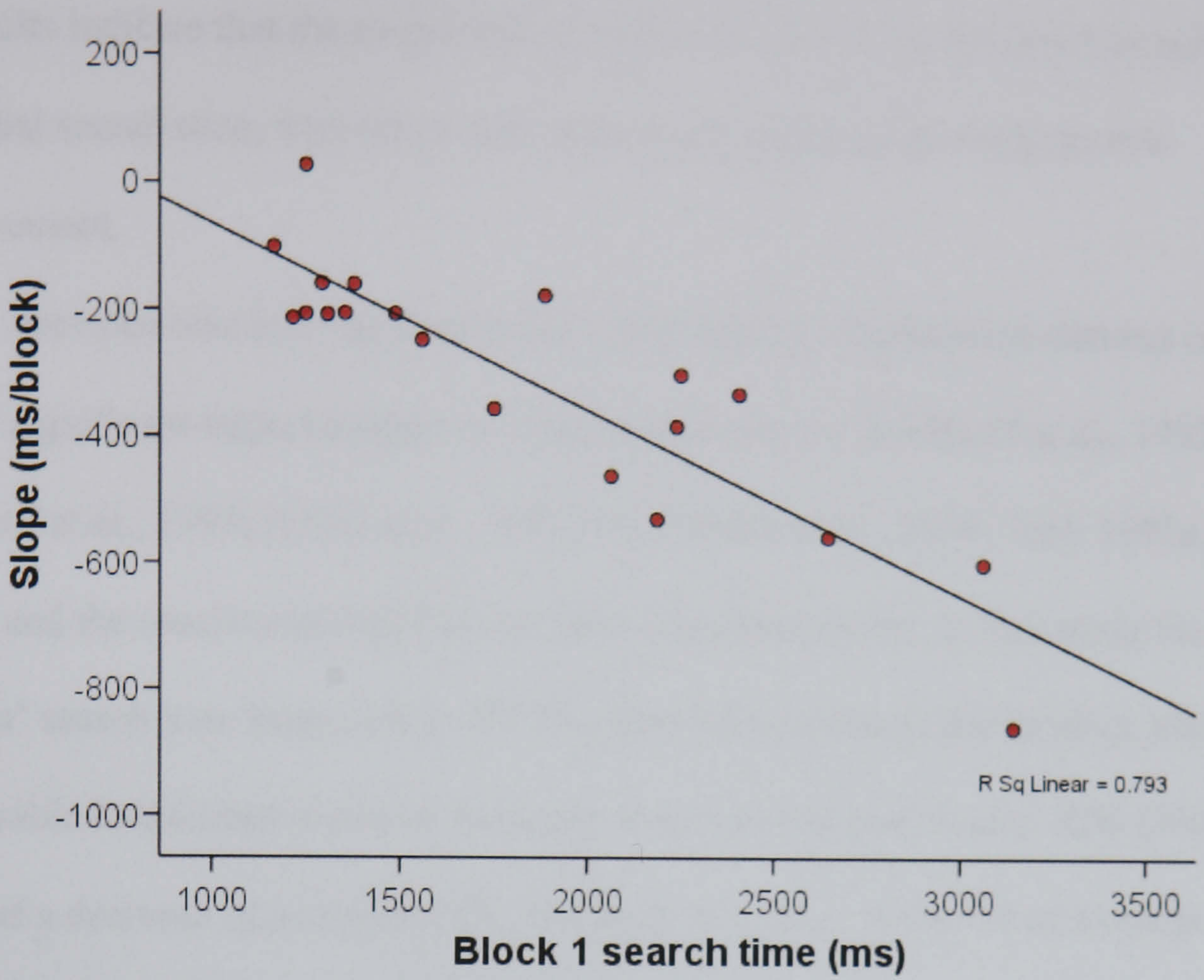

Figure 2.5: Comparison of the training block 1 search time (in milliseconds) and the search slope (ms/block) for the condition in which the target was present.

The graph indicates that initial training search time and improvement in search time are negatively associated; patients who were fastest at the start of the training showed less change than those patients who were more impaired initially. The Pearson correlation coefficient between the variables was -0.89 ($p < 0.001$), indicating a significant negative correlation between block 1 search time and training effect. This implies that baseline search time is associated with the improvement that can be obtained across the course of training, and this could potentially have limited the improvement possible in the seeing hemifield.

In summary, these results show that search time significantly decreased across the course of the training, an improvement which cannot be entirely attributed to a speed-accuracy trade-off effect. The improvement in search was observed for targets which were presented in the seeing and the blind hemifields, although the effect was significantly greater for the latter condition. Furthermore, the results indicate that the magnitude of improvement in search time was related to the initial search time, with those who were more impaired showing greater improvement.

Previous research has shown that compensatory exploration training can lead to significant improvements in visual search ability (Kerkhoff et al., 1992b; Kerkhoff et al., 1994; Nelles et al., 2001; Pambakian et al., 2004; Zihl, 1995a, 2000), and the results reported here confirm that observation. In this study the patients' search time improved by 33.7% across the course of the training which is comparable to the improvements in search time reported previously. Zihl (2000) reported a decrease of just over 50%, Nelles et al. (2001) observed an average improvement in the blind hemifield of 32%, whilst Pambakian et al. (2004) found a decrease in search time of approximately 20%. However, it is important to note that Zihl's sample consisted only of patients who showed significant impairments in visual search performance at baseline relative to neurologically normal controls, and as such the sample represented the more severely impaired end of the patient group. Perhaps this could explain the slightly larger effect observed by Zihl (2000), since the most impaired patients are those who typically show the greatest improvements after training (Kerkhoff et al., 1992b; Pommerenke and Markowitsch, 1989), a finding which was also observed here.

These findings imply that saccadic strategies do not need to be explicitly taught to patients in order for their search behaviour to improve. In this study no instructions were given on how patients should move their eyes. Rather, simply providing the stimulation and scenarios which encourage more efficient searching appears to be sufficient for patients to develop their own improvements in exploration, confirming the earlier findings of Pambakian et al. (2004). This is an important practical issue since it means that the role of the researcher/therapist is minimised, and there is the potential that patients could train themselves.

2.4 Assessment tasks: are the benefits of the training transferable?

2.4.1 Visual search using untrained visual stimuli

2.4.1.1 Method

Tasks and stimulus arrays:

Three visual search tasks were used to assess search performance: 'count the dots', 'find the number' and 'count the numbers'. These tasks (and visual stimuli) had not been involved in the training.

For the 'count the dots' task the display contained a series of dots randomly displayed across the screen such that none of them overlapped (see Figure 2.6 for an example). Each stimulus was a white circular dot, 1° in diameter. In each trial the minimum number of dots presented was six and the maximum was ten, although participants were not informed of this.

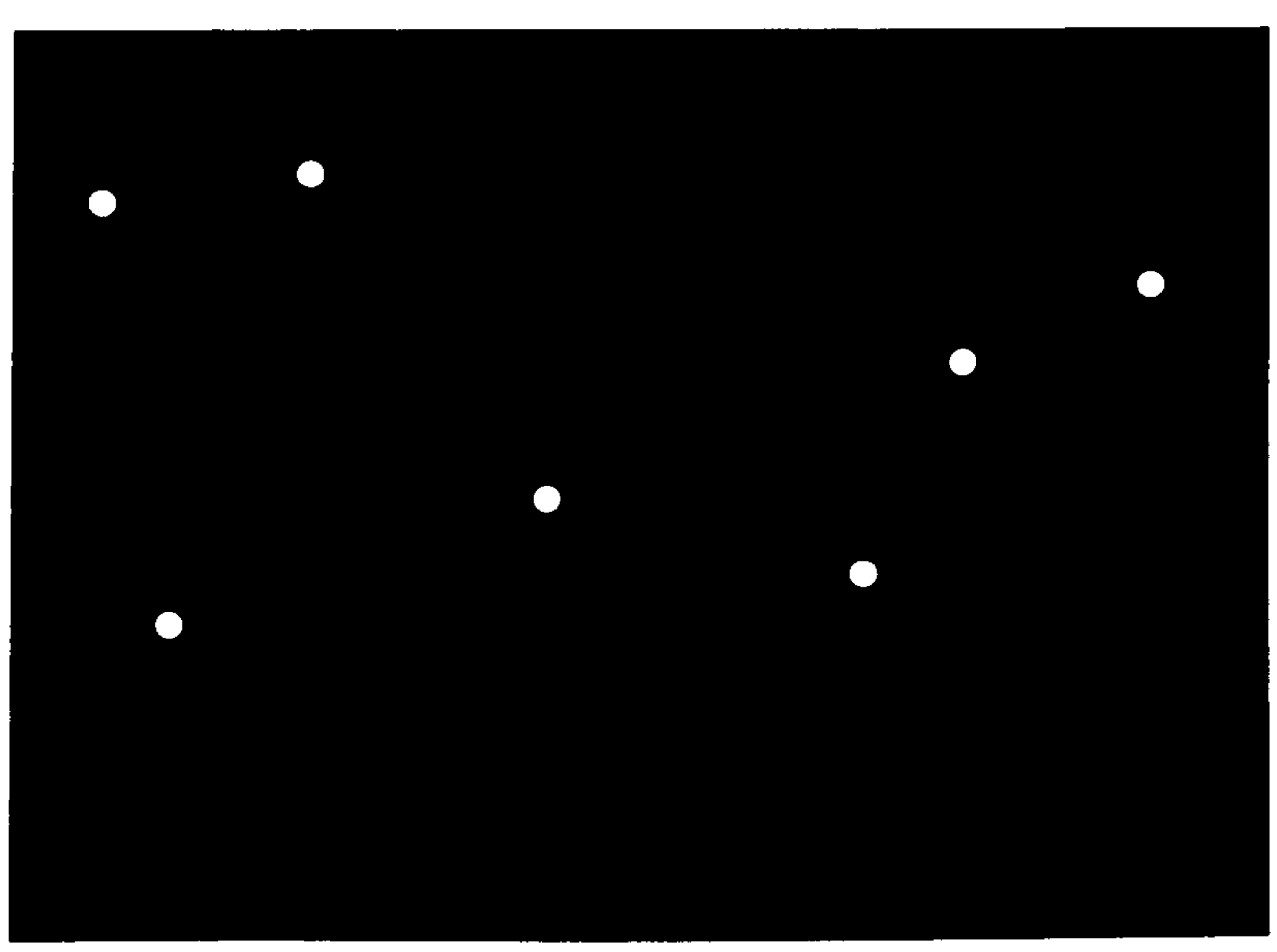

Figure 2.6: Diagram showing an example of a possible display used in the 'count the dots' visual search task (not to scale).

For the 'find the number' task the array contained a series of non-overlapping, randomly displayed distractor symbols such as '&', '%' and '£' (see Figure 2.7). In half of the trials there were four distractors and in the other half there were eight distractors. There was always one target (number) present and this was randomly presented in each quadrant of the scene an equal number of times across the trials. The target and the distractors were all 1° in height.

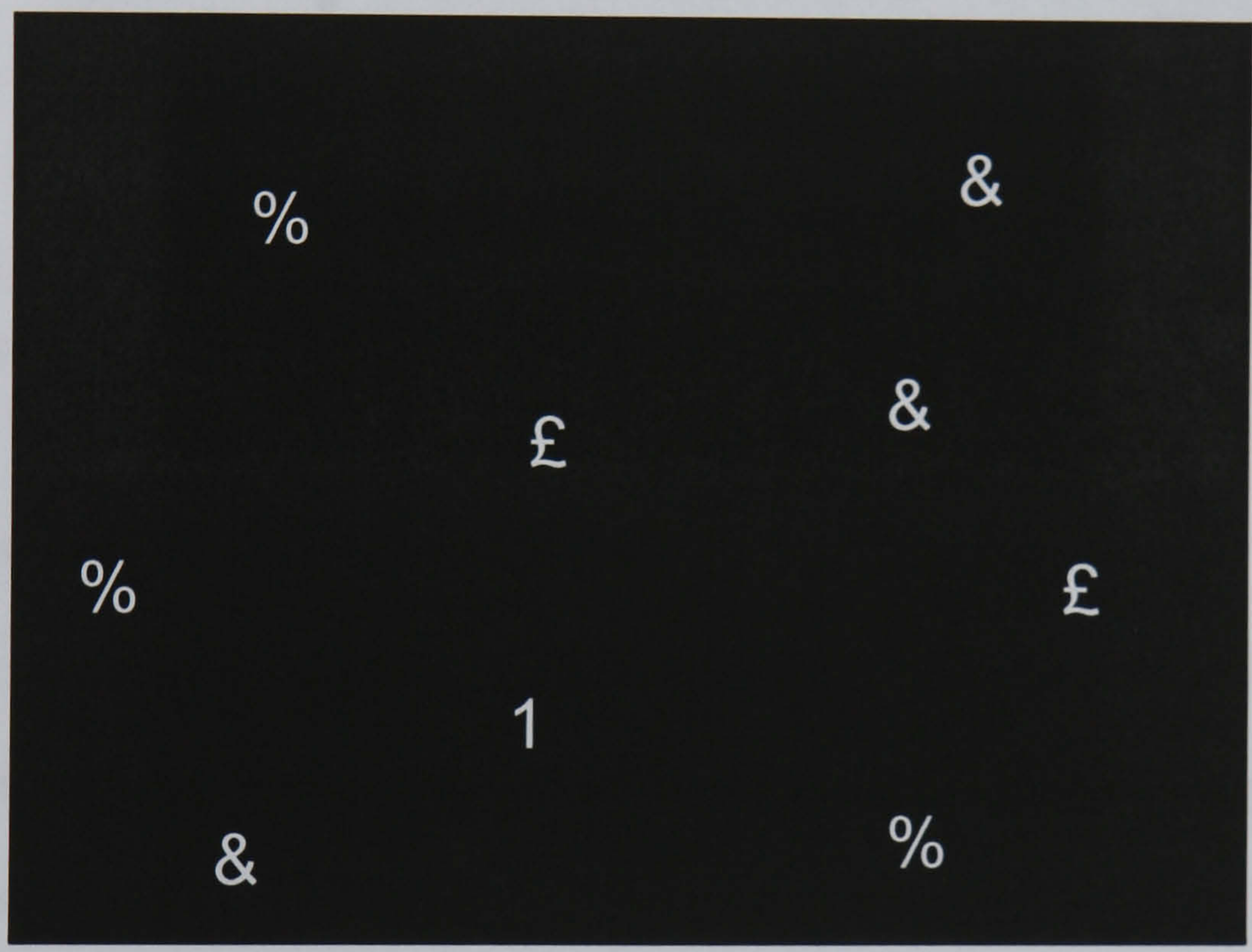

Figure 2.7: Diagram to show an example of a possible display used in the 'find the number' visual search task (not to scale). The target was the number, which in this example is 1.

For the 'count the numbers' task the display on each trial contained the numbers from 1 to 20, randomly presented such that none of the items overlapped (see Figure 2.8 for an example). Each number was 1° in height. There were ten possible displays which were always used in the same order.

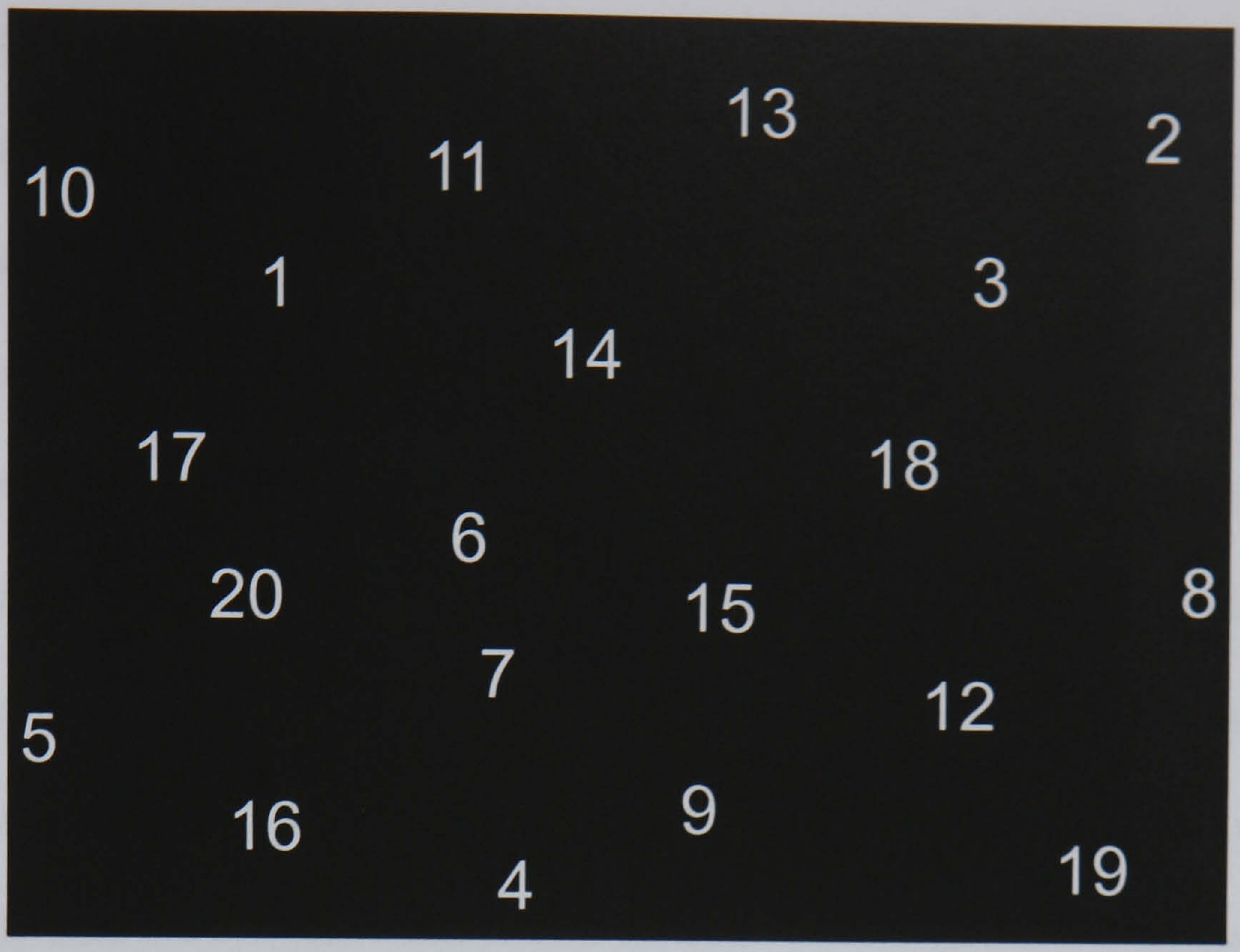

Figure 2.8: Diagram to show an example of a possible display used in the 'count the numbers' visual search task (not to scale).

Apparatus:

The visual search tasks were developed using C++ Builder Professional 6 (Borland Software Corporation, Austin, TX) and the stimuli were generated using a VSG 2/5 graphics card (Cambridge Research Systems, Rochester, UK). The search arrays were presented using a Sony Trinitron monitor with a 100Hz refresh rate. The monitor was centrally aligned and binocularly viewed at a distance of 57cm such that the monitor subtended 40.5° horizontally and 30° vertically, and viewing position was maintained using a head-rest. A standard computer keyboard was used by the experimenter to record the participants' responses.

Procedure:

For all of the visual search tasks participants were instructed to be both as quick and as accurate as possible. For the 'count the dots' and 'find the numbers' tasks the patients completed 40 trials of each at both assessment sessions, whilst for the 'count the numbers' task participants completed between five and ten trials per session, depending on individual levels of fatigue and concentration.

For each trial of the 'count the dots' task the participant had to verbally report how many dots were presented. As soon as the participant made a response the researcher used a key-press to end the trial, at which point a blank, black screen was displayed to the participant. The researcher then typed in the number of dots as reported by the participant. There was a one second delay between the response being entered by the researcher and the appearance of the display for the next trial.

For the 'find the number' task the participants were required to find and then verbally report the one-digit number presented amongst a set of non-number distractors. As soon as the participant made a response the researcher used a key-press to end the trial, at which point a blank, black screen was displayed. The researcher then typed in the number reported by the participant. Following this the display remained blank for a further one second before the display for the next trial appeared.

In the 'count the numbers' task participants were asked to search for each of the 20 randomly presented numbers in sequence (i.e. from 1 to 20). Participants were instructed to verbally report each number once they had found it in order to indicate to the researcher that they had located the number, and were then asked to move onto the next number in the sequence. As soon as the participant reported having found number 20 the researcher used a key-press to end the trial. The researcher also recorded during each trial how many errors were made. Errors included a number being read out of sequence or being missed altogether. Therefore for each trial there was a maximum of 20 possible errors and on the basis of this the number of errors was converted to accuracy.

2.4.1.2 Results and discussion

Wilcoxon signed ranks tests based on the means for individual patients were performed for the analyses of the dependent data. Mann-Whitney U tests were performed for the analyses in which the patients were compared to the control participants, again using the mean values from individual participants. For the analyses of search time, data was only used from the trials in which the correct response was provided, and furthermore, outliers (defined as values in search time which were more than two standard deviations from the mean) were calculated and removed from the individual patient data sets. The outliers were calculated for the two distractor conditions separately in the 'find the number' task. Each of the three visual search tasks were analysed separately.

'Count the dots' visual search task:

Due to a computer failure the data from one participant (05) was missing from the post-training session, and therefore this patient's data was excluded from the analyses. The data from another participant (14) was based on only 20 trials per session since he found the task very strenuous.

The mean search time decreased after the training by 396.62ms (see Figure 2.9), a significant improvement of 6.5% ($z = -2.35$, $p = 0.019$, $r = 0.37$). Despite the improvement in search time, it appears that following the training the patients did not perform at the same level as healthy controls, who were significantly faster than the patients ($U = 6$, $p < 0.001$, $r = 0.82$).

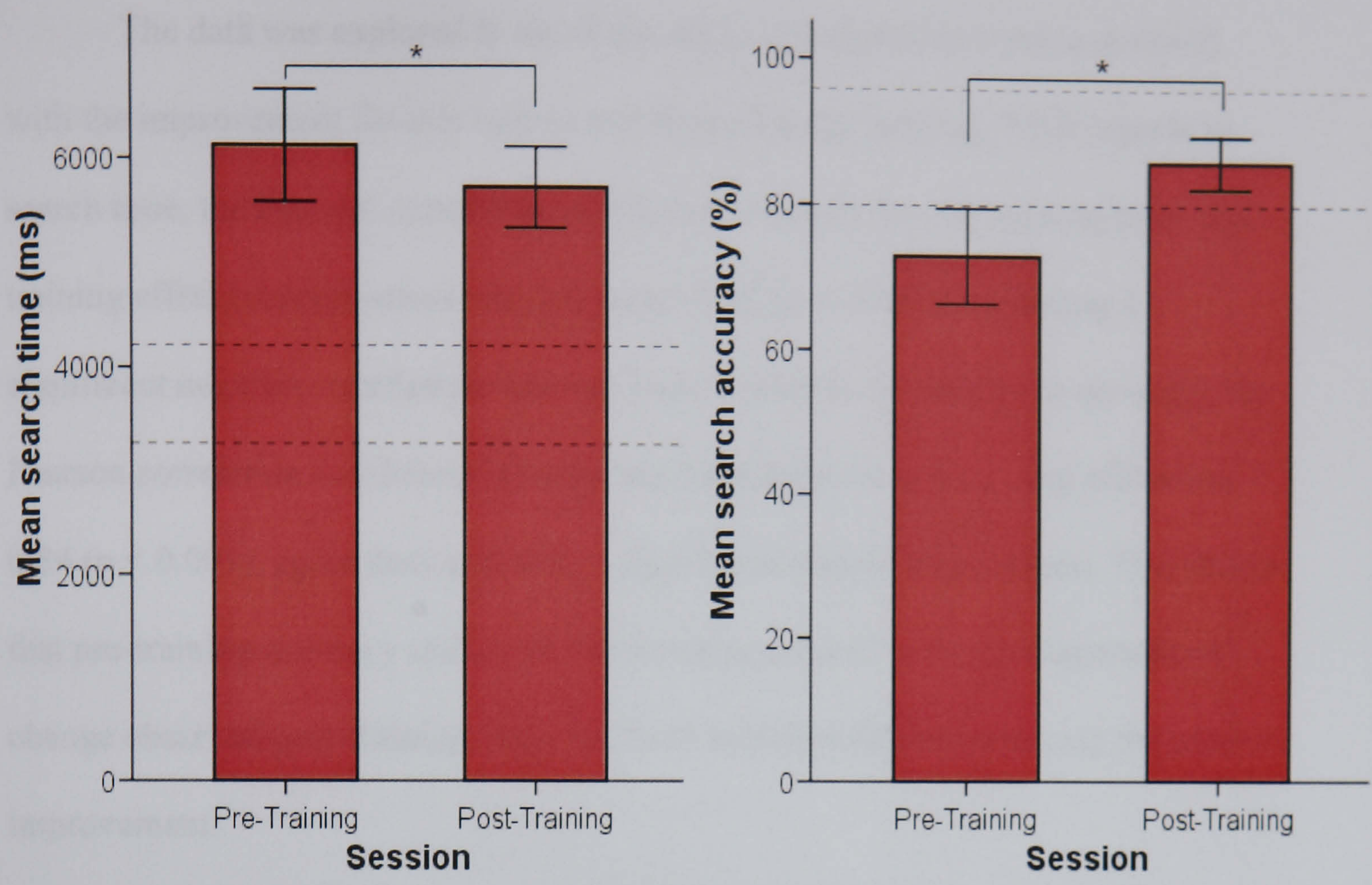

Figure 2.9: Graphs showing the mean search time (in milliseconds) and accuracy (in percent) for the 'count the dots' task for the pre- and post-training sessions. The error bars represent the standard error of the mean and '*' represents a significant difference. The horizontal reference lines represent the mean and the maximum search time, and the mean and minimum accuracy for the control participants.

In order to examine whether the improvement in search time was the result of a speed-accuracy trade-off effect, analyses were performed on the accuracy data. Accuracy increased by approximately 13% after the training (Figure 2.9). This increase was significant ($z = -2.30$, $p = 0.021$, $r = 0.36$) and demonstrates not only that the improvement in search time was not the result of a speed-accuracy trade-off, but that the training also led to improvements in accuracy. However, control participants completed the task with a greater degree of accuracy than patients, even after the training ($U = 138$, $p < 0.034$, $r = 0.32$). Therefore, whilst the patients' accuracy did improve after the training it did not reach normal control levels, although the mean patient accuracy post-training was within the range of that of the controls.

The data was explored to see if pre-training performance was associated with the improvement for this task as was found for the training. With regards to search time, the Pearson correlation coefficient between the pre-training level and training effect (change across sessions) was -0.73 ($p < 0.001$), indicating a significant negative correlation between these variables. In relation to accuracy, the Pearson correlation coefficient between pre-training level and training effect was -0.84 ($p < 0.001$), again demonstrating a significant negative correlation. This shows that pre-training accuracy and search time was associated with the magnitude of change observed post-training, with the more impaired patients showing the greatest improvement.

To summarise, these results show that after the training participants' performance on the 'count the dots' task was significantly improved relative to the pre-training level. The improvements were noted for both accuracy and search time, and were related to the initial level of performance for the task. This indicates that the benefit of the training does transfer to this task.

'Find the number' visual search task:

The data for this task was collapsed across the four and the eight distractor conditions. The mean search time decreased after the training by 727.98ms (see Figure 2.10), a significant improvement of 23.8% ($z = -4.02$, $p < 0.001$, $r = 0.62$). Despite this improvement the patients did not perform at the same level as the control participants, who were significantly faster than the patients even after training ($U = 58$, $p < 0.001$, $r = 0.63$). The mean accuracy remained relatively stable after the training, increasing by only 1.19% (Figure 2.10). This increase was non-significant ($z = -0.99$, $p = 0.323$, $r = 0.15$), but indicates that the improvement in search time was not the result of a speed-accuracy trade-off. The accuracy of the control participants was not significantly different to that of the patients either before the training ($U = 214$, $p = 0.659$, $r = 0.07$) or afterwards ($U = 190$, $p = 0.277$, $r = 0.16$).

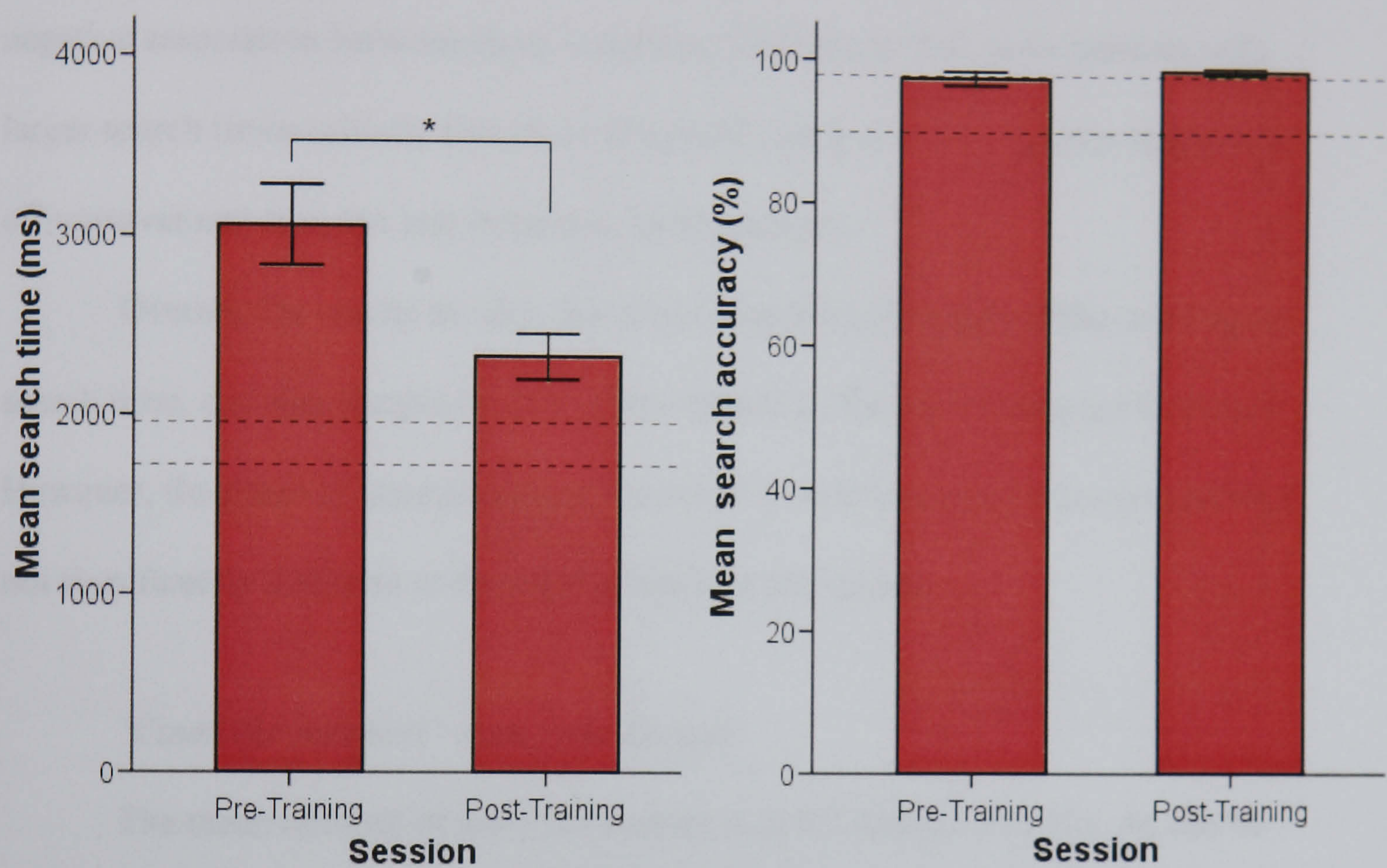

Figure 2.10: Graph showing the mean search time (in milliseconds) and accuracy (in percent) for the 'find the number' task for the pre- and post-training sessions. The error bars represent the standard error of the mean and '*' represents a significant difference. The horizontal reference lines represent the mean and the maximum search time, and the mean and minimum accuracy for the control participants.

In order to distinguish between motor and perceptual search abilities the efficiency of search was examined. Search efficiency was measured as the increase in search time per additional item and was calculated using the data from the two conditions of set size (four and eight distractors). This was compared for the pre-training and post-training sessions. The pre-training mean search efficiency slope was 199.50ms/item whilst for the post-training session this slope was 130.74ms/item. Although the slope became shallower after training, indicating an improvement in search efficiency, the difference between the slopes was non-significant ($z = -1.6$, $p = 0.106$, $r = 0.25$).

The Pearson's correlation coefficient between the pre-training search time and search time training effect was -0.86 ($p < 0.001$) indicating a significant negative association between these variables. This means that those patients with larger search times initially (the more impaired cases) showed a greater magnitude of improvement than the less impaired, faster patients.

Overall, the results for this task show significant benefits of the training on search time, and these improvements were related to the pre-training performance. However, the patients' search accuracy remained constant across sessions and was not significantly different to that of the control participants.

'Count the numbers' visual search task:

The mean number of trials per session was 8.7 (range: 5 to 10). As can be seen from Figure 2.11, accuracy increased after the training by 4.57%. The post-training improvement in accuracy was significant ($z = -2.70$, $p = 0.007$, $r = 0.42$). Despite the fact that the mean accuracy of the patients exceeded 93% at both sessions, all of the control participants completed this task with 100% accuracy, and thus patients showed significantly reduced accuracy relative to the controls even after the post-training improvement ($U = 173$, $p = 0.007$, $r = 0.41$). The mean search time decreased by 10.76 seconds after the training (see Figure 2.11), although this improvement was non-significant ($z = -1.72$, $p = 0.085$, $r = 0.27$). The control participants were however significantly faster than the patients even after the training improvements ($U = 41$, $p = 0.007$, $r = 0.71$).

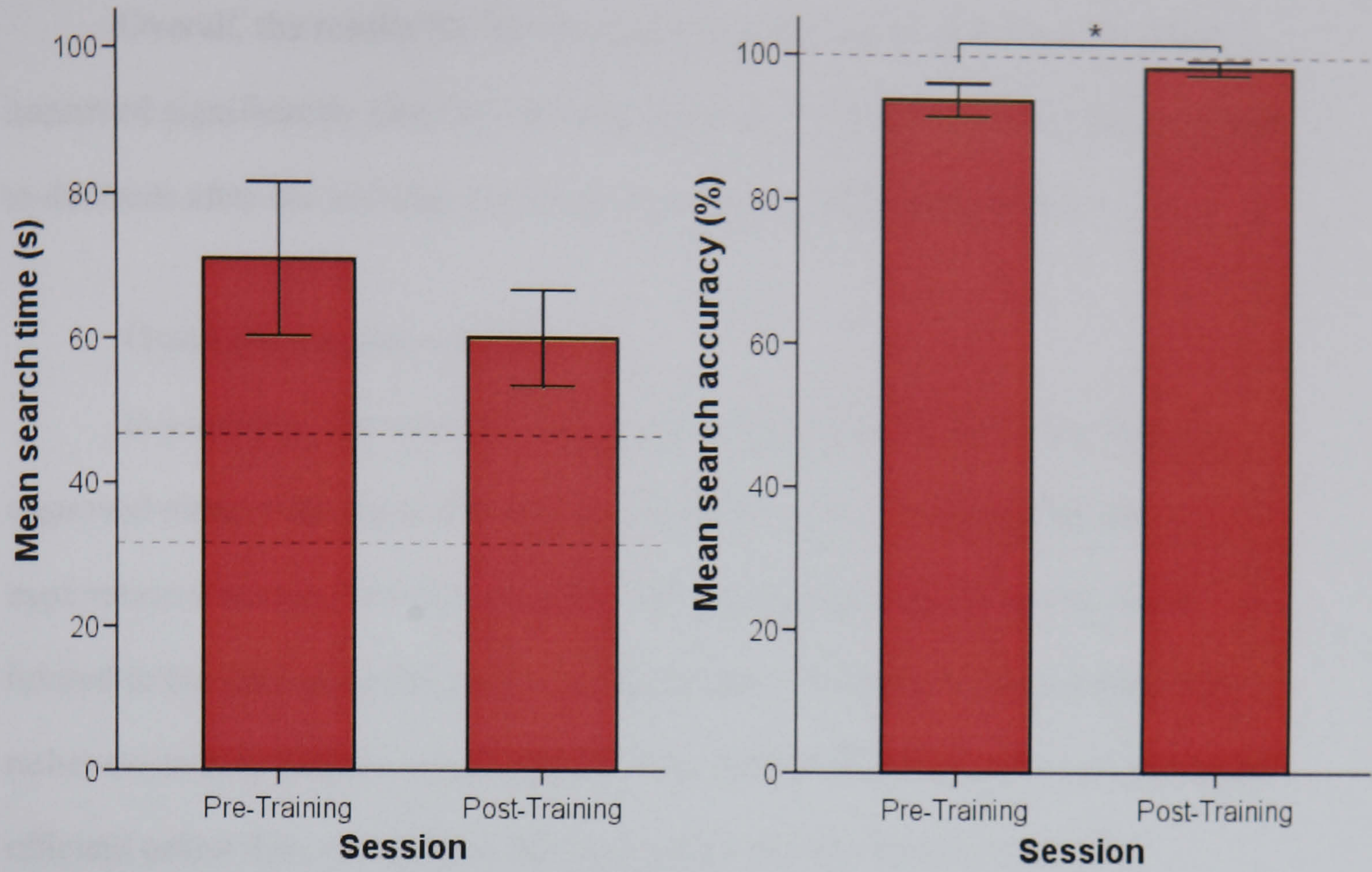

Figure 2.11: Graphs showing the mean search time (in seconds) and accuracy (in percent) for the 'count the numbers' task for the pre- and post-training sessions. The error bars represent the standard error of the mean and '*' represents a significant difference. The horizontal reference lines represent the mean and the maximum search time, and the mean and minimum accuracy (which was always 100%) for the control participants.

The data were examined to see if the pre-training performance was associated with the improvements for this task. In the case of search time, the Pearson's correlation coefficient between the pre-training level and the training effect was significant, ($r = -0.86$, $p < 0.001$). This means that those patients who were more impaired initially showed the greatest magnitude of improvement with regards to search time. With regards to accuracy, the Pearson's correlation coefficient between the pre-training level and the training effect was non-significant, ($r = -0.02$, $p = 0.942$) indicating that the baseline was unrelated to the effect.

Overall, the results for the 'count the numbers' task show that accuracy improved significantly after the training. However, although search time was found to decrease after the training, this was a non-significant improvement.

Visual search tasks overall:

In summary, the results from the three visual search tasks show that all improved either with regards to search time or accuracy (or both) after the exploration training. This demonstrates that the improvement in search is not limited to the content or the display types which were used for the training, but rather extends to various visual stimuli. This implies that search has become more efficient rather than recognition for specifically trained items having been facilitated. Following compensatory saccadic localisation training Pommerenke and Markowitsch (1989) found an approximate 26% reduction in search time for non-trained exploration tasks, whilst Kerkhoff et al. (1994) also found an improvement of just over 21% for search on untrained projected slide arrays after the exploration training. These effects are comparable to the effect found for the 'find the number' task (23.8%) although larger than found for the 'count the dots' and 'count the numbers' tasks (6.5% and 15.2% respectively). However, it is difficult to compare the effects from previous studies because different types of search tasks have been used and they may not be comparable. Since all three of the visual search tasks did benefit significantly from the training, this suggests that the improvements are transferable to other visual stimuli and tasks.

The different effects between tasks may suggest that different tasks benefit to varying extents. However, caution needs to be used before determining that the benefits of the training are greater for some tasks than others, and there are two factors which make it difficult to interpret such comparisons in search time. Firstly, the 'count the dots' and 'count the numbers' tasks also showed significant improvements in accuracy for which there could be a trade-off with speed, whilst no such effect was observed for the 'find the number' task. Secondly, the magnitude of change in search time which is possible is dependent upon the baseline search time and the minimum amount of time required to complete the task. For example, if a task takes at least one second to complete and baseline performance is 1.8 seconds, then the maximum improvement possible is 44%. However, if a task takes a minimum of two seconds to perform, and baseline performance is 2.8 seconds (thus the change is the same as the previous example) then the maximum improvement possible is 29%. These factors make it difficult to directly compare the effects of the training on various tasks. However, it may be the case that the 'find the number' task does show greater transfer, and it is possible to explain this as a consequence of the greater comparability between the training and this task with regards to the task requirements. It is possible that specific skills are acquired as part of the training and if the same combination of skills is required in the transfer task then there may be a greater enhancement in performance, whereas tasks which rely upon only a subset of the skills may show less benefit.

2.4.2 'Projected search'

2.4.2.1 Method

Task and stimuli:

This task involved a conjunction visual search task. The target was a red forward slash (/), and the distractors were blue forward slashes (/) and red backward slashes (\). Each display contained 16 items (either 15 distractors plus the target, or 16 distractors), and all items were 5° in height (see Figure 2.12 for an example of the search array). The displays were created in a pseudo-random manner such that the distractors were evenly distributed across the four quadrants of the display, and such that the target (when present) appeared in each quadrant of the display on an equal number of trials.

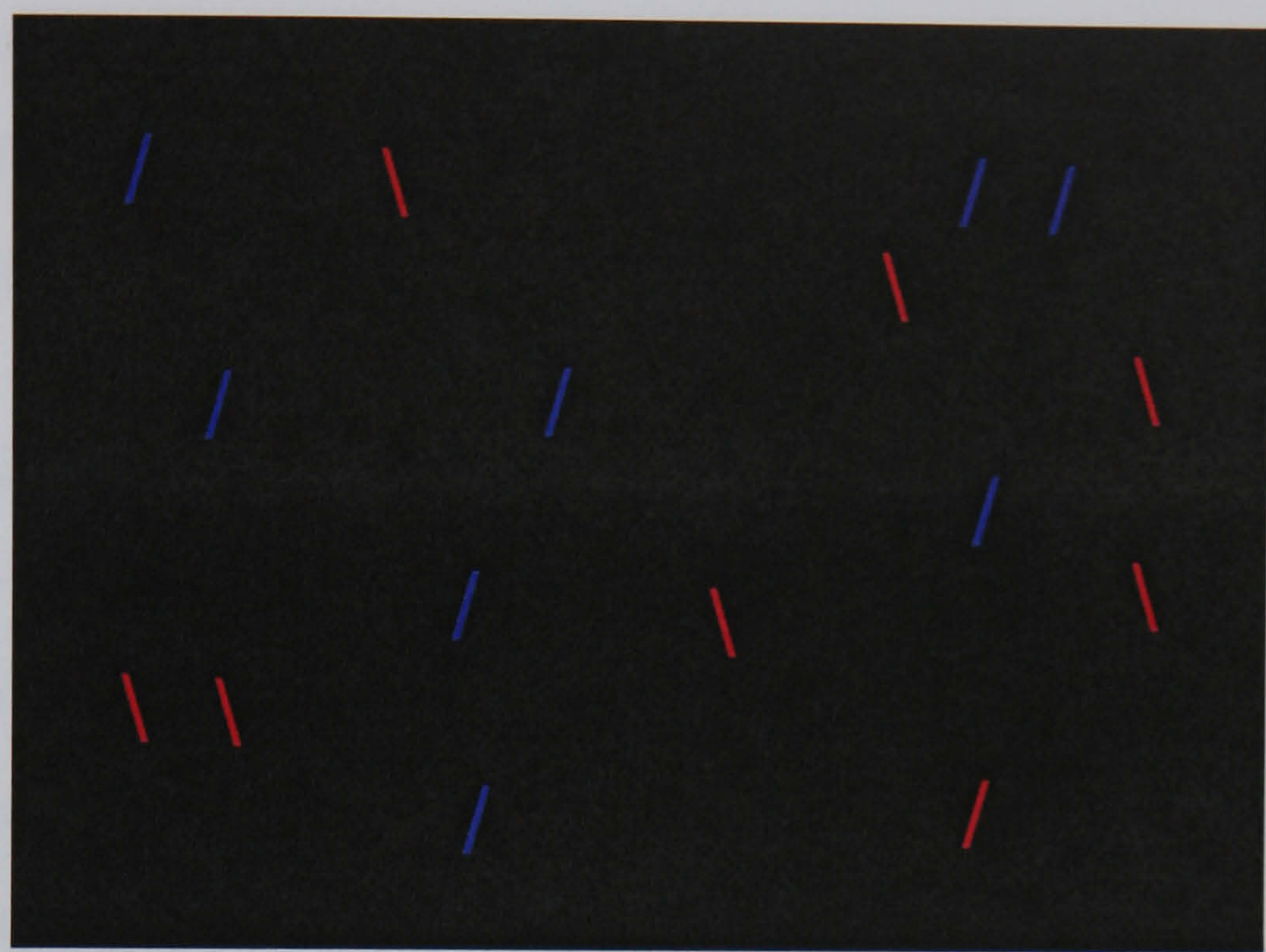

Figure 2.12: An example of a display used in the 'projected search' task. The target was the red forward slash (/), whilst the other items served as distractors.

Apparatus:

The program was created using E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA). The search arrays were presented onto a blank white wall using an Epson projector, such that the display subtended 60° horizontally and 53° vertically. Participant responses regarding the presence or absence of the target were made using a response box (Cambridge Research Systems, Rochester, UK).

Procedure:

The participants were instructed to decide if the specified target was present or absent on each trial. The task consisted of 40 trials, and the target was present on 50% of these. At the beginning of each trial a white, 5° fixation cross appeared at the centre of the display for one second, which the patients were instructed to fixate.

This was followed by the search array which was presented until the participant made a response regarding target presence. No specific instructions were provided to the patients as to how to search for the items, but both speed and accuracy were described as important. Feedback regarding accuracy ('correct' or 'incorrect') was presented after each trial for one second, after which the fixation cross appeared for the next trial.

2.4.2.2 Results and discussion

One participant (10) completed only 20 trials per session since she found the task very strenuous. Due to computer failure data was missing from the post-training session for three participants (04, 07 and 22) and therefore their data was excluded from the analyses. Data was also missing from four of the control participants due to the same problems, and therefore their data was also excluded. For the analyses of search time, the data from the trials in which the participants provided the incorrect response were excluded, and outliers for individual participants were also removed.

The results presented are from the target-present condition (the target-absent results are described in Appendix 3). The mean search time decreased after the training by 2350.75ms (see Figure 2.13) and this 41.1% improvement was significant ($z = -2.94$, $p = 0.003$, $r = 0.49$). However, the mean search time of the patients was still significantly greater than that of the controls ($U = 36$, $p < 0.001$, $r = 0.67$). Accuracy was 3.66% greater post-training relative to the pre-training session (Figure 2.13). This difference in accuracy was non-significant ($z = -0.86$, $p = 0.392$, $r = 0.14$), indicating that the improvement in search time was not the result of a speed-accuracy trade-off effect. The graph also shows that the mean accuracy of the patients on both sessions was greater than the minimum of the control participants. However, the mean accuracy of the patients was significantly reduced relative to that of the control participants even after the post-training improvement (U = 106, p = 0.045, r = 0.50).

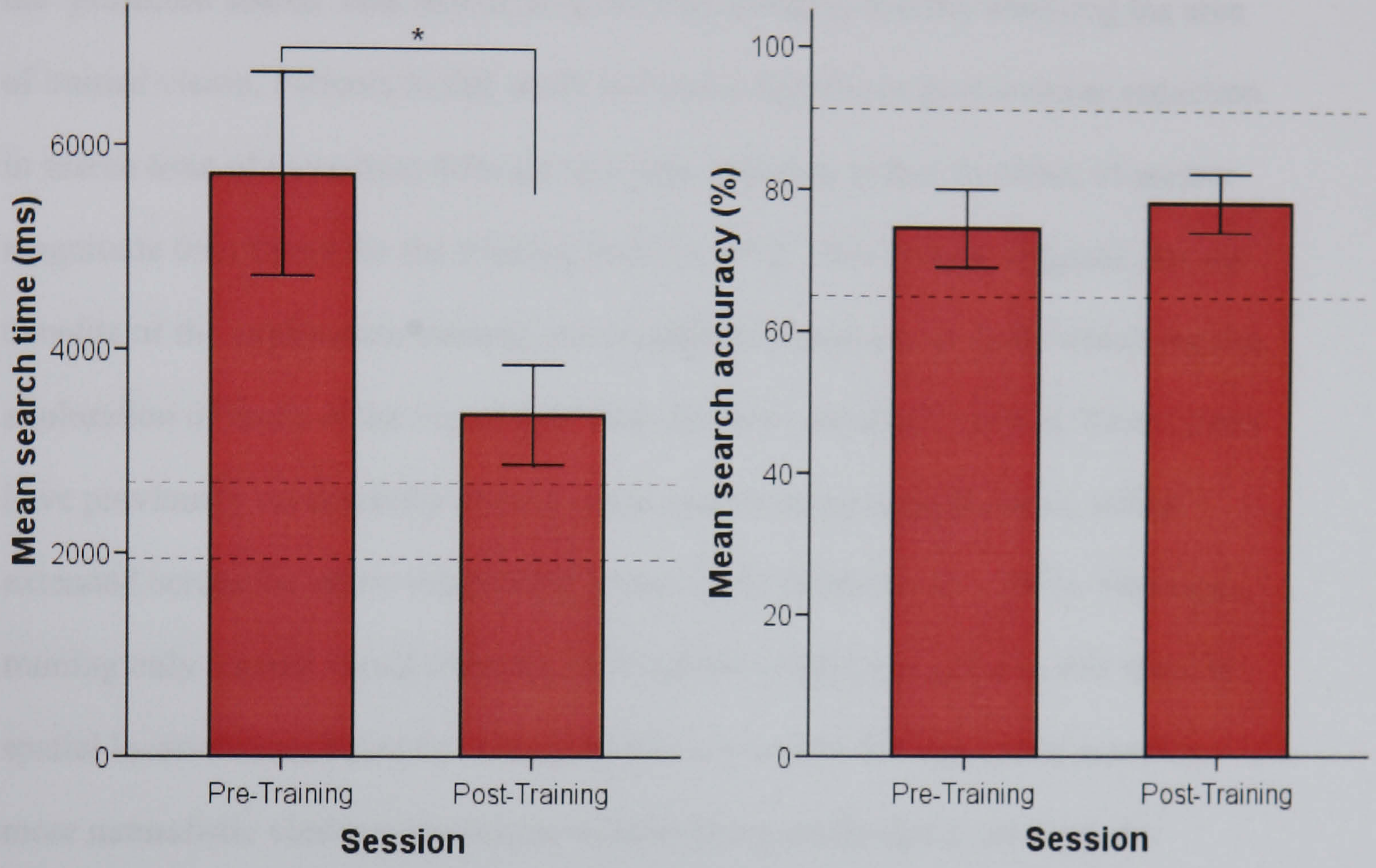

Figure 2.13: Mean search time (in milliseconds) and accuracy (in percent) for the target-present condition of the 'projected search' task, for the pre- and post-training sessions. The error bars represent the standard error of the mean and '*' represents a significant difference. The horizontal reference lines represent the mean and the maximum search time, and the mean and minimum accuracy for the control participants.

The data was examined to see if the pre-training performance was associated with the improvements for this task. Significant negative Pearson's correlation coefficients were found between the pre-training levels and the training effect for both accuracy (r = -0.884, p < 0.001) and search time (r = -0.575, p = 0.012). This shows that the patients who were more impaired initially showed the greatest improvements after the training.

In summary, these results show that for this task patients' search time decreased significantly after training, an improvement which cannot be explained by means of a speed-accuracy trade-off effect. Therefore, this indicates that the benefit of the exploration training does generalise to visual search which extends across a larger display size than used during training (central 30°). The display in the 'projected search' task extended to 60° horizontally, thereby doubling the area of trained vision. Patients in this study showed a significant post-training reduction in search time of more than 40% for this task, which is in fact an effect of greater magnitude than found for the training itself (~34%). This finding suggests that the benefits of the exploration training can transfer to visual search tasks which require exploration of more of the visual field than has been explicitly trained. Researchers have previously successfully trained visual search using large displays, which extended across the entire visual field in one study (Nelles et al., 2001). However, training only a small visual field does not appear to limit the gains to this specific spatial location, consequently indicating that it is useful for improving search in more naturalistic viewing conditions without the need for direct training. As demonstrated here, training the innermost 30° of the visual field can be achieved using a portable system, and given that generalisation across the visual field appears possible this further implies that this approach provides a practical rehabilitation option.

2.4.3 'Visuomotor search'

2.4.3.1 Method

This task required participants to search an array of numbered blocks, pick them up in sequence and then place them into a collection box.

Apparatus:

The search items consisted of 20 wooden 3cm³ blocks, each numbered differently between 1 and 20. The blocks were displayed in an array atop a table, and were positioned using a polystyrene grid (54cm by 88.5cm). The blocks were placed into the appropriate positions on the grid, which when removed left the blocks displayed on the table. Ten different arrays were used (see Appendix 4 for more details). The search time was measured using a standard digital stopwatch.

Procedure:

The search items (blocks) were positioned atop a table, and this process was completed out of view of the participant so as to avoid preview effects. The participant sat so that they were centrally aligned to the display and the height of the seat was pre-determined so that the blocks were all within arms' reach. Participants were instructed to locate and pick up the blocks in sequence and to place them into the container. The collection box was positioned on either the left or the right side of the table (depending on participant handedness).

The search time was recorded by the researcher for each trial, and was defined as the amount of time from when the participant touched the first block until they placed the last block into the container. The number of errors per trial was recorded also, and an error constituted a block being picked up out of sequence and any block being missed completely. The number of errors was converted into search accuracy by calculating that each error constituted a 5% decrease in accuracy (since there were a total of 20 possible errors per trial). The task was repeated for between five and ten trials (depending on individual level of fatigue and concentration) and the trials were conducted in the same order at each session.

2.4.3.2 Results and discussion

The mean number of trials completed per session was 8.7 (range: 5 to 10). The analyses were based on the mean performance of the participants and for the analysis of search time outliers for individual participants were removed.

The mean search time decreased by 10.31 seconds after the training (see Figure 2.14). This improvement in search time was significant ($z = -3.25$, $p = 0.001$, $r = 0.50$), and represents a 15.5% improvement in performance following training. Despite this improvement, the mean search time of the patients was outside the range of the control participants and after the training the mean search time of the patients was still significantly greater than that of the controls ($U = 54$, $p < 0.001$, $r = 0.67$).

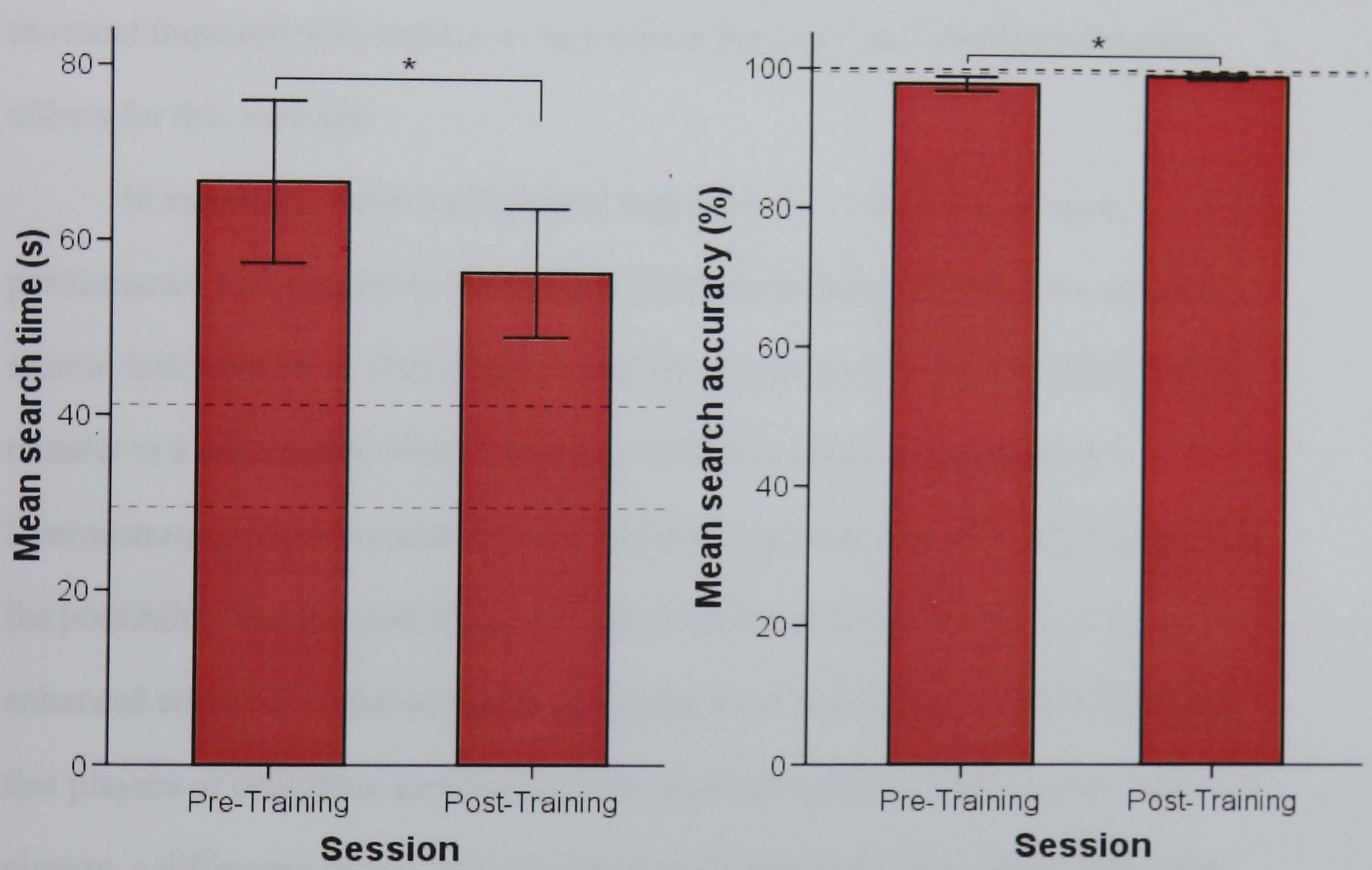

Figure 2.14: Graphs showing the mean search time (in milliseconds) and accuracy (in percent) for the 'visuomotor search' task for the pre- and post-training sessions. The error bars represent the standard error of the mean and '*' represents a significant difference. The horizontal reference lines represent the mean and the maximum search time, and the mean and minimum accuracy for the control participants.

As can also be seen from this figure, the mean accuracy improved after the training, and although this was only by 1.30% this change was statistically significant ($z = -2.30$, $p = 0.022$, $r = 0.35$). Despite the fact that the patients' accuracy was over 97% prior to the training and over 99% after the training, the patients still had significantly reduced accuracy relative to the control participants even for the latter assessment ($U = 181$, $p < 0.001$, $r = 0.34$).

The data was examined to see if the pre-training performance was related to the improvements for the 'visuomotor search' task. Significant negative Pearson's correlation coefficients were found between the pre-training levels and the training effect for both search time ($r = -0.732$, $p < 0.001$) and accuracy ($r = -0.955$, $p < 0.001$). This indicates that patients with the poorest accuracy before the training showed the greatest improvements in accuracy, and also that the patients who were the most impaired with respect to search time demonstrated the largest training effects for this variable.

In summary, these results show that after the training the patients' performance with respect to both search time and accuracy for the 'visuomotor search' task improved. This suggests that the compensatory training benefit does transfer to a search task which involves a different behavioural response. Demonstrating improvements using a different response modality helps to dismiss the possibility that the post-training improvements in visual search may reflect enhanced stimulus-response mapping. Castel, Pratt and Drummond (2005) found that players of computer-games had faster reaction times in visual search than non-players, a difference which was attributed to the game-players' faster ability for stimulus-response mapping in visual attention tasks. However, since the 'visuomotor search' task required a different response to that employed in the training it seems unlikely that such an explanation could account for the visual search improvements found after exploration training.

Whilst previously Kerkhoff et al. (1994) found a post-training decrease in search time using real objects atop a table, unfortunately details of the type of identification response required (i.e. verbal or motor) were not provided. Locating search items with a pointer has also previously been found to improve after saccadic localisation training (Pommerenke & Markowitsch, 1989) showing that visuomotor exploration skills can be improved by compensatory training, although this is an unnatural type of response since in everyday life it is not usual to point at items with a stick. Pambakian et al. (2004) found an approximate improvement of 25% in the performance of various visuomotor ADL tasks (i.e. locating and threading lettered beads in alphabetical order), which was not the result of general enhanced motor ability. In this study a significant improvement in search time of 15% was found for the 'visuomotor search' task after the training, confirming the generalisation of the training benefits to three-dimensional objects and showing that these also transfer to tasks in which the patient has to pick up the items they are searching for and reposition them. The result confirms the findings of Pambakian et al. (although it is not claimed that these tasks represent ADLs), and the findings reveal that the benefits of the portable compensatory training can transfer to visual search tasks which require a different behavioural response.

2.4.4 Reading

2.4.4.1 Method

The reading ability for both text and numbers was assessed.

Stimuli and apparatus:

The text reading material consisted of four modified passages each of which contained 200 words. Each of the four sets of numbers contained 115 digits, which were separated into clusters of between two and seven digits in order to give them a similar visual appearance as the text passages. Copies of the reading material can be found in Appendix 5. Reading time was measured using a standard digital stopwatch.

The control participants each read all four passages of text and four sets of numbers so that the relative difficulty of the different passages could be assessed. Friedman's ANOVAs were used to examine if there was any difference between the reading speeds for the different versions. The results revealed that the corrected reading speed was not significantly affected by the version of the reading passage for either the text material (χ^2 (3) = 1.59, p = 0.662) or for the number material (χ^2 (3) = 6.95, p = 0.073).

Procedure:

Patients were required to read one passage of text and one set of numbers at each session, and were instructed to do so in their natural reading style. The time it took for the participant to read the passage was recorded in seconds, and the researcher also recorded the number of errors made. Errors included omission and substitution errors. For the text material the corrected reading speed in words per minute (wpm) was calculated using the following formula: *(words read – number of errors) / time x 60.* A similar formula was used for the numbers to calculate the corrected reading speed in digits per minute (dpm), with 'words read' replaced with 'numbers read'.

2.4.4.2 Results and discussion

For this task data was missing for the first four patients and the first six control participants because they used alternative versions of the text and numbers for the reading tasks. The reading of text and of numbers was analysed separately.

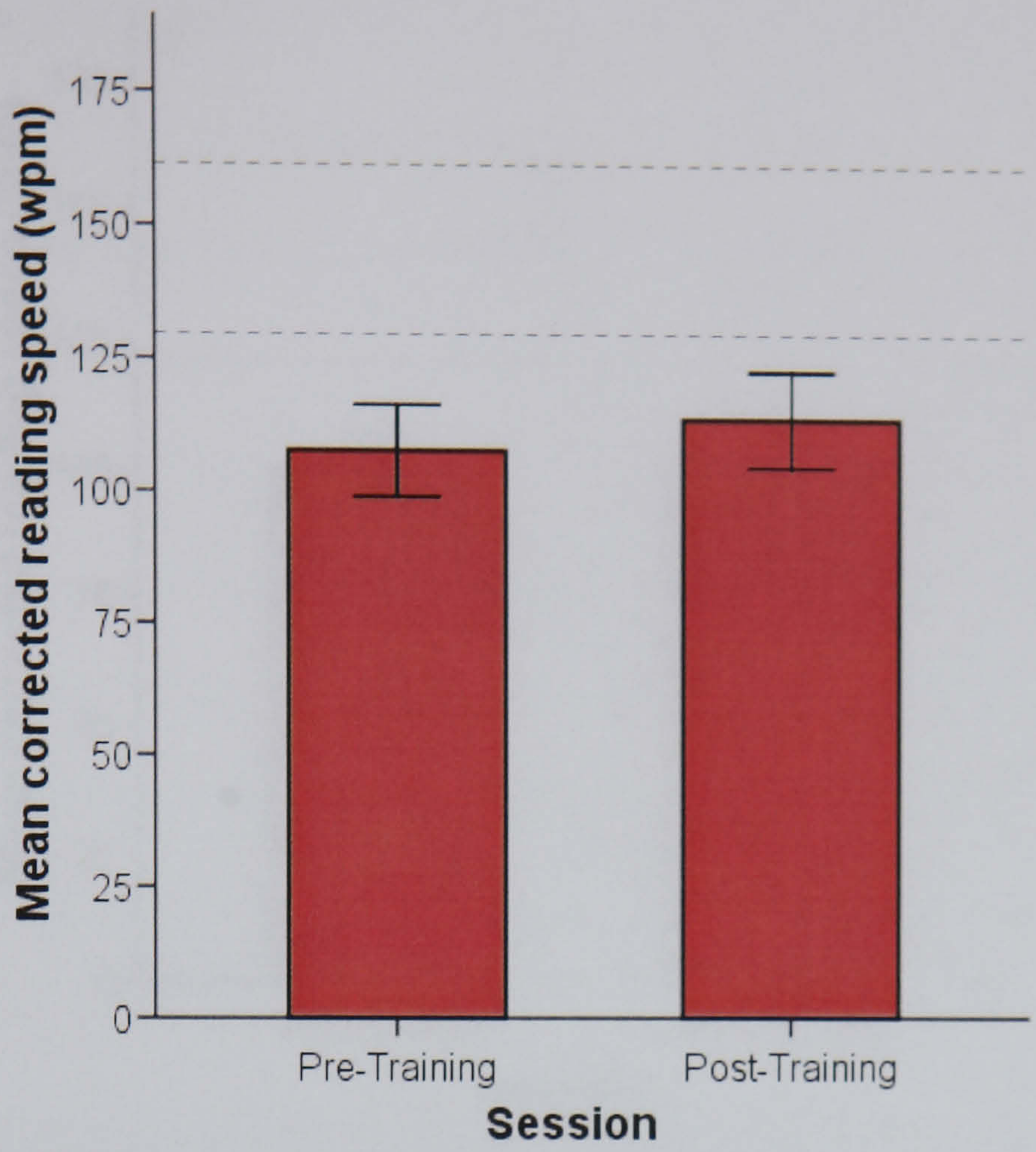

Figure 2.15: Graph showing the mean corrected reading speed for text (in words per minute) for the pre- and post-training sessions. The error bars represent the standard error of the mean. The horizontal reference lines show the mean and minimum reading speed for the control participants.

The mean corrected reading speed for text increased by 5.94wpm after the training (see Figure 2.15) and this change was non-significant ($z = -1.07$, $p = 0.29$, $r = 0.18$). Overall the patients' post-training text reading speed was significantly reduced relative to control participants ($U = 36$, $p < 0.001$, $r = 0.64$).

The mean corrected reading speed for numbers also remained relatively unchanged after the training, increasing by only 1.79dpm (see Figure 2.16). This increase was non-significant ($z = -1.73$, $p = 0.080$, $r = 0.30$). The post-training reading speed for numbers demonstrated by the patients was significantly reduced relative to that for the control participants ($U = 15$, $p < 0.001$, $r = 0.77$).

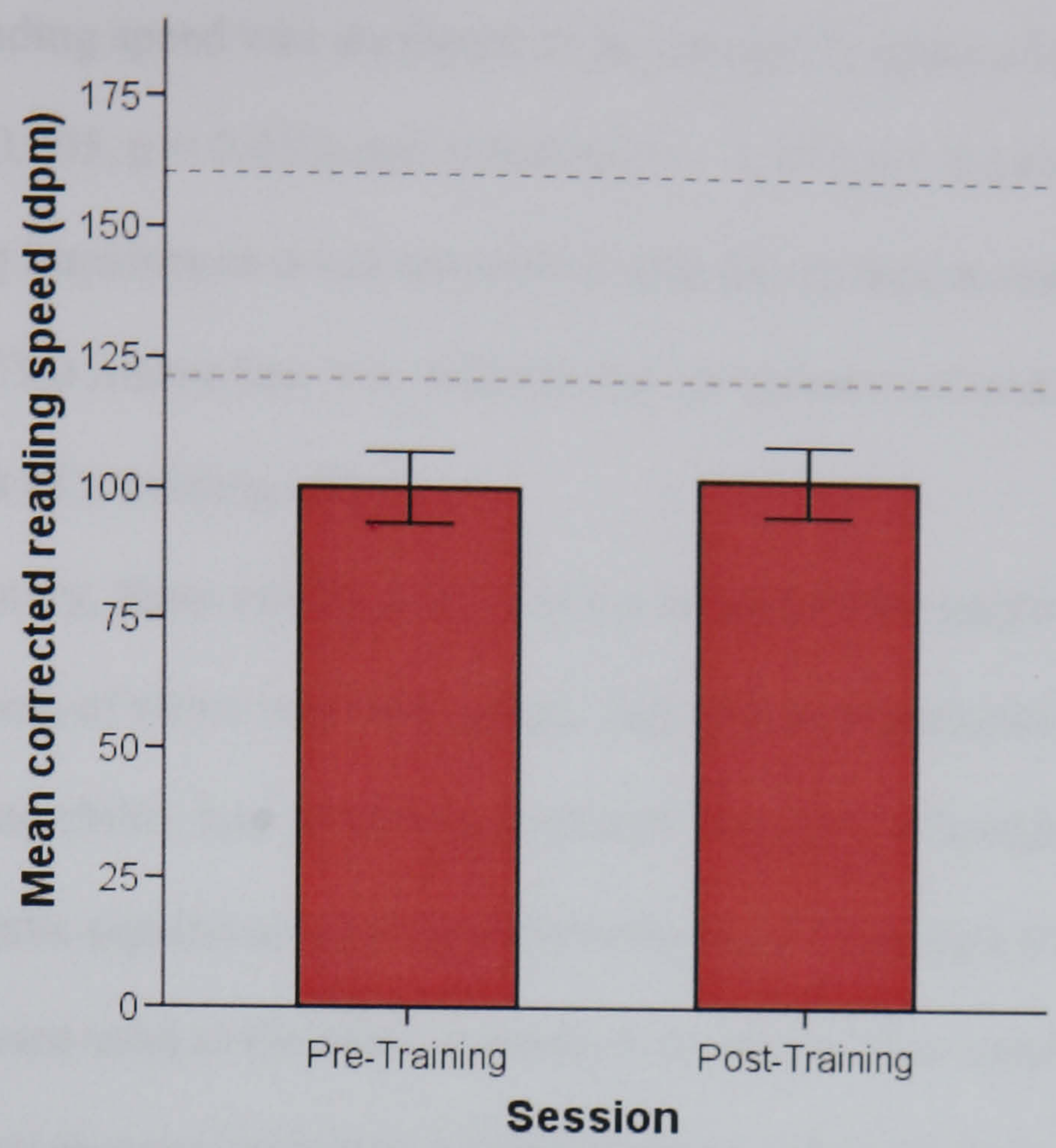

Figure 2.16: Graph showing the mean corrected reading speed for numbers (in digits per minute) for the pre- and post-training sessions. The error bars represent the standard error of them mean. The horizontal reference lines show the mean and minimum reading speed for the control participants.

Although the group as a whole showed impaired reading speeds relative to the control sample, not all patients suffer from hemianopic dyslexia. Here a deficit in reading was defined as a reading speed which was less than two standard deviations below the mean of the control participants. Using this criterion six patients (29%) were identified as having a significant reading impairment. For only the patients with hemianopic dyslexia, the mean reading speed for text was 67.59wpm (SD = 30.63) before the training and 75.44wpm (SD = 32.20) after the training, and the post-training improvement was not significant (z = -0.52, p = 0.600, r = 0.21). For the same sub-group, the mean reading speed for numbers before the training was 84.63dpm (SD = 34.59) and after the training it was 83.62dpm (SD = 27.65), and this change was not significant either (z = -0.73, p = 0.463, r = 0.30). Furthermore, Pearson's correlation coefficients revealed that the pre-training reading speed was unrelated to the change in speed after the training for both text ($r = -0.205$, $p = 0.430$) and numbers ($r = -0.370$, $p = 0.144$). As such, the level of reading impairment is not associated with the change in reading resulting from training. This means that it is unlikely that an absence of reading deficit could explain the lack of a training effect.

In summary, these results show that the benefit of the training does not transfer to reading of either text or numbers. The effect of exploration training on objective reading ability had not been previously reported, although Bolognini et al. (2005) did observe significant reading improvements following a training in which auditory cues were used to facilitate saccadic localisation. The results found here however, suggest that the exploration training does not lead to improvements in reading. In support of this observation, Spitzyna et al. (2007) found no significant change in reading ability after a placebo training, although reading performance did improve after the specific reading training. The placebo condition which Spitzyna et al. used involved patients comparing two pictures in order to spot differences between them (a comparative search task). The absence of reading improvement after such a visual search-based placebo condition supports the observation reported here, although it is not entirely comparable since comparative search does not form the whole of the exploration training as used in this study.

The most likely explanation for the absence of any change in reading performance after exploration training is that the saccade pattern used during reading is very specific: the eyes scan in the direction of the text in a step-wise manner (saccades interspersed with fixations), followed by a large regressive saccade to the beginning of the next line (Rayner, 1998). Therefore, it appears that any oculomotor modification which results from exploration training does not generalise to more precise situations where eye-movements are governed by specific 'rules'. Perhaps saccadic localisation rather than general exploration may be better for generating more comparable eye-movements to those used in reading, which could explain why Bolognini et al. (2005) found a significant effect. The training used by Bolognini et al. involved searching for a light probe along only the horizontal meridian. The search training used in this study involved a display which extended 30° horizontally but also approximately 20° vertically. Perhaps training saccades along one axis only is better for improving reading ability since it could be assumed to induce more similar leftward and rightward saccades as required for reading.

Whilst the controls in this study read at a similar level (161wpm) to those reported by Zihl (2000; 174wpm), the level of reading impairment shown by the patients was not similar. Zihl reported that patients with left-sided HVFDs read at approximately 78wpm and those with right-HVFDs only 56wpm. The mean reading speed for the sample in this study was 110wpm, almost double that of the right-sided hemianopic patients reported by Zihl. Not all patients experience severe reading deficits and in this study only 29% of the sample was classified as having hemianopic dyslexia. Therefore it could be the case that the absence of severe reading impairment prevented the observation of a significant training effect on reading (a potential ceiling effect). However, this seems an unlikely explanation since the results also showed that the level of impairment was not related to the degree of observed change in reading performance and no significant improvements were found for only the sub-sample of patients with hemianopic dyslexia.

Spitzyna et al. (2007) found that specific compensatory reading training can lead to improvements in reading performance above those which can be observed following placebo training. This shows that specific oculomotor modification can successfully help patients with HVFDs to overcome deficits in reading. Unfortunately, it appears that reading training does not produce benefits which transfer to visual search (Schuett, Heywood, Kentridge & Zihl, 2008b). This indicates that exploration and reading training should be used in conjunction to overcome impairments in these two deficient areas of functioning.

2.4.5 Activities of daily living questionnaires

2.4.5.1 Method

Tasks and stimuli:

At the pre-training assessment session the patients completed a short-answer questionnaire designed to assess their subjective complaints. This was translated from a German questionnaire which was developed and validated as an assessment tool (Kerkhoff, Schaub and Zihl, 1990). Further details and a copy of this questionnaire can be found in Appendix 6.

Three further questionnaires were completed at each session. Firstly, the researchers completed specific subsections of the UK FIM+FAM (developed by the UK FIM+FAM Users Group; see Turner-Stokes, Nyein, Turner-Stokes & Gatehouse, 1999), a questionnaire designed to assess the individual level of dysfunction and independence (see Appendix 7). The sub-sections of the FIM+FAM chosen of relevance to our patient group included mobility, communication and psychosocial functioning. The patients completed the EQ-5D (EuroQol Group, 1990) which is a standardised questionnaire used as a measure of health-related quality-of-life (see Appendix 8), and a ten-item rating-scale questionnaire (*visual impairments questionnaire*; see Appendix 9) that was modified from the version developed by Kerkhoff et al. (1994).

Procedure:

The short-answer questionnaire was read aloud to the patients and the responses recorded by the researcher. The FIM+FAM was completed by the researcher. Both the EQ-5D and the visual impairments questionnaire were completed by the patients themselves and required them to rate the level of impairment or difficulty that they experienced with particular activities, behaviours or sensations. These questionnaires were completed in the presence of the researcher who could read aloud questions and mark the responses given by the patient if they had difficulty with these aspects.

2.4.5.2 Results and discussion

Pre-training subjective complaints:

Table 2.3 contains details of the percentage of patients reporting specific complaints prior to the onset of the training. As can be seen from these results many patients experienced problems in everyday activities as a consequence of their HVFD, and often reported difficulties in multiple areas. The items for which the greatest number of patients reported difficulties were the ability to see, reading and the ability to avoid obstacles.

Table 2.3

The percentage of patients who reported impairment after the onset of their visual field defect for the various abilities assessed.

Ability	Patients reporting impairment (%)
Ability to see	81
Reading ability	62
Ability to avoid collisions	62
Ability to judge the depth of steps	24
Ability to withstand bright lights	48
Objects appear darker than they are	33
Amount of light needed for reading	57
Blurriness of vision	57
Intensity of colours	5

The questionnaire used to assess subjective complaints also examined visual perceptual phenomenon. Experiences of visual illusions were reported by eight patients (38%). Two patients experienced basic visual illusions during the neurological incident which led to the HVFD, and these were noted in the side of the visual field which then became impaired. One of these patients also reported continued illusions for several weeks post-onset. The remaining six patients who reported visual illusions only experienced these after the onset of their HVFD, and always described them as occurring in the blind hemifield. Of these, half can be classified as basic illusions and half as complex. The illusions slowly began to cease across the first few weeks post-onset in half of cases, whilst for the others they were still ongoing (even after as long as 14 months).

Visual ability:

Figure 2.17 shows the mean rating of subjective impairment for the ten behaviours assessed using the visual impairments questionnaire. A larger score indicates more impairment than a smaller score. All of the items except 'find way at home' improved (reduced ratings) after the training relative to beforehand. However, only for the item of 'reading' was the reported improvement significant ($z = -2.51$, $p = 0.01$, $r = 0.39$), although it was nearing significance for the item 'find objects in a room' ($z = -1.85$, $p = 0.064$, $r = 0.29$). For all other items the p-value was greater than 0.156 (see Appendix 10).

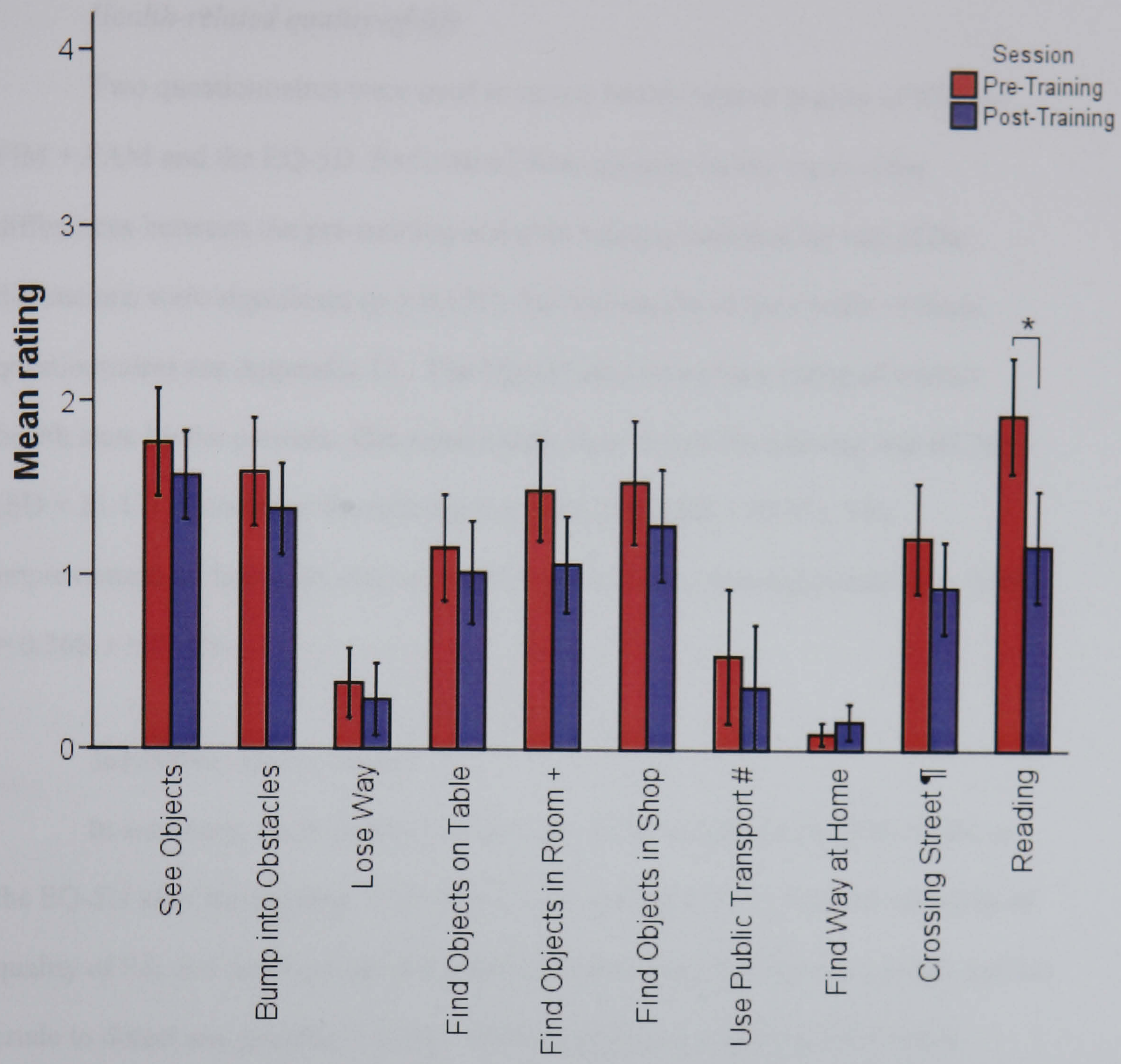

Figure 2.17: Graph depicting the mean ratings of subjective impairment before and after the training. The error bars represent the standard error of the mean and '*' represents a significant difference. Data is missing for some items: + based on 20 patients, # based on 19 patients, ¶ based on 11 patients.

In addition to this questionnaire patients were also asked if they had noticed any change in their ability to see since the start of the training. A post-training improvement in the ability to see was reported by 13 patients (62%). It is worth pointing out that the question did not relate specifically to an increase in the visual field, but rather could also involve general visual functioning, including an improvement in visual scanning. Further to this, none of the patients reported any change in their perception of visual illusions.

Health-related quality-of-life:

Two questionnaires were used to assess health-related quality of life: the FIM + FAM and the EQ-5D. For both of these questionnaires none of the differences between the pre-training and post-training sessions for any of the dimensions were significant ($p \geq 0.157$). For full details of the results of these questionnaires see Appendix 11. The EQ-5D also involved a rating of overall health state by the patients. The mean health state before the training was 63.38% (SD = 21.17) whilst after the training it was 66.29% (SD = 18.37). The improvement in the health state across the sessions was non-significant ($z = -0.90$, $p = 0.366$, $r = 0.14$).

Subjective reports overall:

In summary, these results indicate very little change on the FIM+FAM or the EQ-5D after the training. Both of these are standardised, validated measures of quality of life and functioning, and it appears likely that they are too general and too crude to detect any possible changes. With regards to the FIM+FAM (which assessed functional independence) the mean scores for patients show that prior to the training many patients were already completely independent for all three dimensions assessed, and thus this ceiling effect could possibly explain the lack of any significant changes. The same is true of the five EQ-5D dimensions, and due to the fact that there are only three possible scores for each dimension, it is very likely that the measure was not sensitive enough to detect change. In general, when a patient was impaired on any of the dimensions for these questionnaires it was the consequence of comorbid deficits (i.e. hemiplegia affecting mobility) and as such did not change as a result of the training.

Overall health state was possibly the section of the EQ-5D where greater change could have been detected, however no significant difference was found, meaning that patients did not notice any change in their health state. This could possibly be the result of the way in which they interpreted the question since a post-training improvement in the ability to see was reported by 62% of patients. This is comparable to the two-thirds of patients reporting a subjective improvement in the Pambakian et al. (2004) study. However, whilst this indicates that the majority of patients perceive their visual abilities to improve after intervention this change was not reflected in overall health state. This may suggest that people interpret this question as simply referring to physical signs of health and fitness (i.e. pain).

The visual impairments questionnaire assessed specific activities which are known to be problematic for patients with HVFDs. Reading was the only activity for which there was a significant improvement after the training. This is unlike the findings of Kerkhoff et al. (1994) and Nelles et al. (2001) who reported significant improvements in all of the behaviours which they assessed, however Pambakian et al. (2004) observed improvements for only three items (although they did not include reading). The difference between this and the previous studies cannot be attributed to baseline impairment, since for the majority of the items all studies reported mean ratings of approximately two (occasional problem). This indicates that it is the post-training level which has not improved to a comparable extent. Given that objective measures revealed that the patients' visual search performance had improved in this study, this suggests that it is not a lack of effect generally which explains the differences across studies in subjective ADLs either. Questionnaires are subject to the problems associated with self-report such as socially-desirable responding, memory and the patient's awareness of their problems. These factors influence the validity of the responses and it is possible that these may account for some of the differences across studies. Both in this study and that reported by Pambakian et al. (2004), patients were not provided with specific instructions for how to make searching saccades but instead were allowed to develop their own patterns. This minimised the role of the researcher and could possibly be associated with the differences between the studies.

Reading was a task for which both objective and subjective data was obtained in this study. Whilst there was no significant effect of the training on objective reading performance, there was a significant improvement in self-reported reading ability. As such this does question the reliability of subjective reports.

The findings show that the choice of questionnaire is essential when it comes to subjective measures of ADLs. Whilst significant improvements can be obtained for some very specific activities, the reliability of these reports is questionable when compared to objective measures. This suggests that perhaps we should not rely on patient perceptions of everyday functioning but instead we need to actually observe how they behave in situations such as shopping or walking around a novel environment. Furthermore, generic and crude measures are not relevant for the measure of functioning in patients with HVFDs.

2.5 Perimetry: does the exploration training lead to restorative effects?

2.5.1 Method

2.5.1.1 Apparatus and stimuli

Binocular visual fields were mapped using manual kinetic Tübingen perimetry (Oculus Inc., Tübingen, Germany) with standardised background luminance. The central fixation point was a red circular dot with a diameter of 30 minutes of arc of visual angle. The test stimulus was a white circular dot with a diameter of 26 minutes of arc of visual angle and a supraliminal brightness of 160cd/m^2.

2.5.1.2 Procedure

Perimetry was completed with patients wearing their own glasses if required in order that visual performance was optimised (Jobke, Kasten & Sabel, 2007). Whenever possible, the assessment sessions were conducted at a similar time of day on each occasion for individual patients in order to try and reduce the potential confounding impact of diurnal visual field variations on the results (Zihl, Pöppel & von Cramon, 1977).

During the assessment the researcher gradually moved the test stimulus inwards from the edges of the visual field until it could be detected. The participants were instructed to keep their eyes on the red dot in the centre of the perimeter and to push the buzzer when they could see the white dot. During perimetry the researcher monitored the participant's fixation via a telescope and when eye-movements were detected the visual field at that position was re-tested.

The extent of the visual field was assessed for 24 meridians (each 15° apart) in a pseudo-random order (see Figure 2.18). A buzzer-press signalled that the participant had detected the target, at which point the position was plotted. The positions from all meridians were used to define the edges of the seeing field. Patients with homonymous scotomas could sometimes detect targets in the periphery along all meridians. For these patients the test stimuli were moved both inwards and outwards starting at various locations along the meridians which encountered the scotoma, in order to define the borders.

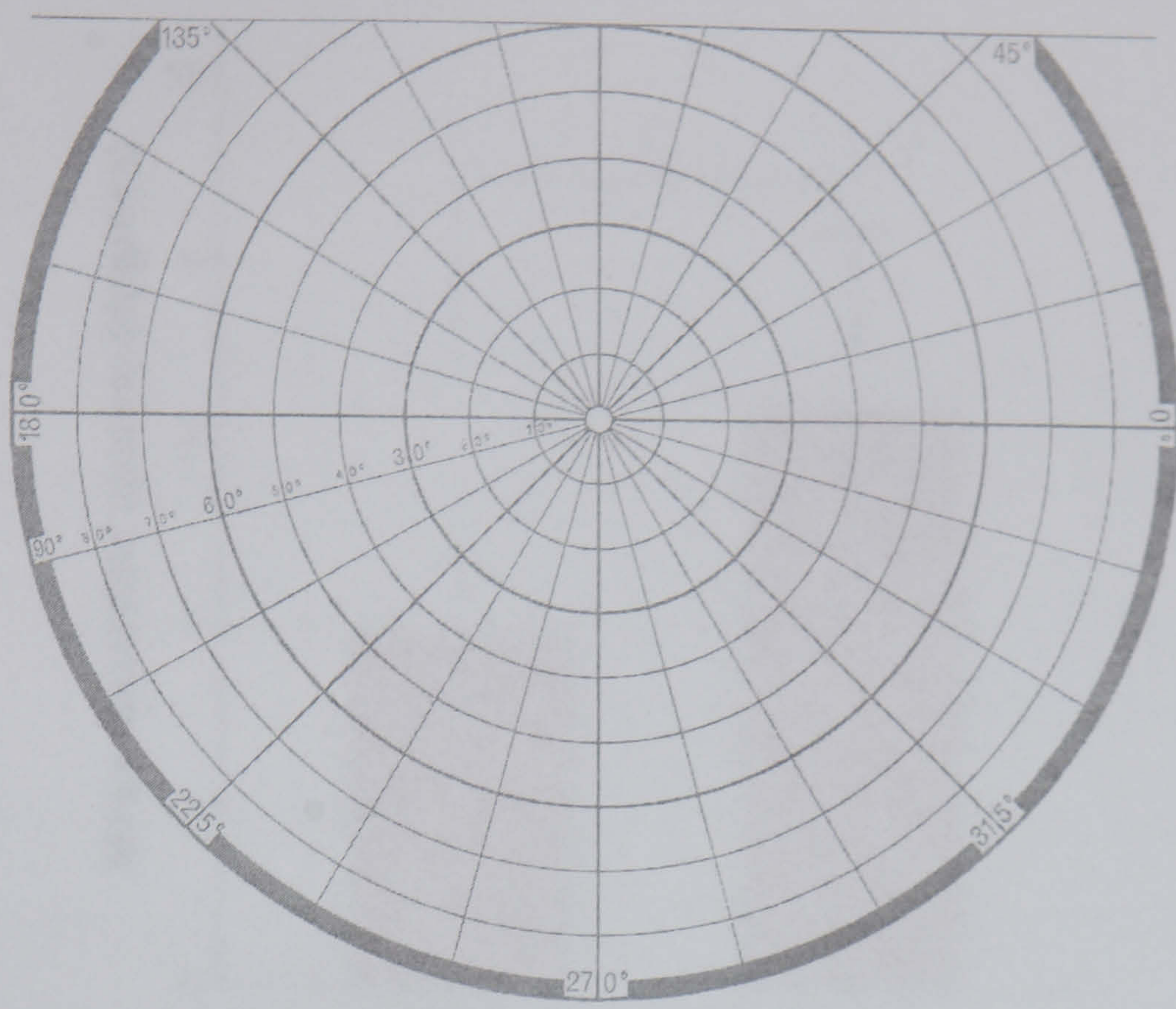

Figure 2.18: Example of the perimetric plot used to measure the visual field. The extent of the visual field was measured along the 24 meridians around the circumference of the plot, each 15° degrees apart.

The degree of visual field sparing was measured as the distance (in visual degrees) from the centre of the fovea to the nearest edge of the blind field along any meridian. A field sparing of 0° denoted complete macular splitting. However, it should be noted that using the perimetric settings outlined and a 180° field plot any absence of detection of the stimulus within the central 2° was classified as 0°.

2.5.2 Results and discussion

Figure 2.19 shows the mean amount of visual field sparing along the most impaired meridian, for the pre-training and post-training sessions. As can be seen from this graph the visual sparing increased significantly by 2.50° after the training ($z = -2.22$, $p = 0.027$, $r = 0.34$).

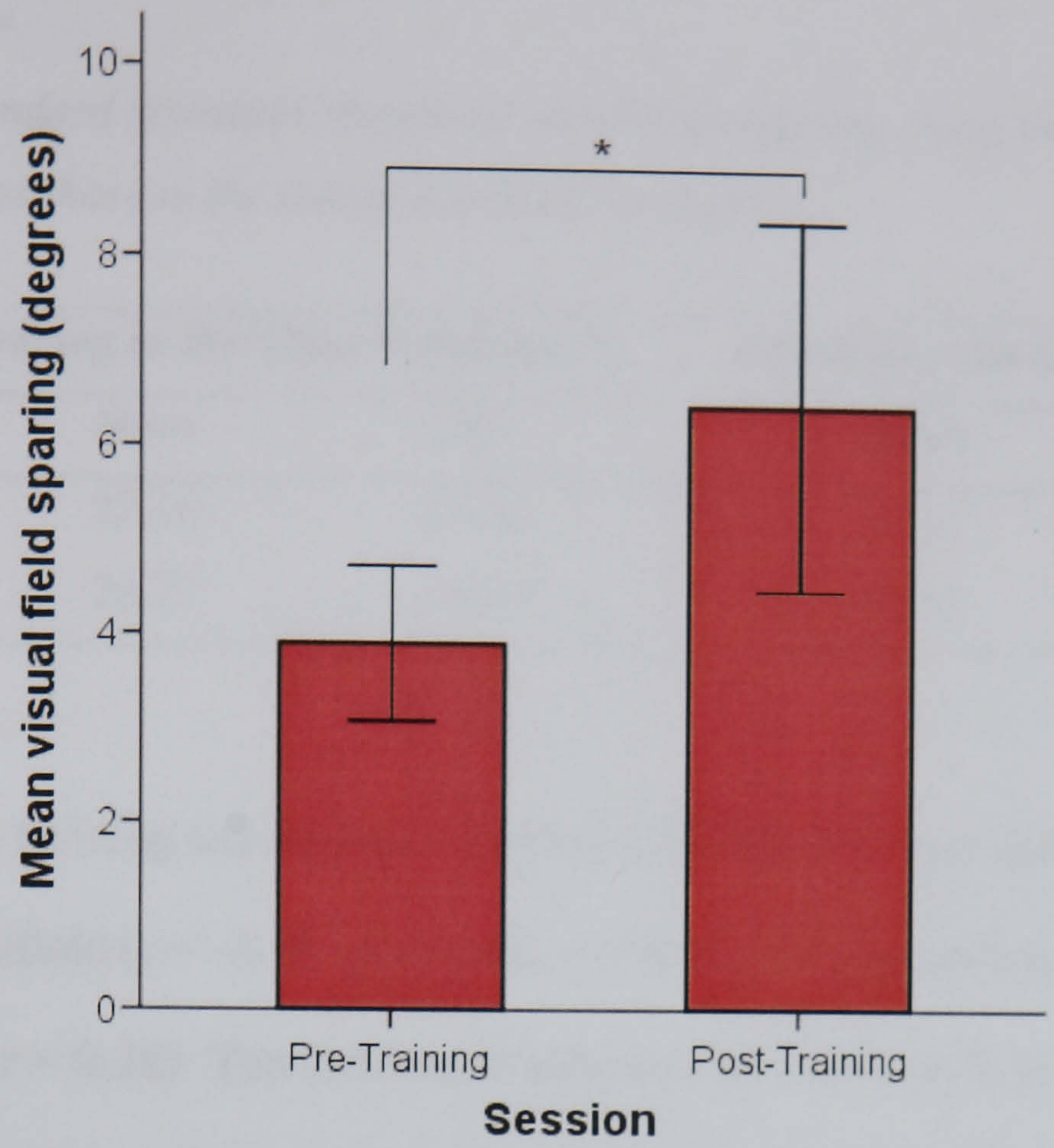

Figure 2.19: Graph showing the mean amount of visual field sparing (in degrees) along the most impaired meridian for the pre-training and post-training sessions. The error bars represent the standard error of the mean and '*' represents a significant difference.

It is worth noting that the effect was not equally distributed across patients; eight patients (38%) showed no change after the training whilst two patients' visual field increased by more than 5° along the most impaired meridian. It is possible that this increase in the visual field after training was the result of factors such as fixation bias, criterion shifts or changes in attention rather than reflecting true visual restoration. In order to examine these possibilities further analyses were conducted.

The effect of the training on the mean amount of sparing along all of the meridians in both the blind and the seeing hemifields were compared in order to examine whether or not the field increase reflected visual restoration. If the training produced visual restoration then the field increase should be limited to the blind hemifield. The details of the mean sparing along meridians in the seeing and blind hemifields both before and after training are shown in Table 2.4, and as can be seen from these results the sparing increased for both hemifields.

Table 2.4

The mean and standard deviation amount of visual field sparing along the meridians in the blind hemifield and those in the seeing hemifield (in degrees).

	Sparing in the blind hemifield (°)		Sparing in the seeing hemifield (°)	
	Mean	*SD*	*Mean*	*SD*
Pre-Training	22.16	13.42	52.75	11.08
Post-Training	26.77	14.14	55.61	9.42

After the training the amount of visual field sparing increased significantly in the blind hemifield (z = -3.70, p < 0.001, r = 0.57) and the seeing hemifield (z = -2.45, p = 0.014, r = 0.38). The difference between the increase found for the two hemifields was non-significant (z = -1.55, p = 0.122, r = 0.33). This indicates that the effect on the visual field resulting from the training was not specific to the impaired location, suggesting that factors other than restoration may account for the increase, for example a change in the distribution of visual attention or a criterion-shift.

Furthermore, analyses were conducted to examine if the increase in the visual field might be explained by small eye-movements which were not detected during assessment. Data was collected to determine the size of eye-movements that could be detected by the researcher when monitoring fixation during perimetry. Since researcher AL conducted 79% of the perimetric assessments for this study, it was AL's ability to detect eye-movements that was examined. AL monitored fixation via the telescope and verbally reported when she observed an eye-movement. Another researcher randomly presented the light-probe at different eccentricities in the perimeter, whilst a third researcher sat in the perimeter, fixated centrally and then moved their eyes to fixate the probe on onset. Using this method the threshold for detection of eye-movements was determined and the results revealed that eye-movements less than 3° could not be reliably detected by the observing researcher. As such, this suggests that the mean increase in visual sparing (2.5°) could be accounted for by small saccades. Six patients (29%) showed a change in the visual field which was at least 3° (although one actually decreased), and for those patients the change in the field was non-significant ($z = -1.37$, $p = 0.172$, $r = 0.56$), although this could possibly be explained, at part in least, by the reduced sample size on which this statistic was based, especially if one considers the large effect size obtained ($r = 0.56$). However, this sub-sample of patients did also show increases in both hemifields, and the difference between the effects in the two hemifields was non-significant ($z = -0.73$, $p = 0.463$, $r = 0.30$). Therefore factors other than restoration could still possibly explain the larger increases in the visual field found after training.

In summary, the results show that the visual field can increase significantly after compensatory exploration training in support of previous work by Kerkhoff et al. (1992b, 1994), and in opposition to other previous studies (Nelles et al., 2001; Pambakian et al., 2004; Zihl, 1995a, 2000). However, as the results of this study show, the field increase does not necessarily reflect visual restoration as implied previously. Firstly, the mean increase reported here was modest and possibly exaggerated since any absence of detection which was less than 2° was defined as 0°. Therefore, if a patient was classified as having 0° sparing prior to training and greater than 2° sparing afterwards this would not necessarily indicate an increase of 2° or more. In addition to this the mean increase was not sufficiently large to rule out the possible influence of small eye-movements or an eccentric fixation as an explanation for the change. It was determined that the observing researcher could not detect eye-movements during perimetry which were less than 3° in magnitude. Once the data was removed from those patients who showed increases in the visual field which were less than this amount, the significance of the effect was lost, although possibly as a consequence of reduced statistical power. This finding indicates that small eye-movements may mediate the effect as previously proposed for restorative techniques also (Balliet et al., 1985). Future research could perhaps consider using a scanning laser opthalmoscope to monitor fixation very reliably during perimetry as has been done with restorative techniques in order to try and dismiss fixation bias as a factor.

Possession of some residual vision is a pre-requisite for VRT to be successful (Sabel & Kasten, 2000), and perhaps this is the case for restoration following compensatory training as well. Areas of residual vision are typically less than 5° for approximately 70% of HVFD patients (Zihl, 1995a). In accordance with this, approximately 24% of the sample in this study showed an increase in the visual field which could not be accounted for by eye-movements and it is possible that these patients were those with the largest areas of residual vision. Since a supraliminal as opposed to a thresholding perimetric method was used areas of relative defect could not be defined, although this method is sufficient for use with HVFD patients who typically present without such blind regions (Schiefer, Skalej, Dietrich & Braun, 1999).

Since the visual field increase was observed not only for the blind hemifield but a comparable increase was also noted for the seeing hemifield, this indicates that factors which could affect both the intact and impaired visual field may be responsible for the increase reported. Such an effect is possibly the result of a criterion shift by the patients (i.e. responding when they 'think' they see something rather than waiting until they definitely perceive it). Attention has been shown to be related to visual detection and the visual field (Wall, Woodward & Brito, 2004; Williams and Gassel, 1962), and the detection of visual stimuli (and thus the visual field) can be modified by attentional load (Russell, Malhotra & Husain, 2004). A case study has even revealed an example of a patient with a right-sided HVFD who could modify the extent of her visual field loss voluntarily (Trexler, 1998). The ability of this patient to amend the visual field was removed with competing cognitive tasks suggesting that an attentional mechanism was mediating the effect. The functional neuroimaging data from this patient also revealed increased activation in various brain areas including prefrontal cortex, which have been associated with the control of attention (Corbetta, 1998). This observation further supports the possibility that visual attention may contribute to the observed increase of the visual field associated with compensatory training.

Selective visual attention has been associated with visual restoration for many years (Zihl & von Cramon, 1979), although its role may have been underestimated. The relationship between VRT and attention has recently been highlighted further. Kasten et al. (2007) found that spatial attention and alertness improved significantly following VRT and that the increase in attention was correlated with the extent of the field enlargement. This finding demonstrates an association between these variables, although the direction of the relationship cannot be inferred on the basis of such results. Furthermore, the increase in the visual field was not restricted to the trained areas, but rather extended across the visual field as also reported here following exploration training. This suggests that localised mechanisms cannot be solely responsible for the improvements, perhaps indicating that attention could provide a means of explaining the pseudo-restoration resulting from the different forms of HVFD rehabilitation.

2.6 Overall discussion

2.6.1 Overview of the results

The primary aim of this chapter was to examine the transferability of compensatory exploration training benefits for patients with HVFDs. The results overall have revealed that performance of visual search improved across the course of the training. With regards to transfer, the improvement in visual search ability generalised to tasks using different non-trained visual stimuli, to display sizes which exceeded those used during training and the benefits also transferred to visual search in which a different response modality was employed. Despite these positive transfer elements not all tasks were found to benefit significantly from the training, namely reading and subjective patient-report of ADLs.

The secondary aim of this chapter was to investigate whether or not compensatory exploration training could lead to visual restoration. Whilst the results did reveal an increase in the visual field after the training, the influence of small eye-movements on the perimetric measurement could not be reliably excluded, and furthermore the visual field was found to increase in both the blind and seeing hemifields. This suggests that factors such as criterion-shifts or enhanced attention which could influence both hemifields may underlie the visual field increase as opposed to it reflecting visual restoration which would be restricted to the blind portions.

2.6.2 The transferability of the compensatory training benefits

2.6.2.1 For which tasks was transfer obtained?

This study addressed the transfer of the exploration training benefits to various different tasks. The training benefits were found to transfer to various visual stimuli which had not been involved in the training, which indicates that the specific content of the display does not prevent an improvement in visual search performance and thus suggests a general enhancement of visual exploration. This finding confirms the observation that compensatory training can alleviate some of the impairments in visual search experienced by patients with HVFDs (Kerkhoff et al., 1992b, 1994; Nelles et al., 2001; Pambakian et al., 2004; Pommerenke & Markowitsch, 1989; Zihl, 1995a). The training benefit was also shown to transfer to a larger visual display size than had been involved in the training, indicating that a small visual field can be trained and yet improvements in visual search can be found across the wider visual field. The final task for which effective transfer was obtained was the visuomotor search task which demonstrates that an improvement in exploration can be obtained using a different, more practically-relevant response modality, namely grasping the target items.

However, transfer was not observed for all of the tasks assessed. Both objective reading ability and the majority of the subjective reports of ADLs remained unchanged after the intervention. The fact that the only task for which patients reported a significant improvement was reading, which is contradictory to the objective measure, does lead one to question the reliability of subjective report. As such, researchers should be wary about placing too much emphasis on such outcome measures when assessing therapeutic efficacy. Since it is shown here that the benefits of exploration training do not transfer to reading, this implies that reading is a behaviour which requires independent rehabilitation. This may be achieved using specific reading training (Spitzyna et al., 2007), although it is possible that saccadic localisation could be an alternative (Bolognini et al., 2005).

Having provided evidence that the benefits transfer to a variety of laboratory-based visual search tasks, the question still remains as to the ecological validity of the results. Despite Pambakian et al. (2004) suggesting that their search tasks represented ADL behaviours, such activities do not represent ideal everyday situations. The findings of Martin, Riley, Kelly, Hayhoe and Huxlin (2007) that natural tasks may not be performed in the same manner as computer-generated visual search highlights the importance of directly observing patients doing everyday activities in order to examine the effect of an intervention. Martin et al. found that during a naturalistic model-building task, patients with hemianopia did not display the same types of compensatory gaze strategies as previously observed using visual search tasks (Chédru et al., 1973; Meienberg et al., 1981; Pambakian et al., 2000; Zihl, 1995a; Zihl, 1999b). They proposed that patients placed greater reliance on visuo-spatial memory during simple naturalistic tasks, which allowed them to continue to use relatively typical saccades. If a patient is not using ineffective scanning strategies initially, then trying to alter scanning behaviour would be an irrelevant factor for improvement. However, there are some issues of concern regarding the findings of Martin et al.; they used only a small sample (n = 4), they did not measure the saccade patterns of the patients during visual search tasks in order to directly compare the differences, and there was a lot of inconsistency in the behaviour of the patients. However, the results do highlight the requirement to examine if improvements do transfer to relevant activities such as shopping and getting around one's environment. Kerkhoff et al. (1992b, 1994) included transfer to relevant ADL tasks as part of the training, and objectively measuring these activities is important in order to determine if such additional training is required.

Overall, the results suggest that this type of visual search training yields benefits for various exploration tasks other than just those involved in the training. As such, this adds to the growing body of evidence promoting the efficacy of compensatory training as a viable approach to HVFD rehabilitation. The clinical implications of the results reported here are also that a portable system in which only a small visual field is trained, transfer to everyday situations is not directly incorporated into the training and specific search strategies are not dictated by the researcher, can still be an effective type of training. This means that compensatory training utilising visual search may be a practical rehabilitation option.

2.6.2.2 The role of attention in visual compensation

Visual search encourages patients to voluntarily attend to the blind hemifield in order to effectively explore this location. In fact, visual search is more frequently discussed in relation to the mechanisms of attention (Treisman & Gelade, 1980; Wolfe, 1998) than in relation to saccades. As such it can be assumed that attention is enhanced by exploration training, and it is possible that this may be the mechanism by which the improvements in visual search are obtained. Zihl (2000) proposed that the additional element of attention contained in visual search tasks would facilitate the improvement in oculomotor searching strategies developed as a consequence of exploration, although it is possible that attention is the driving force rather than the facilitator.

In support of this proposition there is evidence that if attention is focused on a specific location within the visual field, then this enhances visual processing of stimuli which are presented in or near to this location (Posner, 1980; Posner & Cohen, 1984; Smith & Schenk, 2008). Bearing this in mind it is possible that a general enhancement of visual attention could underlie the improvement reported here for the visual search tasks. Whilst the improvement for performance of the training itself was greater for targets in the blind hemifield, some gain was still obtained for those items in the seeing hemifield. This implies that the benefits are not spatially limited, possibly as a result of an attentional mechanism. Furthermore, some tasks ('find the number' visual search and 'projected search') possibly show greater transfer effects than the other types of visual search. These two tasks do share a specific element in common, which was also integral to the training tasks: deployment of selective attention. In these tasks selective attention to a specific pre-defined target was important whilst non-relevant distractors could be disregarded. In the other tasks ('count the dots', 'count the numbers' and 'visuomotor search') all stimuli were required at some stage in the search process and therefore can be assumed to involve different searching strategies. When all items are required, and in no particular order (like in the 'count the dots' task), then the participant might simply search from one side of the display to the other. Where all items are required and order is specified then when the participant encounters the item before they need it they might monitor this item (divided attention) so as to locate it more quickly later on. It could therefore be the case that tasks which share similar attentional and exploration demands with the practiced tasks also show the greatest amount of transfer. If tasks which require comparable attentional skills benefit the most from exploration training then this implies that attention may play a key role in the transferability of the training benefits.

However, it is worth noting that the null finding observed for the reading tasks in this study implies that attention may not be the only factor mediating the effects. This is because, of all the tasks involved in this study, reading is the only one which requires attention but not exploration. As such, if attention were increased as a result of the training then it may be predicted that reading ability should also improve.

Not only could attention act as a potential mechanism by which the improvement in visual search is obtained, but it is also possible that attention could be used to facilitate training further. Bolognini et al. (2005) found that the addition of an auditory cue to saccadic localisation training could improve exploration benefits. Saccadic training encourages patients to voluntarily shift their attention to the blind hemifield, whereas the addition of a cue means that the patient is not expected to invoke the attention themselves. Making the attention component of the training more explicit could facilitate the compensatory training benefits.

In summary, the training does lead to improvements in various types of visual search. However, since visual search requires attention, exploration and eye-movements the contribution of each of these to compensation cannot currently be determined. The results lead one to question the separate roles of attention and exploration in compensatory training, and this issue is examined further in Chapter 4.

2.6.3 What is the most effective type of training?

The results described here show that various visual search tasks can improve after the compensatory exploration training. This implies that a portable training using small display visual search tasks, and in which specific search strategies are not made explicit by the researcher, can be effective. As such the training offers a practical rehabilitation approach for patients with HVFDs.

The issue of the 'normalisation' of patient performance with respect to that of neurologically normal control participants is important when considering how optimal a training procedure is. The results of this study show that despite significant improvements in visual search performance post-training, the patients did not improve to the same level as the healthy control participants for any of the tasks. This finding suggests that the training is not maximally effective.

Previous research has provided insufficient detail regarding the impact of the training on the process of normalisation, either for training or transfer tasks. Zihl (2000) reported that patients' search times normalised after the training, but then this was the criterion used to determine the course and duration of the training which makes it difficult to compare the results obtained across the studies. Furthermore, whilst both Pommerenke and Markowitsch (1989) and Nelles et al. (2001) obtained data from healthy control participants, the patients were not directly compared to them post-training and thus one cannot be sure of the extent to which the performance of the patients in these studies did normalise. However, examining the mean search time values in these studies, it appears that although patients did improve they did not match the controls. In the Nelles et al. (2001) study the mean search time for the control participants was approximately 1000ms, whilst post-training patients had a search time of 1532.5ms in the blind hemifield (compared to 2344.5ms pre-training). In the Pommerenke and Markowitsch study (1989), the mean search time for the control participants on transfer visual search tasks was approximately 83s, whilst post-training patients had a search time of 134.5s in the blind hemifield (compared to 185.6s pre-training). Unfortunately, the statistical significance of such differences between patients and control participants is unknown.

The evidence from this study combined with the previous results suggests that patients' performance on both the trained visual search tasks and the untrained transfer tasks can improve significantly, but patients may not become as proficient at exploration as healthy control participants. However, the results of this study do not show whether or not patients have reached the maximum achievable benefit or if further gains may be possible with more extensive training. Given that for the exploration training tasks the search time did not appear to plateau in block 3, it may be the case that further improvements may be possible. Determining the time-course of training and transfer is essential for optimising the therapeutic outcomes and utilising resources to their greatest advantage.

2.6.4 The restorative effects of compensatory exploration training

The issue of whether or not restoration of the visual field may be achieved using compensatory rehabilitation approaches is controversial. Kerkhoff and colleagues (1992b, 1994) found a significant enlargement of visual field after compensatory training, although other researchers have failed to observe such an effect (Nelles et al., 2001; Pambakian et al., 2004; Pommerenke & Markowitsch, 1989; Zihl, 1995a). The same issues surround this effect as apply to restorative rehabilitation approaches such as VRT, which are mainly the issues of measurement reliability and the validity of supposed restoration. Whilst the results reported here confirm the findings of Kerkhoff and colleagues (1992b, 1994), that significant visual field increases are possible after exploration training, the explanation for this effect does differ due to the additional analyses conducted.

Fixation bias cannot be reliably excluded as a possible factor influencing the field increase reported here. Perhaps more important is the finding that the visual field was observed to increase not only in the blind hemifield but also in the seeing hemifield to a comparable extent. Restoration can be assumed to be limited to the deficient area of the visual field, and this finding implies that factors which would influence the visual field as a whole may therefore underlie the increases found. One possible candidate for such a mechanism is visual attention, which is known to affect visual detection (Wall et al., 2004) and has previously been associated with the ability of one patient to consciously control the extent of their visual impairment (Trexler, 1998). Given that visual attention may also be associated with the post-training improvement in visual search as discussed above, it could be the case that both the transfer of the therapeutic benefits and the visual field enlargement may be a consequence of this same underlying mechanism.

2.6.5 Conclusion

The results of this chapter show that the visual search performance of patients with HVFDs improves after exploration training. Furthermore, the benefits of the therapy transfer to tasks which involve different visual stimuli, a larger display size and a different response modality to those used in the training. As such, it appears that transfer is possible to tasks which require exploration of the visual scene. However, the benefit does not extend to reading or subjective measures of ADLs suggesting the need to rehabilitate reading deficits independently. With regards to visual restoration it appears that enlargements can be obtained in the visual field after the training, but that this does not necessarily indicate visual restoration. The results with regards to both transfer and restoration highlight the possible importance that attentional processes could play in compensatory rehabilitation for patients with HVFDs, a role which may previously have been underestimated.

Future research needs to address the issue of how to optimise the training, and attempt to determine whether or not the normalisation of performance to that of healthy control participants is an achievable goal for the majority of patients. One of the most important clinical questions which remains is if the training effects can be maintained beyond the duration of the training without further intervention (which is addressed in the following chapter). However, the main limitation of this study is the lack of a patient control group which means that it is impossible to determine whether or not the improvements are the result of the specific components of the training provided or represent placebo effects. Whether or not the same effects can be achieved using a more general attention-based training is a question which is examined in Chapter 4.

Chapter 3: Does compensatory exploration training lead to stable transferable benefits for patients with HVFDs?

3.1 Introduction

3.1.1 Stability of change

There are several important aspects when trying to determine the clinical efficacy of a rehabilitation approach and one of these is to establish that the therapeutic improvements persist across time. Reding and Potes (1990) found that the prognosis for patients with homonymous visual field defects (HVFDs) with regards to activities of daily living (ADLs), functional status, independence and autonomy was poor and thus rehabilitation for such patients is important. It is essential for a therapeutic method to have long-term benefits in order to impact on the social and vocational functioning of a patient. If compensatory training can alleviate the impairments resulting from HVFDs for a duration extending beyond the training itself, then it could have a meaningful improvement on the quality of life of the patient. If the benefits of therapy are not maintained effectively then the patient would have to revert to a more impaired level of functioning, or else would have to receive ongoing treatment. As the duration of rehabilitation increases then cost and effort also increase, not only on the part of the patient but also the clinician. This also increases the likelihood of the patient becoming frustrated and de-motivated with the intervention.

Research into compensatory approaches to HVFD rehabilitation previously revealed some long-term benefits of exploration training. Several studies reported improved search skills such as decreased search times, increased accuracy and an increase in the search field after training, and also found that these improvements were maintained over a follow-up period of at least one month (Kerkhoff et al., 1992b, 1994; Nelles et al., 2001; Pambakian et al., 2004; Zihl, 2000). In fact, Kerkhoff et al. (1992b) observed stability in the increased search field over a mean follow-up period of 22 months. Bolognini et al. (2005) found improvements in visual exploration which persisted for one month following a saccadic localisation training which incorporated additional auditory attention stimulation. These studies all suggest that the benefits found for visual search persist beyond the duration of the compensatory training.

As discussed in the previous chapter it is important that an intervention produces transferable benefits. However, transfer has received relatively little consideration in previous compensatory HVFD training studies and the stability of the benefits for transfer tasks has not been established. It has been shown that compensatory exploration training can lead to benefits for tasks such as visual search using untrained visual stimuli and search involving real three-dimensional items, improvements which were also maintained after a mean follow-up period of three months (Kerkhoff et al., 1994). Whilst Pambakian et al. (2004) reported improvements in objective exploration tasks, which were proposed to reflect ADLs, unfortunately these benefits were not examined at the follow-up session. Furthermore, whilst many studies have demonstrated improved subjective abilities as described by the patients after compensatory training (Bolognini et al., 2005; Kerkhoff et al., 1994; Nelles et al., 2001; Pambakian et al., 2004; Zihl, 2000), only two reported having examined these at a follow-up session. Following combined audio-visual saccadic localisation training Bolognini et al. (2005) found persistent subjective benefits for one month, whilst Zihl (2000) reported some additional improvements in subjective reports at a follow-up session after exploration therapy. The results reported in Chapter 2 revealed the transfer of the training benefits to various exploration tasks including visual search using a large display size and a different behavioural response. However, it is important to determine the stability of such gains in transfer tasks.

Overall, the research to date shows that the reported gains found with compensatory exploration training persist over time and the results suggest that patients do not have to continue to undergo treatment in order to maintain the benefits. However, further research examining the extent to which patients' improved performance is maintained across multiple tasks would be useful in order to fully evaluate the clinical rehabilitation potential of the compensatory exploration therapy.

3.1.2 Study aims

The aim of this study was to examine whether or not the benefits observed after the compensatory exploration training, as reported in Chapter 2, were maintained over a period of approximately six months post-training. Not all of the patients who participated in the previous study could be successfully followed-up and therefore the data presented are only from those patients who were assessed at a follow-up session. Such sample attrition will undoubtedly have impacted on the statistical significance of the results obtained herein.

The main point of interest in this study was whether or not the improvements found after exploration training were stable over time. Therefore, focus is directed towards those tasks which were found to improve post-training including all three visual search tasks which used non-trained visual stimuli ('count the dots', 'find the number' and 'count the numbers'), the 'projected search' task and the 'visuomotor search' task. A significant subjective improvement in reading ability was also reported by the patients and consequently this outcome has been followed-up as well. The other tasks (perimetry, reading and ADLs questionnaires) were also performed by the patients at the follow-up assessment, but the results are not described since these were not considered to be primary outcome measures. Although the results in Chapter 2 revealed a significant change in the size of the perimetric visual field plot post-training, this was not interpreted as reflecting visual restoration. As such it is not explicitly considered in this study. Previous research revealed that improvements in visual search tasks which occurred after HVFD compensatory training were preserved for at least several months after the cessation of the training (Kerkhoff et al., 1994). On the basis of this finding it was predicted that the improvements in these objective tasks would also persist over the follow-up period.

3.2 Method

3.2.1 Design

The patients involved in this study had all previously participated in the compensatory exploration training study described in Chapter 2. As such prior to their involvement in this study the patients had undergone a pre-training assessment session, 15 sessions of exploration training and then a post-training assessment. During this study the patients completed a follow-up assessment which was conducted at least three and a half months after the post-training session. This was completed for as many participants as possible from the previous study.

3.2.2 Sample

Fourteen of the patients (61%) from the sample involved in the exploration training study described in Chapter 2 were successfully followed-up. The mean follow-up period was 6.0 months (range: 3.5 to 7 months), during which time patients did not receive any rehabilitation for their HVFD. Reasons for the failure of a patient to attend a follow-up session included an inability to re-contact patients, illness and large travel distances which were not deemed suitable for a follow-up assessment session. Also, two patients had only recently completed the post-training assessments and therefore these patients were not eligible for inclusion in this study.

All of the participants provided informed consent to partake in the study in accordance with the Declaration of Helsinki (International Committee of Medical Journal Editors, 1991). Approval for the study was obtained from the departmental ethics committee at Durham University and from the local NHS multi-centre research ethics committee. The demographic and clinical details of the patients are outlined in Table 3.1.

Table 3.1

Demographic and clinical characteristics of the patients seen at the follow-up assessment session.

	Follow-up sample
	Mean (range)
Age (years)	68.21 (46 – 79)
Visual field sparing (°)	3.14 (0 – 12)
Time since onset (m)	28.43 (3 – 276)
	Number of people
Gender: Male/Female	12/2
Aetiology[a]: IS/Haem/Trauma	10/4/1
HVFD side: Left/Right	11/3

Note: [a] IS: Ischaemic stroke, Haem: haemorrhage

In order to determine if any of these variables might be associated with whether or not a patient was seen at the follow-up assessment, the patients who were and were not successfully followed-up were compared on several characteristics. The baseline characteristics assessed were age, gender, aetiology, side of defect, visual field sparing and duration of HVFD. These variables did not differ between those patients who were and who were not followed-up ($p \geq 0.062$; see Appendix 12 for the details of the statistical comparisons).

3.2.3 Procedure

All of the patients had previously participated in the exploration training study described in Chapter 2. Therefore, these patients had already completed two assessment sessions (pre-training and post-training) and 15 sessions of exploration training. This study involved the participants repeating the assessment tasks. For the methodological details of the training and assessment tasks see Chapter 2 (pp. 62-65, 73-75, 78-79, 82-83, 88-89, 95-97).

The outcome tasks which assessed transfer and which are considered in this study are those which showed a significant training benefit in the previous study: 'count the dots', 'find the number', 'count the numbers', 'projected search' and 'visuomotor search' tasks. The results from the item relating to reading from the visual impairments questionnaire are also reported.

3.2.4 Statistical analyses

The statistical tests were performed using SPSS and were two-tailed. Outliers (values more than two standard deviations from the mean) were identified and removed for individual patients separately for each of the outcome tasks. The data analyses were conducted using the mean data from the patients. For each of the tasks the independent variable was session (pre-training, post-training and follow-up). The focus of this study was on those outcomes which were found to improve after the training, and further to this the analyses were limited to the dependent variable which demonstrated the change (accuracy, search time or both where appropriate). Wilcoxon signed ranks tests were conducted to compare ability at the follow-up session to the previous sessions, both pre- and post-training. As such the alpha-level for the statistical tests was set at 0.025 to take into consideration multiple comparisons using a Bonferroni correction.

3.3 Results

3.3.1 'Count the dots' visual search task

Previously it was determined that the training led to significant improvements in the 'count the dots' visual search task with regards to both search time and accuracy (see Chapter 2, pp. 66-67). Therefore, the extent to which the benefit was maintained at the follow-up session was examined for both of these variables. The mean search time at the follow-up session was 153.60ms longer than it had been after the training (see Table 3.2). This difference in search time between the two sessions was non-significant ($z = -0.16$, $p = 0.875$, $r = 0.03$), suggesting that the improvement in search time resulting from the training was maintained over the follow-up period. The mean search time at the follow-up session was 361.41ms (5.6%) faster than the pre-training session. However, despite this difference the change was not statistically significant either ($z = -0.85$, $p = 0.397$, $r = 0.16$). The results suggest that the post-training improvement in search time observed for this task was neither fully retained nor completely lost at the follow-up assessment.

Table 3.2

Details (mean and standard deviation) of the search time and the accuracy for the 'count the dots' task for each of the three assessment sessions.

	Search time (ms)		Accuracy (%)	
	M	*SD*	*M*	*SD*
Pre-Training	6445.33	2728.60	73.36	28.07
Post-Training	5930.32	1990.55	84.14	16.19
Follow-Up	6083.92	2705.07	77.29	21.52

The results for this task also reveal that mean accuracy had declined at the follow-up session relative to the post-training one, although the difference was not significant ($z = -1.82$, $p = 0.068$, $r = 0.34$). As with search time this outcome variable was also still improved relative to the pre-training level, although not to a significant extent ($z = -0.43$, $p = 0.666$, $r = 0.08$). This indicates that the training benefit in accuracy was also neither fully retained nor completely lost during the follow-up period.

In summary, these results indicate that the performance of the 'count the dots' visual search task did decline at the follow-up relative to the post-training session, although remained improved relative to the pre-training level. However, it is likely that the reduced sample size makes it difficult to reliably interpret the results for this task.

3.3.2 'Find the number' visual search task

For the 'find the number' task the previous study found that there was a significant improvement in search time after the exploration training whilst accuracy remained unchanged (Chapter 2, pp. 68-69), and therefore the follow-up session results focus on the former variable.

The mean search time increased slightly at the follow-up session relative to the post-training one (see Figure 3.1), although this increase was not significant ($z = -1.22$, $p = 0.221$, $r = 0.23$). This finding indicates that the training benefit had been maintained over the months following the end of the training. The search time at the follow-up session was 555.95ms (18.0%) faster than the pre-training level which was a significant improvement ($z = -3.17$, $p = 0.002$, $r = 0.60$). This further confirms the finding that the training effect was retained for the 'find the number' visual search task.

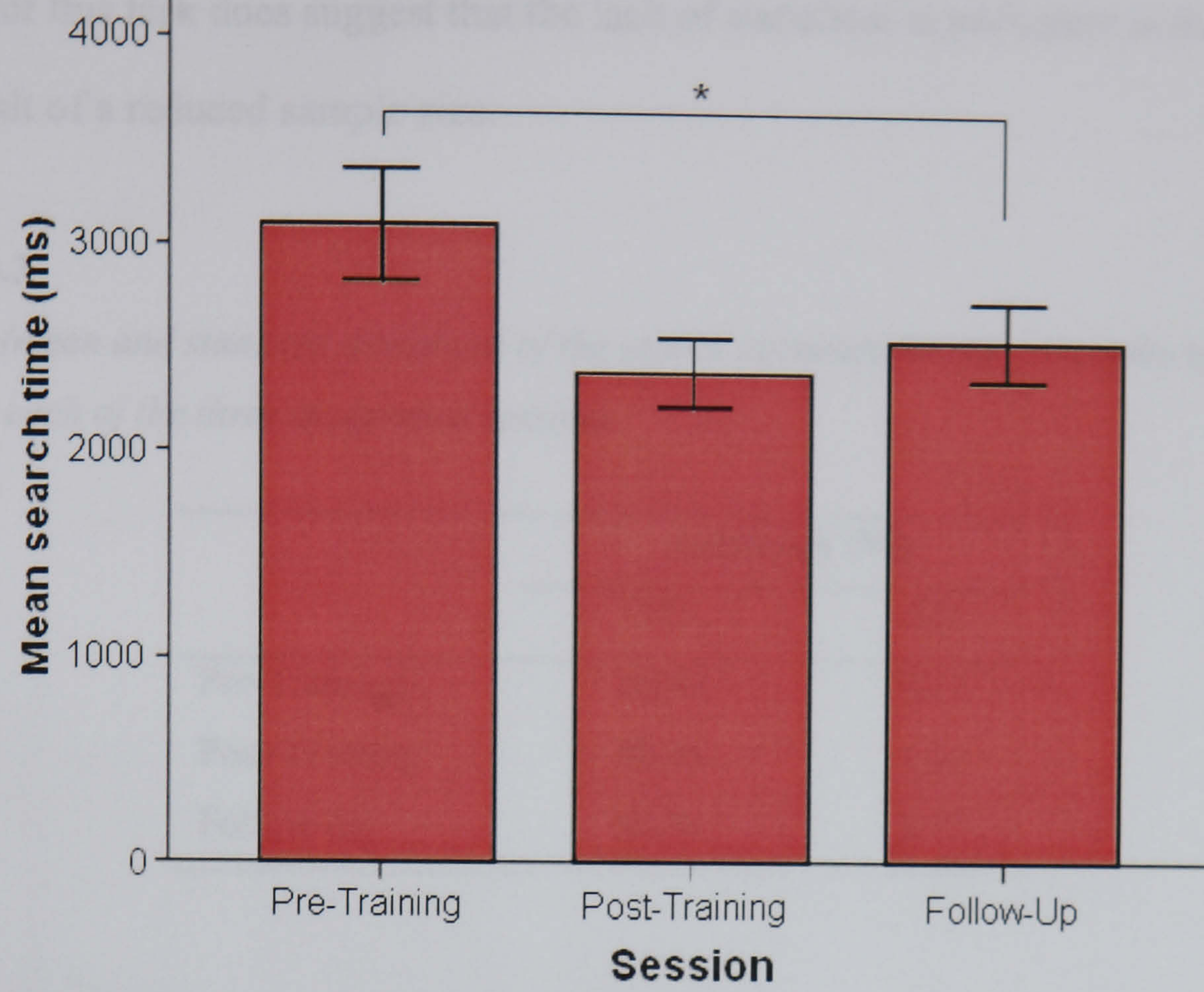

Figure 3.1: Graph showing the mean search time for each of the three assessment sessions for the 'find the number' visual search task. The error bars represent the standard error of the mean and '*' represents significant differences.

<u>3.3.3 'Count the numbers' visual search task</u>

The previous study found that there was a significant improvement in accuracy for the 'count the numbers' task after the training, but that search time did not change significantly (Chapter 2, pp. 70). Accuracy was therefore chosen as the variable of interest for this task. Table 3.3 contains details of the accuracy levels for each of the three testing sessions.

As can be seen from these results accuracy gradually increased across all of the assessment sessions. The accuracy at the follow-up session was not significantly different to the post-training level (z = -0.11, p = 0.916, r = 0.02), indicating that the treatment effect was maintained. However, the accuracy at the follow-up session relative to the pre-training session was also non-significant (z = -2.10, p = 0.036, r = 0.40). Nevertheless, this effect was nearing significance and the medium effect size found for this task does suggest that the lack of statistical significance is most likely the result of a reduced sample size.

Table 3.3

Details (mean and standard deviation) of the search accuracy for the 'count the numbers' task for each of the three assessment sessions.

	Accuracy (%)	
	M	*SD*
Pre-Training	95.04	9.11
Post-Training	98.39	5.34
Follow-Up	99.01	2.77

3.3.4 'Projected search'

For the 'projected search' task the results described in Chapter 2 (pp. 75-76) revealed that there was a significant improvement in search time after the training, but no significant change in search accuracy. The results described here therefore focus on the former of these variables. The follow-up results are based on the data from 12 patients (data was missing from two patients due to computer difficulties). The data described here are for the target-present condition.

The search time gradually decreased across the sessions (see Figure 3.2). The follow-up search time was not significantly different to the post-training session (z =-1.020, p = 0.308, r = 0.21), thus indicating that the improvement obtained after the training was retained. However the difference between the follow-up and pre-training sessions was not significant either (z = -1.883, p = 0.060, r = 0.38), and the pre- and post-training sessions were also no longer significantly different from one another (z = -2.040, p = 0.041, r = 0.42). Nevertheless, the trend towards improved search time post-training and at the follow-up session relative to the pre-training level were nearing significance (p = 0.04 and 0.06 respectively, with medium effect sizes for both), indicating a persistent training benefit. It is probable that the effect of sample attrition makes it difficult to interpret these findings accurately.

Figure 3.2: Graph showing the mean search time for each of the three assessment sessions for the target-present condition of the 'projected search' task. The error bars represent the standard error of the mean.

3.3.5 'Visuomotor search'

The previous findings showed that the training led to significant improvements in the 'visuomotor search' task for both search time and accuracy (see Chapter 2, pp. 79), and therefore both variables have been examined in relation to the follow-up session. As can be seen from the results presented in Table 3.4, search time decreased across all three of the assessment sessions. The search time at the follow-up session was significantly reduced relative to the pre-training session ($z = -3.23$, $p = 0.001$, $r = 0.61$), but not significantly different to the post-training search time (z = -1.04, p = 0.300, r = 0.20). This shows that the effect of the training on search time was stable across the follow-up period for this task.

Table 3.4

Details (mean and standard deviation) of the search time for the 'visuomotor search' task for each of the three assessment sessions.

	Search time (ms)		**Accuracy (%)**	
	M	*SD*	*M*	*SD*
Pre-Training	74.15	48.85	97.03	5.65
Post-Training	61.70	37.99	98.92	2.78
Follow-Up	58.93	30.88	98.38	4.13

Furthermore, accuracy was slightly reduced at the follow-up session relative to the post-training session, although this decline in performance was not significant (z = -0.95, p = 0.340, r = 0.18). This suggests that the improvement in accuracy for the 'visuomotor search' task found after the exploration training was also retained. However, the accuracy at the follow-up session was not significantly greater than the pre-training session (z = -2.20, p = 0.028, r = 0.42), although this effect was close to significant.

3.3.6 Visual impairments questionnaire: reading

The only item on the visual impairments questionnaire for which patients previously reported a significant improvement was reading (Chapter 2, pp. 91). As can be seen from the results in Table 3.5 the follow-up rating of reading impairment had actually improved (lower rating) relative to the post-training session, although this difference was non-significant (z = -0.95, p = 0.340, r = 0.18).

Table 3.5

Details (mean and standard deviation) of the ratings for the reading item on the visual impairments questionnaire for each of the three assessment sessions. A low rating indicates a lesser degree of perceived impairment.

	Rating of reading ability	
	M	*SD*
Pre-Training	2.21	1.31
Post-Training	1.25	1.55
Follow-Up	1.00	1.47

These results also reveal that the follow-up rating of reading was still significantly improved relative to the pre-training session ($z = -2.70$, $p = 0.007$, $r = 0.51$). Therefore, this shows that the subjective reading ability remained stable across the follow-up period.

3.4 Discussion

3.4.1 Interpretation of the results

The results of this study showed that for some of the tasks ('find the number', 'visuomotor search' and the patient report of reading ability) the post-training improvement in performance was maintained over the follow-up period of six months. Therefore, ongoing therapy is not required for these long-term benefits to be obtained. This confirms the findings of previous research which has demonstrated that the exploration training benefits, with regards to visual search ability, persist over a follow-up period (Kerkhoff et al., 1992b, 1994; Nelles et al., 2001; Pambakian et al., 2004; Zihl, 2000). Furthermore, the findings of this study reveal that the benefits of the training which extend to some of the transfer tasks can be maintained. The fact that the patients' perception of their reading ability remained improved across the follow-up period indicates some long-term psychological benefit of the training. This is in accordance with the previous observations by Bolognini et al. (2005) and Zihl (2000) that compensatory HVFD therapy can improve subjective ability, and that this can be maintained over a follow-up period despite no further intervention being provided. Furthermore, the results of this study extend the follow-up period from one month to six months.

However, for the other tasks ('count the dots', 'count the numbers' and 'projected search') the results did not reveal persistent post-training gains, since the follow-up performance was not significantly different to the pre-training level. However, nor was the follow-up performance significantly different to the post-training session for these tasks. It is likely that sample attrition (and thus reduced statistical power) will have influenced these results and could explain the lack of significance for these tasks. The 'count the dots' task was the visual search task which showed the smallest training effect for search time, however, it was also the only one for which a post-training improvement in accuracy was also found. Since the training benefit was distributed across two variables this could explain the null finding with regards to this task. It would presumably be harder to obtain significant results in either variable when both are affected and thus the effect is split across them, especially when the sample size and thus also statistical power has been reduced.

With regards to the 'count the numbers' visual search task accuracy was the variable examined and since this shows a smaller magnitude of change than the variable of search time, this could again potentially explain the lack of significance for this task. The results for this task were nearing significance which indicates that it is likely that the training benefit was maintained.

As for the 'projected search' task there are several reasons why the data suggests that the benefit was upheld despite the lack of a significant difference between the pre-training and follow-up sessions. The mean scores for each session imply that the decrease in search time obtained after the training was still present (perhaps even improved upon slightly) at the follow-up session, this trend was nearing significance ($p = 0.06$), and there were only 12 patients involved in this task (whereas there are 14 for the others) reducing the statistical power of the analyses further than for the other tasks. This does suggest that the training benefit for search which required a larger display size than had been used in the training may also have been maintained over the follow-up period.

In the study reported in Chapter 2 several outcome measures did not show any significant benefit from the training. These included restoration of the visual field (which, although it did change significantly post-training, was interpreted as reflecting changes other than visual restoration), reading of both text and numbers, and a variety of subjective questionnaires. These measures were also included in the follow-up assessment despite having shown no significant exploration training effects, and the results are described in Appendix 13. To summarise these findings, for none of these measures was the follow-up session performance significantly different to the pre-training or post-training sessions. The only item on any of the questionnaires to change was reading (as already discussed above). Therefore, these results imply that if a benefit is not observed for a transfer task immediately after the training then it does not occur at a later date (approximately six months later). Of course this possibility cannot be ruled out for other outcomes which have not been assessed in this study. As such it would appear that when transfer does occur it happens relatively quickly (immediately after training) and the benefits also appear to be enduring.

3.4.2 Open research questions and possible future research

These results suggest that the portable and easy to conduct visual search compensatory training approach has long-term potential as a means of HVFD rehabilitation. However, the stability of the training effects has not been established for all of the transfer tasks and future research should examine the effects using a larger sample, and preferably also using a control condition. It is important to note that since the effects of the compensatory exploration training have not yet been shown to be more substantial than those which can be obtained using a placebo therapy that the same limitations resulting from this apply to the follow-up data. It could be the case that the results are the product of placebo effects, including the stable improvements. Therefore, it is important that research be conducted which investigates the effect of compensatory exploration-based training relative to a placebo condition, and the study reported in Chapter 4 examines this issue.

It would also be beneficial to determine the extent of the stability since six months could be considered as a relatively short duration. It would be valuable to establish if there is a maximum amount of time for which the improvements are upheld. Information relating to this issue may prove constructive in terms of trying to convince clinicians and patients of the usefulness of the training.

3.4.3 Conclusion

This study has shown that the benefits of compensatory exploration training, which are found for a variety of tasks requiring visual exploration, are stable across a follow-up period of six months during which no further HVFD rehabilitation is provided. It also shows that the post-training subjective improvements reported by the patients persist across the same period. These findings provide additional promise to the use of compensatory training in rehabilitation; since the training benefits appear to persist across a variety of tasks ongoing training would not be required. However, there is some concern regarding the reliability of these findings given the reduced statistical power and therefore replicating these results would be desirable.

Chapter 4: Evaluation of the efficacy of exploration training relative to an attention-based placebo therapy for patients with HVFDs.

4.1 Introduction

4.1.1 Overview of the chapter

This chapter addresses the question of whether or not the exploration training leads to greater improvements than can be obtained using a placebo therapy. The introduction considers the controls used in previous research into compensatory training, highlights the importance of conducting placebo controlled research and explains the choice of the training which has been used as the placebo in the current study. Results are then described which compare the efficacy of the exploration training to an attention-based placebo therapy. Both within-subjects and between-subjects comparisons are made as part of this evaluation. The potential impact of the findings is then discussed.

4.1.2 Controlled research into compensatory HVFD rehabilitation

Compensatory rehabilitation approaches aim to help patients to utilise their remaining visual abilities in order for them to adapt effectively to their visual field loss. Previous studies examining the efficacy of compensatory exploration training for patients with HVFDs have failed to include a placebo condition. Unfortunately, this lack of control means that it is impossible to know whether the benefits reported in these studies are specific to the exploration training received, or a more general consequence of attention or concentration for example. Compensatory reading training has been shown to be more effective than a placebo (Spitzyna et al.,

2007) which demonstrates the advantage of this type of intervention beyond other non-specific types of therapy, indicating that the training produces a specific effect.

With regards to compensatory exploration training, research using repeated-baseline measures has been conducted in order to examine the benefits of training compared to spontaneous improvements (Kerkhoff et al., 1994; Pambakian et al., 2004). These studies have shown that the exploration training is more beneficial at improving visual search behaviour than when no intervention is provided, indicating that the effects are not the result of spontaneous adaptation, or a product of repeated testing such as the patient becoming more familiar with the assessment tasks. However, the question remains as to whether or not exploration training is more beneficial than patients being provided with any form of therapy since such repeated baseline conditions do not allow researchers to dismiss the possible influence of placebo effects.

The lack of adequate controlled research to date may be one possible reason why currently many patients with HVFDs do not receive any particular rehabilitation for their visual defects (Kerkhoff, 1999; Pambakian et al., 2005), since without such evidence clinicians may remain unconvinced of the benefits of the training. Establishing the effectiveness of an intervention over a placebo condition is important in order to justify any cost and effort which is associated with the technique. The benefits of compensatory exploration training over a placebo therapy need to be effectively demonstrated in order to advance our understanding of the efficacy of exploration training, to maximise training potential, and to potentially influence clinical practice.

4.1.3 Attention as the basis for a placebo condition

Compensatory exploration training which is based upon visual search tasks also comprises an element of attention. Visual search is known to require attention as even highly practiced search tasks have been found to interfere with the performance of concurrent visual tasks (Hoffman, Nelson & Houck, 1983) and visual search is typically discussed in relation to theories of attention (Treisman & Gelade, 1980; Wolfe, 1998). Compensatory training encourages patients to orient their attention to their blind hemifield as well as increasing visual exploration, since patients are required to voluntarily maintain attention on the blind hemifield in order to search this location. Furthermore, selective attention is required to search for specific targets. Zihl (2000) proposed that such additional shifting of attention elicited by visual search tasks would facilitate the process of oculomotor modification resulting from exploration. However, it is possible that attention plays a more integral role in compensation than previously proposed. In further support of this, the previous results reported in Chapter 2 suggest that attention may be an important cognitive factor involved in HVFD rehabilitation. Therefore, the contribution of both exploration and attention needs to be established.

If attention is the main factor which contributes to the improvements found after exploration training then a placebo therapy which trains attention in the absence of exploration could be expected to yield the same magnitude of effect. Therefore, not only would a purely attentional training help to determine if the exploration training is more effective than an alternative intervention, but would also address the question of whether or not enhancing attention is sufficient to ameliorate the behavioural impairments resulting from a HVFD. The concept for the placebo condition (*attention training*) used in this study is similar to that employed in the VRT studies which used fixation training as a placebo (Kasten et al., 1998, 2001). For this study the attention training involved similar stimuli to those used in the exploration training but these were positioned only close to fixation (within 1°) to reduce the need for searching strategies in order to complete the tasks. Subsequently, the attention training involved visual attention and visual processing skills but not visual exploration.

4.1.4 Study aims

The aim of this study was to evaluate the efficacy of the compensatory exploration training compared to a placebo therapy which trained attention but not visual exploration. This method allows both the examination of the comparable efficacy of the two types of intervention and the investigation of the relative contributions of both attention and exploration to HVFD compensation.

4.2 Overview of the design of the study

4.2.1 Design

This was a within-subjects repeated-measures study. Patients completed a series of tasks in a baseline assessment session. These tasks were perimetry, three non-trained visual search tasks ('count the dots', 'find the number' and 'count the numbers'), a 'projected search' task, a 'visuomotor search' task, reading tasks and subjective questionnaires assessing activities of daily living (ADLs). The baseline assessment was followed by 15 sessions of attention training and then a post-attention training assessment session which involved the same tasks as previously completed. The patients were not aware that this was a placebo condition and were informed that this was the first stage of therapy. After completing the attention training and assessment, the patients received 15 sessions of visual exploration training and then completed a final assessment session.

Participants were assigned to this study as opposed to the exploration training only study (Chapter 2) based on the time of recruitment. The first patients who were recruited were allocated to the exploration training only study (n = 23), whilst the later recruits were assigned to the condition in which they received both the attention and the exploration training (n = 15).

4.2.2 Sample

All patients gave informed consent to participate in the study in accordance with the Declaration of Helsinki (International Committee of Medical Journal Editors, 1991). Approval for the study was obtained from the departmental ethics committee at Durham University and from the local NHS multi-centre research ethics committee. The participants were recruited from those patients who were referred to the study from local hospitals or who referred themselves, in accordance with the same inclusion/exclusion criteria used in the study reported in Chapter 2 (pp. 47). Fifteen right-handed patients with HVFDs resulting from post-chiasmatic damage participated in the study (10 male and 5 female). The individual characteristics of these patients are detailed in Table 4.1.

Table 4.1

Characteristics of the patients and their visual field defects. Details include gender, age, handedness, type and location of HVFD, presence of neglect, visual field sparing, aetiology, and HVFD duration.

Participant	Gender	Age (yrs)	Handedness	HVFD[a]	Neglect	Sparing (°)	Aetiology	Duration (m)
1	Male	75	Right	LSQ	No	7	Ischaemic stroke	33.5
2	Female	46	Right	LH	Yes	0	Haemorrhage	14.0
3	Male	62	Right	RIQ	No	38	Ischaemic stroke	3.0
4	Female	21	Right	RH	No	2	Haemorrhage	3.0
5	Male	74	Right	LH	No	0	Ischaemic stroke	5.0
6	Female	51	Right	Bi	No	3	Haemorrhage	63.0
7	Male	82	Right	LH	No	2	Ischaemic stroke	5.0
8	Male	44	Right	LH	Yes	0	Trauma	9.5
9	Male	69	Right	LH	No	2	Ischaemic stroke	3.0
10	Male	71	Right	LH	No	2	Ischaemic stroke	17.0
11	Male	62	Right	LH	No	7	Ischaemic stroke	3.0
12	Female	58	Right	LH	No	0	Ischaemic stroke	12.0
13	Female	57	Right	RH	No	2	Ischaemic stroke	8.0
14	Male	37	Right	RH	No	0	Haemorrhage	5.5
15	Male	67	Right	RH	No	6	Ischaemic stroke	7.0

Note: [a] RH: right hemianopia; LH: left hemianopia; LSQ: left superior quadrantanopia; RIQ: right inferior quadrantanopia, Bi: Bilateral defects.

All of the patients except patient 06 had either normal or corrected-to-normal visual acuity (patient 06 had extreme myopia which could not be corrected with glasses). The mean age of the sample was 58.4 years (range: 21 - 82 years). The aetiologies underlying the HVFDs included ischaemic stroke (n = 10), haemorrhage (n = 4) and trauma (n = 1). Five patients had a right-hemifield HVFD (33%), nine patients had a left-hemifield HVFD (60%) and one patient (7%) had bilateral visual loss. The mean amount of visual sparing was 4.7° (range: 0° to 38°). The mean time since HVFD onset was 12.8 months (range: 3 to 63 months) and no patient participated in the study until at least three months after the onset of their visual loss to try and reduce any possible confounding resulting from spontaneous recovery.

Two of the patients (02 and 08) had a comorbid hemispatial neglect as assessed using the star cancellation task (Halligan et al., 1991), and confirmed using medical records. Some patients had additional difficulties including hemiplegia or hemiparesis (n = 3), memory and cognitive impairments (n = 3), aphasia (n = 1) and diplopia (n = 1), although none of these were sufficient to prevent participation.

4.2.2.1 Dropouts and exclusions

Of the 15 patients included in the study one of them (13) did not attend the final assessment session due to illness and their data has therefore been excluded. The remaining patients completed all training sessions and attended the three assessments. However, patient 02 has been excluded since neurosurgical intervention was performed midway through the study which could have influenced subsequent performance.

4.2.3 Comparisons

With regards to examining the effects of the attention training relative to the effects of the exploration training two types of comparisons were made: within-subjects and between-subjects. Within-subjects comparisons are useful because they avoid the difficulties associated with having to match samples, although do encounter the problem of order effects. In this study the patients always completed the attention training before the exploration training. Consequently a reduced exploration training effect could be found as a result of the attention training having exhausted the scope for improvement. In order to address the issue of order effects between-subjects comparisons were also made between the sample who received only the exploration training and those who received both the attention and then the exploration training (see Table 4.2).

Table 4.2

Details of the samples involved in the within-subjects and between-subjects comparisons.

	Training 1	Training 2	Sample description	
Exploration only	*A* Exploration	-----	Chapter 2	
Attention then Exploration	*B* Attention	*C* Exploration	Chapter 4	→ Within-subjects
	↓ Between-subjects			

4.2.3.1 Comparability of the samples

To try and ensure that differences in the between-subjects comparisons reflected variations in training and not baseline variation, the two samples ('exploration only' and 'attention then exploration') were compared on several demographic and search performance variables. Table 4.3 contains the demographic and lesion details of the two samples of patients. The variables compared included age, degree of visual field sparing, side of HVFD, aetiology and time since the onset of the HVFD. None of the variables were significantly different between the two groups of patients ($p \geq 0.367$; see Appendix 14 for the analyses).

Table 4.3

Demographic and clinical characteristics of the patients who completed the attention then the exploration training and the sample who completed only the exploration training.

	Attention then exploration	**Exploration only**
	Mean	*Mean*
Age (years)	49.5	64.3
Visual field sparing (°)	5.5	3.9
Time since onset (m)	13.0	24.5
	Number of patients	*Number of patients*
Gender:		
Male/Female	10/3	16/5
Aetiology[a]:		
IS/Haem/Trauma	9/3/1	14/6/1
HVFD side:		
Left/Right/Bilateral	8/4/1	16/5/0

Note: [a] IS: Ischaemic stroke, Haem: haemorrhage

Visual search performance prior to training is negatively associated with the amount of improvement obtained after the exploration training (as reported in Chapter 2), and was therefore compared across the two samples. Table 4.4 shows the mean search time and accuracy for the three visual search tasks ('count the dots', 'find the number' and 'count the numbers'), the 'projected search' task and the 'visuomotor search' task, for the baseline assessment session (prior to any training) for both of the patient samples. For neither accuracy nor search time were any of the tasks significantly different at baseline between the two samples ($p \geq 0.366$).

Table 4.4

Search time (in seconds) and accuracy (in percent) for each of the three visual search tasks, the projected search task and the visuomotor search task. The results are for the baseline session separately for the sample who performed the attention then the exploration training and those who performed only the exploration training.

	Attention training baseline		**Exploration training baseline**		**Mann-Whitney U**		
	M	*SD*	*M*	*SD*	*U*	*p*	*r*
Search time (s)							
Count the Dots	6.27	2.65	6.13	2.40	113	0.531	0.11
Find the Number	2.85	0.62	3.06	1.02	127	0.736	0.06
Count the Numbers	67.36	23.39	71.02	48.62	111	0.366	0.16
Projected	5.49	4.14	5.72	4.21	113	0.873	0.03
Visuomotor	69.57	37.49	66.66	42.55	120	0.559	0.10
Accuracy (%)							
Count the Dots	65.92	33.57	72.95	29.36	115	0.567	0.10
Find the Number	94.69	10.11	97.48	4.38	126	0.686	0.07
Count the Numbers	93.59	14.84	93.96	10.45	127	0.722	0.06
Projected	77.77	18.92	74.67	23.26	112	0.825	0.04
Visuomotor	97.78	5.24	97.92	4.74	122	0.572	0.10

4.3 Training

4.3.1 Method

4.3.1.1 Attention training

Tasks and stimuli:

The attention training was designed to be as similar as possible to the exploration training (i.e. same stimulus colours, shapes and sizes) but the exploration component of each of the tasks was removed by positioning all stimuli around the central fixation point. The training consisted of 15 sessions, which were separated into three blocks of five sessions, and each session involved nine different tasks which are described in Table 4.5.

Table 4.5
Details of the visual search tasks used in each session of the attention training. The details include the defining characteristics of the target and the minimum and maximum display duration (in seconds).

Task type	Target	Display (s)	
		Max	*Min*
Feature	Colour	12	0.75
Feature	Form	12	0.75
Feature	Size	12	0.75
Easy Conjunction	Colour & Form	15	1.20
Hard Conjunction	Colour & Form	15	1.20
Easy Conjunction	Size & Form	15	1.20
Hard Conjunction	Size & Form	15	1.20
Mental Rotation 1	Letter	10	10.00
Mental Rotation 2	Number/Character	10	10.00

The first three tasks were feature visual searches in which the target was pre-defined by colour, form (specific letter) or size (small letter). On each trial participants had to decide if the specified target was present or not. The target was present on 50% of trials and trial order was randomised. For each of these tasks four items were presented, all of which were located around the central point of the screen (see Figure 4.1 for an example). The items each subtended 0.5° (except for the small letters which subtended half of this height), and the innermost edge was 0.5° from fixation. This meant that the entire display filled the central 2° horizontally (1° in each hemifield). Difficulty was modified across the sessions by reducing the stimulus presentation time. The trial duration was modified for each session and for each participant individually, such that accuracy levels did not fall below 80%.

Figure 4.1: Example of a target-present display from the colour feature visual search task. In this example the target is the red letter (not to scale; the display extended 1° into each hemifield).

The following four tasks were all versions of conjunction visual searches, which again required patients to decide upon the presence or absence of a pre-defined target which was present on half of the trials. The same positioning of the stimuli was used as in the feature searches. In the first of these tasks the target was defined by colour and form (*easy colour-form conjunction*). In the following task the target remained the same but the difficulty was increased by making the distractors more similar to the target (*hard colour-shape conjunction*). In the third conjunction search the target was defined by form and size (*easy form-size conjunction*), and the same target was then used in the final task of this type, although the difficulty was increased by increasing the similarity between the items (*hard form-size conjunction*). The difficulty of the conjunction searches was modified by reducing the stimulus presentation time in the same manner as for the feature visual search tasks.

The final two tasks involved in each session of the attention training were mental rotation tasks. In each of these tasks one item was displayed in the centre of the screen on each trial which subtended 2.5° in height. The item could be a number (i.e. 7, 5, 2), letter (i.e. L, F, R) or character (i.e. £, $, &), and these could be facing the normal direction or else could be mirror-reversed (see Figure 4.2 for an example).

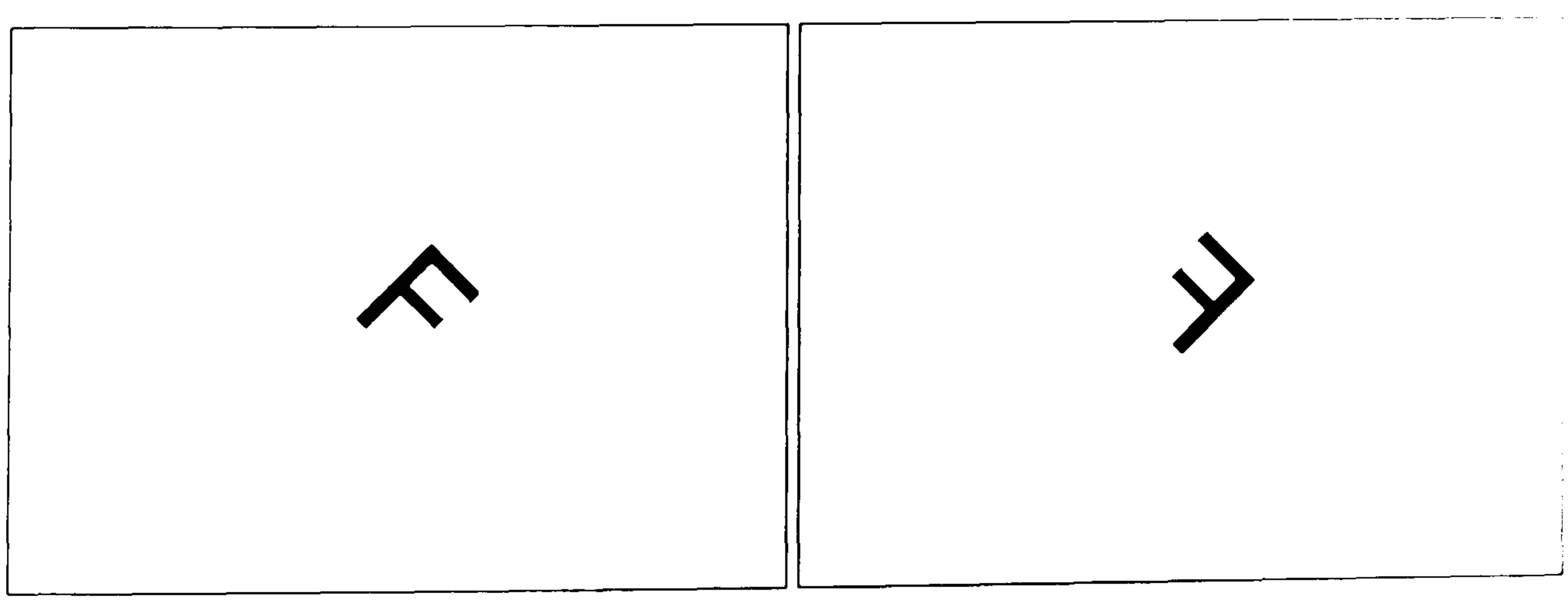

Figure 4.2: Two possible displays from the mental rotation task. The image on the left represents a rotated letter F, whilst the image on the right depicts a rotated mirror-image of a letter F (not to scale; the letter was 2.5° in height).

Items were rotated into one of five different positions (0°, 45°, 135°, 225° and 315°), and each trial duration was 10 seconds. The patient had to report whether the stimulus was the correct way round or was mirror-reversed. The first of the mental rotation tasks involved letters, whilst the second involved either numbers or characters.

Apparatus:

The training program was created using E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA), and was performed using a laptop computer. The screen of the laptop computer was viewed binocularly at an approximate distance of 57cm, which meant that the display subtended approximately 30° horizontally (15° in each hemifield) and 21° vertically.

Procedure:

The training was performed in the participants' homes, in a dimly-lit room with few distractions. Participants sat comfortably such that they were centrally-aligned with the computer and with their hands resting on the keyboard. Each trial of each of the tasks began with a central fixation cross which was presented for one second. The central search display was then presented until the participant made a response, which they did using an appropriate key-press ('B' for present/the correct way round or 'N' for absent/mirror-image). If a response was not made before the pre-determined trial duration was reached then a blank, black screen was presented for two seconds within which time patients were encouraged to provide a response. After the patient's response feedback regarding trial accuracy ('[illegible]' or 'incorrect') was presented for 500ms.

Patients completed 288 trials per training session (i.e. 32 trials for each of the nine tasks), and overall feedback (accuracy in percent and mean search time in seconds) was given at the end of each task. The next task within the session began when the patient indicated that they were ready to continue. Where it was appropriate the researcher would provide additional verbal feedback, and participants were instructed to perform the tasks both as quickly and accurately as possible. The mean duration of the training was 3.5 weeks (range: 2 to 7 weeks).

4.3.1.2 Exploration training

The patients received 15 sessions of exploration training which was the same as previously described in Chapter 2 (pp. 51-55). The mean duration of the training was 4.0 weeks (range: 2 to 8 weeks).

4.3.2 Results and discussion

4.3.2.1 Attention training

Feature search was selected as the task type used to examine the change in performance across the attention training because it was previously examined in relation to the exploration training. The data was collapsed across the three different feature search tasks (colour, form and size). Computer failures meant that data from some patients was missing for some of the sessions (16.9% of the total values, see Appendix 15 for further details), and these missing values were replaced using the mean for the session. The mean value for each training block was calculated based on the results from each of the five consecutive sessions which the block was comprised of. Wilcoxon signed ranks tests were performed on the mean data and the alpha-level was set at 0.05. The analyses of search time were based on only those trials in which the correct response was given. Effect sizes were calculated using the following formula: $r = z / \sqrt{N}$.

The results described are for the target-present condition (the target-absent results are described in Appendix 16). The mean search time decreased in the second block of training relative to the first and then remained relatively constant across the third training block (see Figure 4.3). The decrease in search time in block 3 relative to the first training block was 289.68ms, which represents a significant improvement across the course of the training of 24.3% (z = -2.97, p = 0.003) as confirmed by the large effect size (r = 0.58).

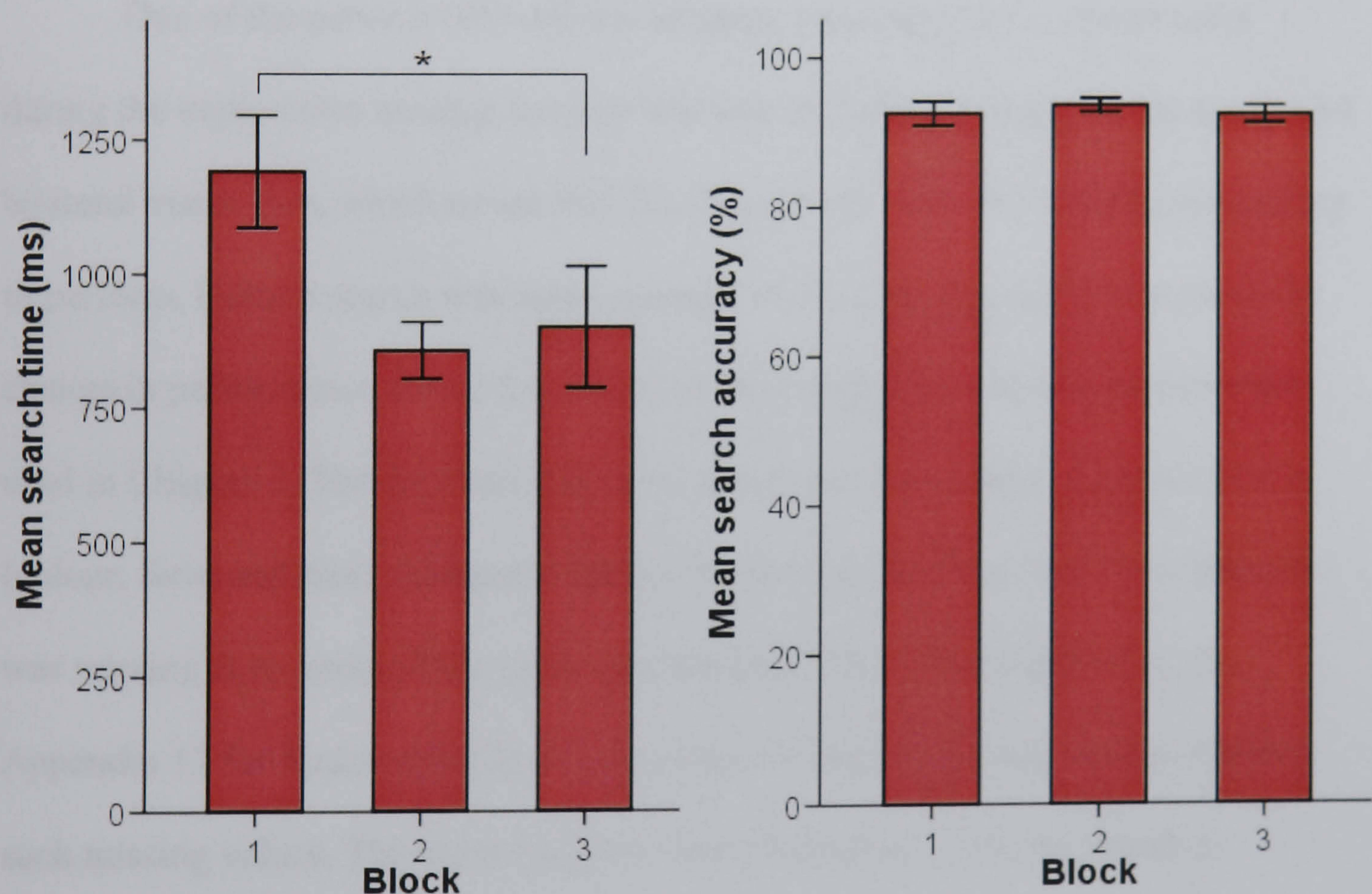

Figure 4.3: Graphs showing the mean search time (in milliseconds) and accuracy (in percent) for each block of the attention training for the target-present condition. The error bars represent the standard error of the mean and '*' represents a significant difference.

Figure 4.3 also shows that the overall increase in accuracy across the training (block 3 versus block 1) was non-significant (z = -0.18, p = 0.861, r =

0.17). Consequently this reveals that the improvement observed for search time across the progression of the training was not the product of a speed-accuracy trade-off effect. The slope of improvement in search time was calculated for each individual and the mean slope for the attention training was -144.84ms/block.

In summary, the results for the attention training reveal that as the training progressed search time decreased, whilst accuracy remained constant. The decrease in search time occurred after the second block of training and then remained unchanged across the third block of the attention training.

4.3.2.2 Exploration training

One of the patients (06) did not complete the conjunction search tasks during the exploration training because she had extremely reduced visual acuity and bilateral visual loss, which meant that she found these tasks too visually demanding to perform. Feature search was again selected as the task type used to examine the change in performance across the course of the exploration training as previously used in Chapter 2. The data was collapsed across the three types of feature search (colour, form and size). Computer failures meant that the data from some patients was missing from some of the training sessions (7.7% of the total values, see Appendix 17 for further details) and the mean for the session was used to replace such missing values. The same analyses were performed as for the attention training.

The results presented are for the target-present condition (see Appendix 18 for the target-absent data analyses). The mean search time gradually decreased across the three training blocks (Figure 4.4), and the search time had decreased by 462.69ms in the third training block as compared to the first one. As such the search time was 27.1% faster at the end of the exploration training relative to the start of training, which was a significant improvement (z = -2.97, p = 0.003, r = 0.58).

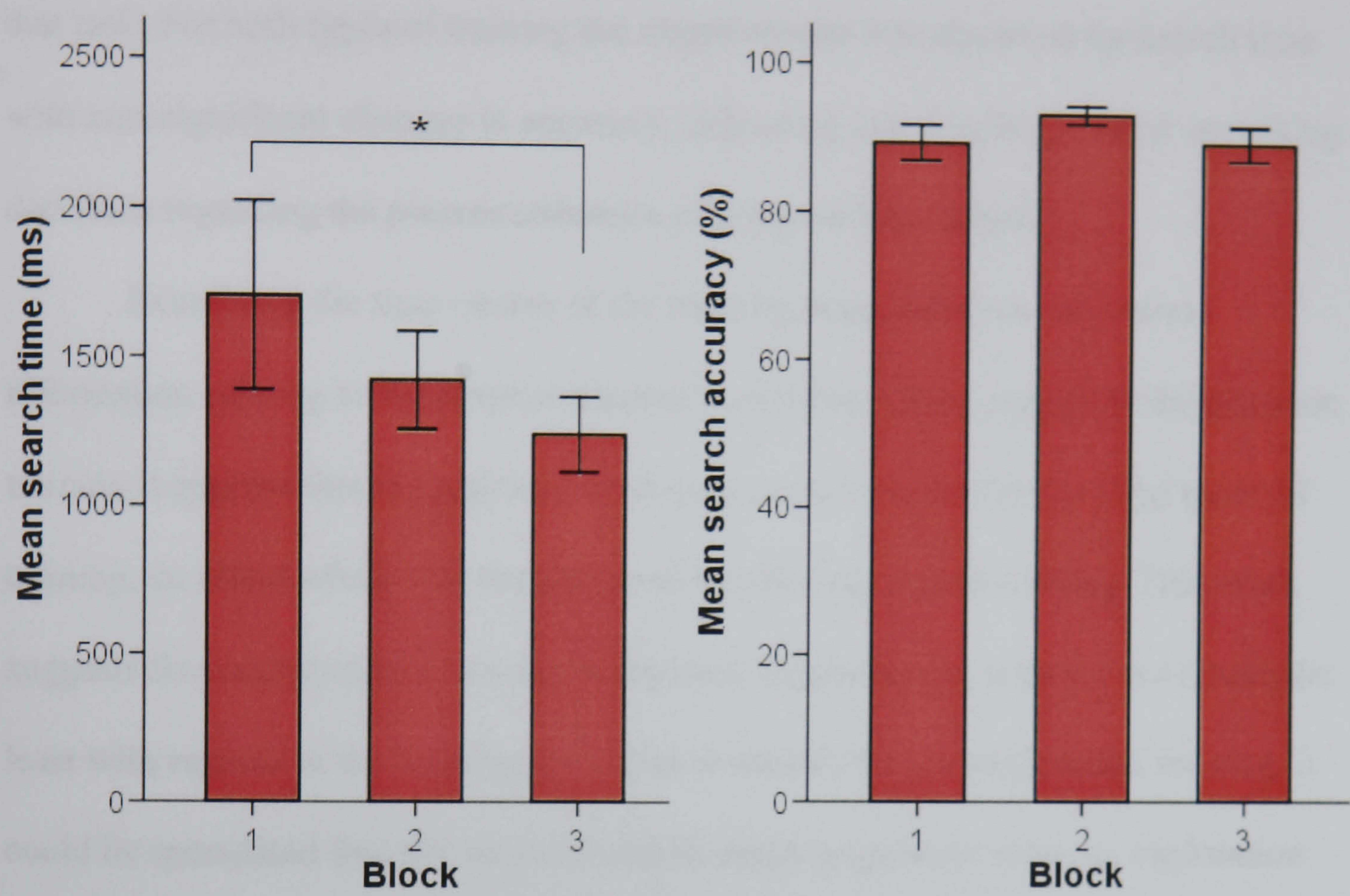

Figure 4.4: Graphs showing the mean search time (in milliseconds) and accuracy (in percent) for each block of the exploration training for the target-present condition. The error bars represent the standard error of the mean and '*' represents a significant difference.

Figure 4.4 also shows that accuracy did not change significantly between blocks 1 and 3 of the training (z = -0.32, p = 0.753, r = 0.06) indicating that the improvement in search time was not the result of a speed-accuracy trade-off effect. The slope of improvement in search time was calculated for each individual and the mean slope for the exploration training was –231.35ms/block. In summary, the results of the exploration training show that as the training progressed search time gradually decreased to a significant extent whilst accuracy remained unchanged.

4.3.2.3 Training overall

The results from both the attention training and the exploration training reveal that repeated practice on a specific task leads to improved performance of that task. For both types of training the improvement was observed for search time with non-significant changes in accuracy, indicating that people get faster at making decisions regarding the presence/absence of a pre-defined target.

Examining the time course of the training improvements may reveal information relating to the optimal training parameters. With regards to the attention training it appears that the patients' performance may plateau by the third block of training, an effect which was not observed for the exploration training. This result suggests that less attention training is required for patients to improve maximally (at least with regards to the training task) than is needed for the exploration training. It could be speculated that the attention task is easier to perform than the exploration equivalent, since the items always appear close to fixation. As a consequence, search is not required and reaction times are subsequently shorter (as can be seen if one compares the block 1 search times for each of the training types). In this case the potential for improvement may be less for the attention training, and this could explain why the plateau in performance appears earlier.

However, just because an improvement found for the training task is present after two blocks of training does not mean that any potential transfer can occur within this time as well. Whilst it is possible that the maximum amount of improvement for the training task may occur within two blocks, in order for the benefits to transfer then the further training may be required. The results of this study do not allow this possibility to be determined. In order to examine the duration of training which is required in order for transfer to additional tasks to be obtained, research is needed in which the transfer tasks are repeatedly tested throughout the course of the intervention. Furthermore, since no plateau appears to occur across the course of the exploration training then it is possible that with an extended duration additional benefits could be obtained, not only for the training but also for the transfer tasks. If this is the case, extending the duration of the exploration training could potentially increase the efficacy of the intervention.

4.4 Assessment tasks: what is the effect of the attention training and the exploration training on the transfer tasks?

4.4.1 Visual search tasks

4.4.1.1 Method

Performance was assessed for three different, non-trained visual search tasks: 'count the dots', 'find the number' and 'count the numbers'. For the details of the methods relating to these tasks see Chapter 2 (pp. 62-65).

4.4.1.2 Results and discussion

Wilcoxon signed ranks tests were performed for the analyses of the dependent data (within-subject comparisons), whilst Mann-Whitney U tests were conducted for the independent data analyses (between-subjects comparisons). The alpha-level was set at 0.025 using a Bonferroni correction for multiple comparisons. The analyses of search time were based on the data only from those trials in which the correct response was provided, and outliers (defined as values in search time which were more than two standard deviations from the mean) were identified and removed from the individual patient data sets. Effect sizes were calculated in the same manner as for the training tasks. The same analyses were performed for each of the assessment tasks, not only the visual search tasks.

'Count the dots' visual search task

Within-subjects comparisons:

For the 'count the dots' visual search task the accuracy gradually increased across the three assessment sessions whilst search time remained relatively stable (see Figure 4.5). The increase in accuracy after the attention training was non-significant (z = -1.02, p = 0.307, r = 0.20), but the additional increase in accuracy of 14.7% after the exploration training was significant (z = -2.55, p = 0.011, r = 0.50). Since search time did not change significantly after the attention training (z = -0.31, p = 0.753, r = 0.06) or after the exploration training (z = -1.15, p = 0.249, r = 0.23) it can be determined that the improvement in accuracy was not the result of a significant speed-accuracy trade-off effect.

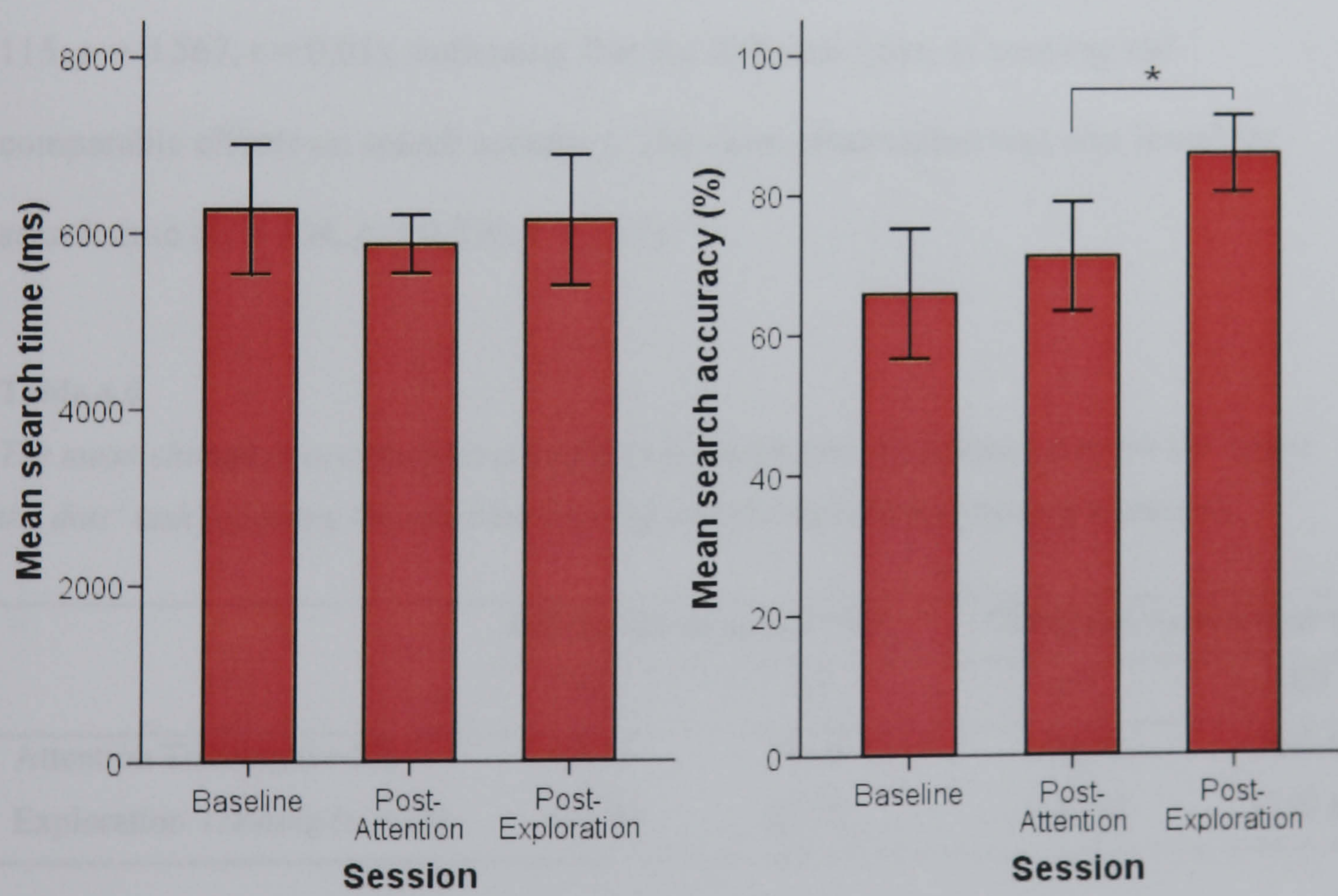

Figure 4.5: Graphs showing the mean search time (in milliseconds) and accuracy (in percent) for the 'count the dots' task for the baseline, post-attention and post-exploration training sessions. The error bars represent the standard error of the mean and '*' represents a significant difference.

Between-subjects comparisons:

The between-subjects analyses compare the effect of the attention training to the effect of the exploration training as previously obtained in chapter 2. Table 4.6 contains details of the effects of each type of training on both accuracy and search time. Previously exploration training was found to have a significant effect on both variables for this task (Chapter 2, pp. 66-67), whilst the attention training produced non-significant effects on both of these variables (see above). The results for the exploration training only sample are based on the data from 20 patients since one patient's results were missing as a consequence of a computer failure.

As can be seen from the results in Table 4.6 the improvement in accuracy after the exploration training was more than double that found after the attention training. However, the difference between the two effects was non-significant (U = 115, p = 0.567, r = 0.01), indicating that the different types of training had comparable effects on search accuracy. The same observation was also found for search time (U = 104, p = 0.338, r = 0.17).

Table 4.6

The mean change in accuracy (in percent) and search time (in milliseconds) for the 'count the dots' task following the attention training and the exploration training separately.

	Change in accuracy (%)		Change in search time (ms)	
	M	*SD*	*M*	*SD*
Attention Training (n=13)	+5.38	15.46	-398.94	1849.64
Exploration Training (n = 20)	+12.95	22.53	-396.62	1179.83

In summary, with regards to the 'count the dots' task the results show that both accuracy and search time did not change significantly after the attention training. However, after the additional exploration training the search accuracy increased significantly. Whilst this implies that the exploration training was more beneficial than the attention training, the results of the between-subjects comparisons did not confirm this, instead showing that the benefits of both type of training were not significantly different.

'Find the number' visual search task

Within-subjects comparisons:

As can be seen from Figure 4.6 the mean search time increased slightly after the attention training although not to a significant extent (z = -0.66, p = 0.507, r = 0.13). After the exploration training, the search time decreased by 205.69ms (7.2%). This improvement was nearing significance (z = -2.20, p = 0.028, r = 0.43), indicating a specific benefit of the exploration training for this task.

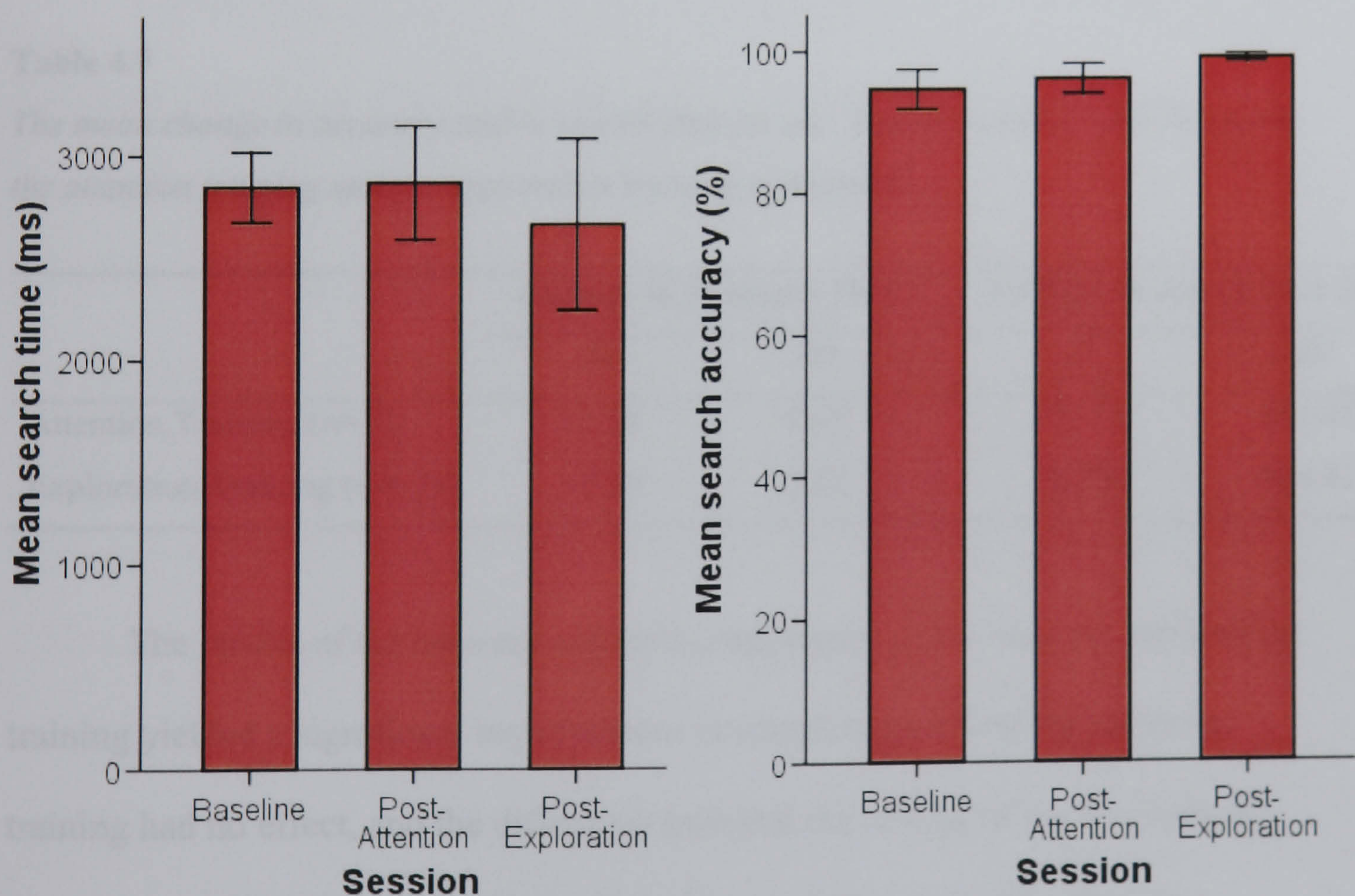

Figure 4.6: Graphs showing the mean search time (in milliseconds) and accuracy (in percent) for the 'find the number' task for the baseline, post-attention and post-exploration training sessions. The error bars represent the standard error of the mean.

As can also be seen from Figure 4.6 there was a gradual increase in accuracy across the three assessment sessions. The slight increase in accuracy after the attention training was not significant ($z = -0.41$, $p = 0.680$, $r = 0.08$), and the further increase of 3.1% post-exploration training was not significant either ($z = -2.02$, $p = 0.043$, $r = 0.40$), although did show a non-significant trend towards improvement.

Between-subjects comparisons:

Table 4.7 contains details of the effects of each type of training separately on both accuracy and search time. Previously it was shown that the exploration training had a significant effect on search time but not on accuracy for the 'find the number' task (Chapter 2, pp. 68-69), whilst the attention training did not significantly affect either variable (as described above).

Table 4.7

The mean change in accuracy and in search time for the 'find the number' task following the attention training and the exploration training separately.

	Change in accuracy (%)		**Change in search time (ms)**	
	M	*SD*	*M*	*SD*
Attention Training (n=13)	+1.54	8.01	+23.30	814.48
Exploration Training (n = 21)	+1.19	3.82	-727.97	624.81

The results of the between-subjects comparisons show that the exploration training yielded a significant improvement in search time whilst the attention training had no effect, and the difference between the effects of the two training types on search time was significant ($U = 55$, $p = 0.004$, $r = 0.50$). Thus the exploration training produced a significantly greater improvement in search time for the 'find the numbers' visual search task than the attention training, indicating a specific benefit of the exploration training for the performance of this task. However, the results also show that the benefit of each of the training types on search accuracy was less than 1.6%, and was comparable across the two treatment conditions (U = 130, p = 0.803, r = 0.04).

In summary, with regards to the 'find the number' visual search task the exploration training significantly improved search time, whereas the attention training produced no improvement in search time, suggesting exploration training-specific improvements for this task. The accuracy remained unchanged following either training type.

'Count the numbers' visual search task

Within-subjects comparisons:

For this task the mean number of trials per session was 7.8 (range: 5 to 10). The mean search accuracy steadily increased across the three assessment sessions (see Figure 4.7). The increase post-attention training was non-significant (*z* = -1.48, p = 0.139, r = 0.29), whilst the increase after the exploration training of 3.1% was nearing significance (z = -2.21, p = 0.027, r = 0.43). The slight increase in the mean search time after the attention training was not significant (z = -0.45, p = 0.650, r = 0.09) as was the small decrease in search time after the exploration training (z = -1.22, p = 0.221, r = 0.24).

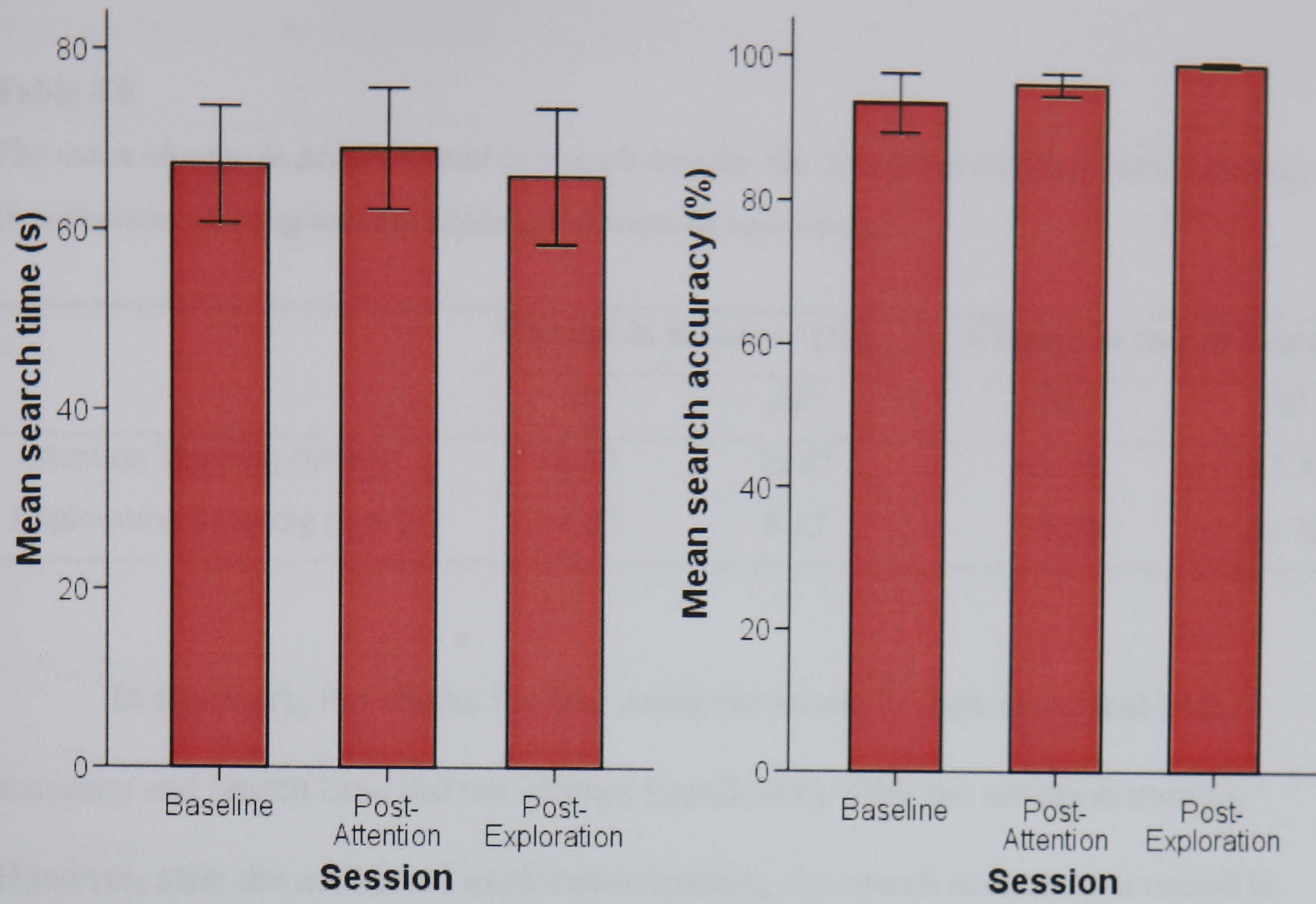

Figure 4.7: Graphs showing the mean search time (in seconds) and accuracy (in percent) for the 'count the numbers' task for the baseline, post-attention and post-exploration training sessions. The error bars represent the standard error of the mean.

Between-subjects comparisons:

A significant increase in accuracy was found after the exploration training in Chapter 2, and a non-significant decrease in search time was observed (pp. 70). The attention training did not significantly affect either variable. Although the results in Table 4.8 reveal that the increase in accuracy after the exploration training was larger than that obtained after the attention training, the difference in the effects of the two training types was not significant ($U = 123$, $p = 0.617$, r = 0.09). After the exploration training the mean search time decreased, whilst after the attention training it increased. Despite this fact, the difference between the effects of the two types of training was also not significant ($U = 108$, $p = 0.312$, r = 0.17).

Table 4.8

The mean change in accuracy and in search time for the 'count the numbers' task following the attention training and the exploration training separately.

	Change in accuracy (%)		Change in search time (ms)	
	M	*SD*	*M*	*SD*
Attention Training (n=13)	+2.75	10.55	+1.79	12.70
Exploration Training (n = 21)	+4.57	8.15	-10.76	24.70

In summary, the results for the 'count the numbers' task show that both accuracy and search time did not change significantly after the attention training. However, after the additional exploration training the search accuracy increased to an almost significant extent.Whilst this indicates that the exploration training was more beneficial than the attention training, the results of the between-subjects comparisons did not confirm this, instead showing that the two types of training produced comparable effects on both search time and accuracy.

Visual search overall:

The 'find the number' task was the only one of the visual search tasks to conclusively show a specific effect of the exploration training compared to the attention training. This task was also the one which showed the largest post-exploration training improvement in search time, suggesting the greatest transferability of the training benefit to this task. The 'find the number' task shares the most similarity with the tasks used in the exploration training, since in both the participant is required to search the display and identify a target from some distractors. As such, participants can dismiss some search items and focus on the one item of interest (selective attention). Since the 'find the number' task is the most comparable to the training, it is perhaps not surprising to see a large amount of transferability and training specificity. The results indicate that practiced exploration skills are transferable to this task, and that performance does not improve to a comparable extent as a result of placebo effects.

The other two visual search tasks ('count the dots' and 'count the numbers') showed less consistent results. Neither task improved significantly following the attention training. However, they did improve (at least to an almost significant amount) after both the exploration training which followed the attention training, and the exploration training performed independently (Chapter 2). This implies that the exploration training was producing a specific effect for these tasks also, although the between-subjects comparisons revealed the effects of the two training types to be not significantly different. In other words, even though the exploration training improved performance for these tasks this was not sufficient to make it different to the non-significant improvement observed after the attention training. This finding questions the validity and the reliability of the post-exploration training benefits. The 'count the dots' and 'count the numbers' tasks improved to a lesser extent than the 'find the numbers' task with regards to search time. They are also less similar in nature to the training tasks since they require the inclusion of all items in the display and would therefore, presumably, require different searching strategies. Overall, these results suggest that perhaps even small deviations from the training task may be sufficient to reduce the training effect, and that task-specific training might be needed for maximal gains on particular tasks.

Given that, on face value at least, it appears that the exploration training may have had an effect on the 'count the dots' and 'count the numbers' tasks when the attention training did not, perhaps the current lack of significance between the two training types is the consequence of a lack of statistical power. However, bearing in mind the small effect sizes relating to the between-subjects comparisons for these two tasks (< 0.2) reduced statistical power may not underlie the effect. Further research using a larger sample in order to increase statistical power would be beneficial in order to establish the pattern of effects with regards to the visual search tasks.

4.4.2 'Projected search'

4.4.2.1 Method

This assessment task was the same as conducted in the study reported in Chapter 2 and the details of the method relating to the 'projected search' task can be found in that chapter (see pp. 73-75).

4.4.2.2 Results and discussion

Within-subjects comparisons:

The results described are for the target-present condition (see Appendix 19 for the target-absent results). The search time gradually decreased across the assessment sessions (see Figure 4.8). The search time decreased by 1788.21ms after the attention training, a significant improvement of 32.6% ($z = -2.27$, $p = 0.023$, $r = 0.45$). However, the additional improvement of 1087.79ms (29.4%) after the exploration training was not significant ($z = -0.59$, $p = 0.552$, $r = 0.12$). These results imply that the attention training may actually be more beneficial than the exploration training with regards to the 'projected search' task, although order effects may partially explain this pattern of results.

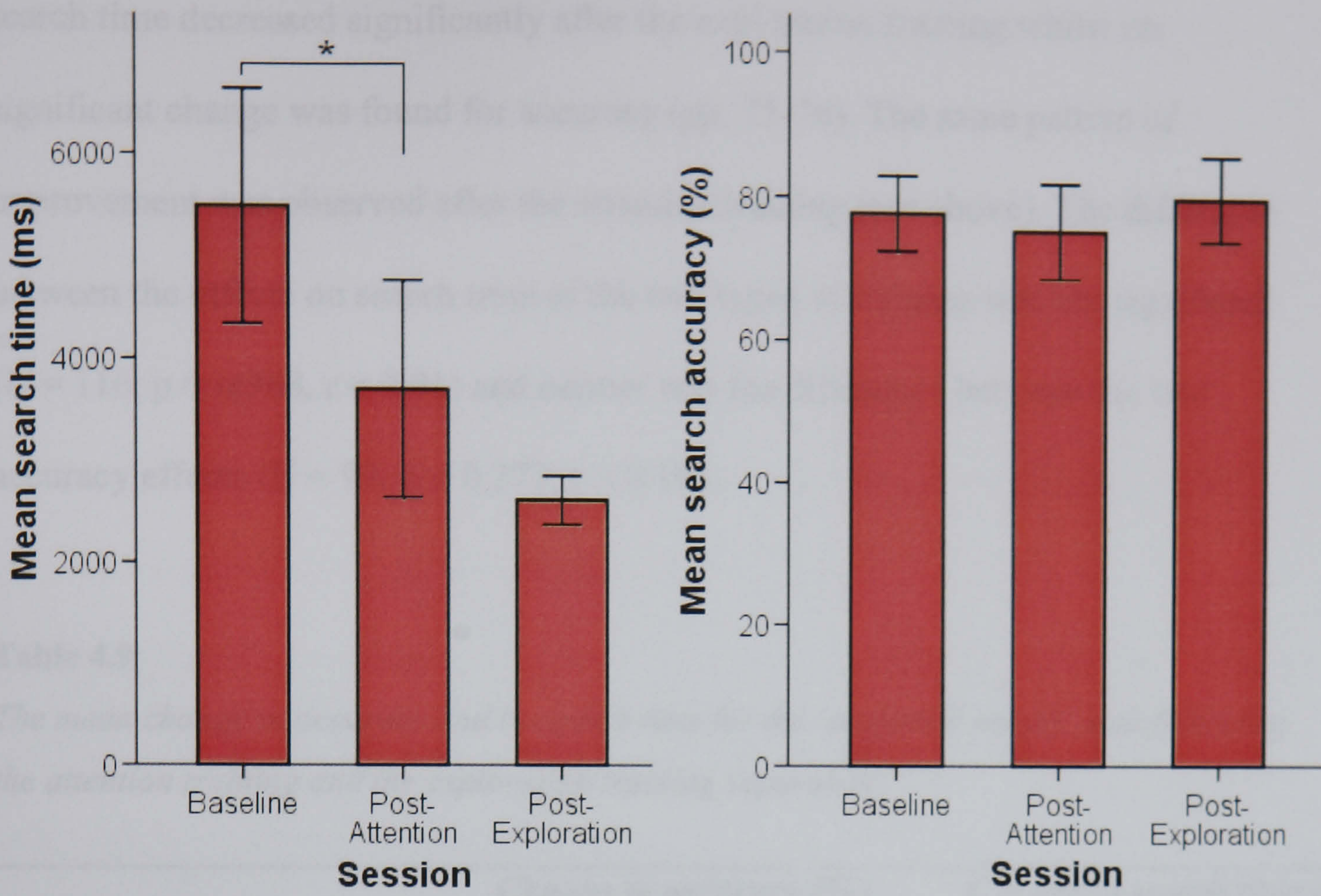

Figure 4.8: Graphs showing the mean search time (in milliseconds) and accuracy (in percent) for the 'projected search' task for the baseline, post-attention and post-exploration training sessions. The error bars represent the standard error of the mean and '*' represents a significant difference.

Figure 4.8 also shows that the accuracy remained relatively constant across the three assessment sessions. The slight decrease after the attention training was not significant ($z = -0.67$, $p = 0.500$, $r = 0.13$), nor was the increase after the exploration training ($z = -0.36$, $p = 0.720$, $r = 0.07$). Consequently the improvement in search time cannot be attributed to a speed-accuracy trade-off effect.

Between-subjects comparisons:

Table 4.9 contains details of the effects of each training type separately on both accuracy and search time. The results for the exploration training only sample are based on the data from 18 patients since three patients' results were missing as a consequence of a computer failure. The results in Chapter 2 showed that the mean search time decreased significantly after the exploration training whilst no significant change was found for accuracy (pp. 75-76). The same pattern of improvement was observed after the attention training (see above). The difference between the effects on search time of the two types of training was not significant ($U = 116$, $p = 0.968$, $r = 0.01$) and neither was the difference between the two accuracy effects ($U = 90$, $p = 0.277$, $r = 0.19$).

Table 4.9

The mean change in accuracy and in search time for the 'projected search' task following the attention training and the exploration training separately.

	Change in accuracy (%)		Change in search time (ms)	
	M	*SD*	*M*	*SD*
Attention Training (n=13)	-2.38	13.12	-1788.22	4084.10
Exploration Training (n = 18)	+3.67	28.34	-2442.29	3372.79

In summary, the results for the 'projected search' task show that the mean search time was significantly reduced after the attention training, although the additional improvement found after the exploration training was not significant. The mean accuracy remained unchanged after both types of training. The results of the between-subjects analyses revealed comparable improvements following both training types, indicating non-specific training benefits. Therefore, for visual search which extends across a larger display size than is involved in the training it appears that the benefits of the exploration training are not greater than can be achieved with a placebo.

Since an improvement was found at each assessment session it could be the case that the benefits were the result of repeated testing effects. Whilst this possibility cannot be entirely dismissed in this study, it seems perhaps improbable based on previous studies in which visual search improvements have been limited to training periods (Kerkhoff et al., 1994; Pambakian et al., 2004). Furthermore, since no additional improvement was observed at the follow-up assessment session as reported in Chapter 3 (see pp. 122) this further suggests that it is unlikely that the results reflect repeated testing effects.

For this task an additional improvement was found after the exploration training which followed the attention training, indicating that the patients' performance had not reached a plateau. Consequently this suggests that the attention training is not sufficient to entirely overcome search deficiencies apparent in this task. However, the results do not allow one to determine if any additional improvement is possible in the absence of any extra training, and if training is required it is not known which type of training is the more beneficial. It could be the case that the attention training is equally effective as exploration training at improving performance of visual search across a large display but only if the patients have demonstrated no improvement so far. Alternatively, it may be that the exploration training is necessary to yield the additional benefit beyond the placebo effects. A study in which both attention and exploration training are provided but the order is randomised could help to distinguish between these possibilities.

4.4.3 'Visuomotor search'

4.4.3.1 Method

The 'visuomotor search' task was previously conducted in the study reported in Chapter 2 and the details relating to the method of this task can be found in that chapter (pp. 78-79).

4.4.3.2 Results and discussion

Within-subjects comparisons:

The search time for the 'visuomotor search' task gradually decreased across the three assessment sessions (see Figure 4.9).

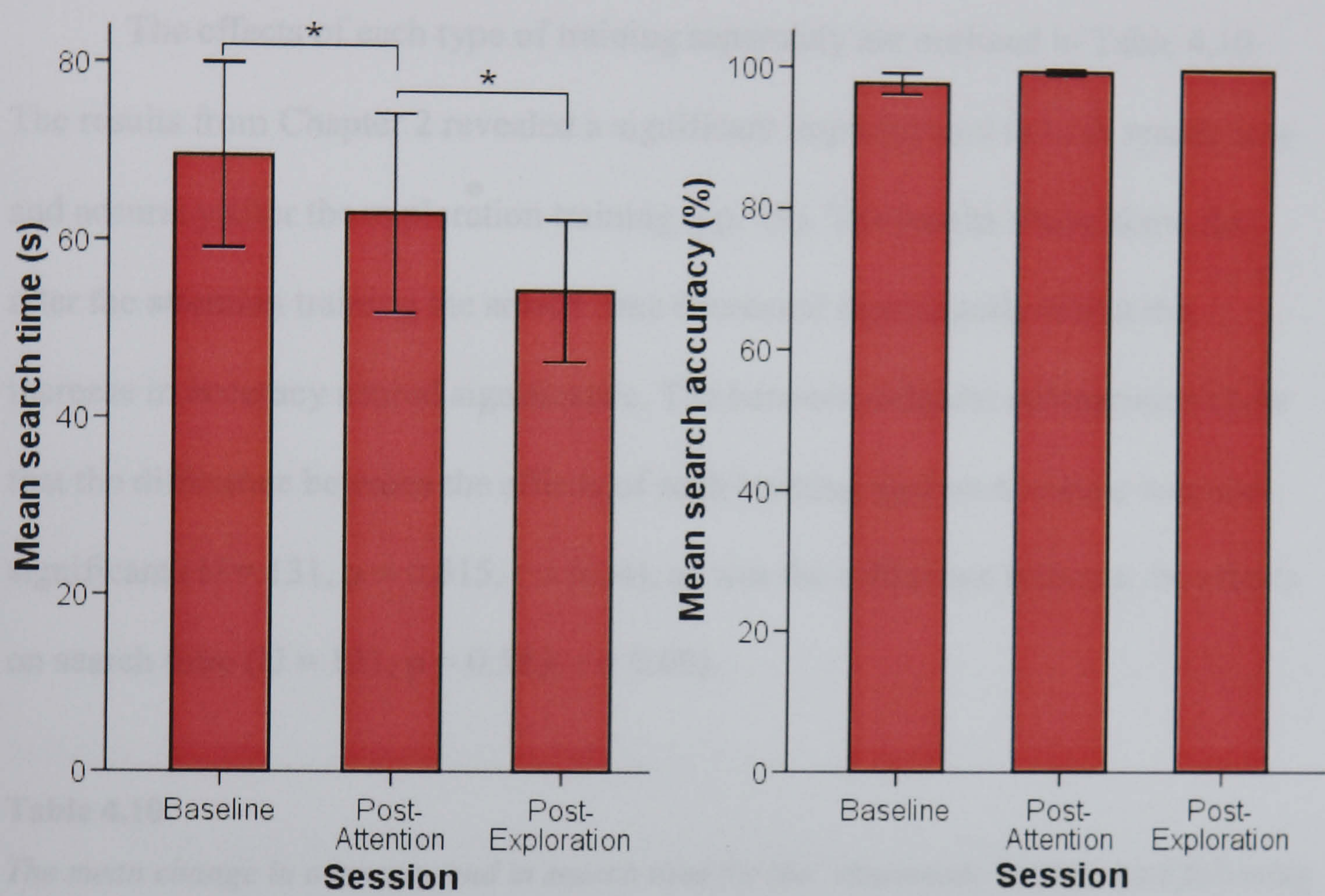

Figure 4.9: Graphs showing the mean search time (in seconds) and accuracy (in percent) for the 'visuomotor search' task for the baseline, post-attention and post-exploration training sessions. The error bars represent the standard error of the mean and '*' represents a significant difference.

Search time decreased by 6.45 seconds (9.3%) after the attention training and this improvement was significant ($z = -2.34$, $p = 0.019$, $r = 0.46$). The mean search time further decreased by 8.63 seconds (13.7%) after the exploration training which followed, and again this was significant ($z = -3.18$, $p = 0.001$, $r = 0.62$). The graph also shows that accuracy increased by 1.8% after the attention training, which was not significant ($z = -2.02$, $p = 0.043$, $r = 0.40$), although there was a non-significant trend towards improvement. The additional increase after the exploration training was also not significant (z = -1.00, p = 0.317, r = 0.20), but given that the post-attention training accuracy level was 99.6% this is not surprising.

Between-subjects comparisons:

The effects of each type of training separately are outlined in Table 4.10. The results from Chapter 2 revealed a significant improvement in both search time and accuracy after the exploration training (pp. 79). The results above show that after the attention training the search time decreased significantly whilst the increase in accuracy neared significance. The between-subjects comparisons show that the difference between the effects of each training type on accuracy was non-significant (U = 131, p = 0.815, r = 0.04), as was the difference between the effects on search time (U = 121, p = 0.583, r = 0.09).

Table 4.10

The mean change in accuracy and in search time for the 'visuomotor search' task following the attention training and the exploration training separately.

	Change in accuracy (%)		Change in search time (ms)	
	M	*SD*	*M*	*SD*
Attention Training (n=13)	+1.84	4.12	-6.45	7.69
Exploration Training (n = 21)	+1.33	2.71	-10.31	13.72

In summary, the results for the 'visuomotor search' task show that the search time improved after the attention training, and that further improvements were observed after the additional exploration training. The increase in search accuracy after the attention training was nearing significance whilst the post-exploration training change was not significant. It is likely that this is the result of a ceiling effect. The results of the between-subjects analyses revealed comparable improvements following both training types, indicating non-specific training benefits for this task. Therefore, it appears that the benefits of the exploration training are not greater than can be achieved with an attention-based placebo when visual search requires a different behavioural response to that used in training.

As with the 'projected search' task the influence of repeated testing effects cannot be entirely dismissed. However, it is perhaps unlikely that this could explain the results found, since previous studies using repeated baseline measures have observed improvements in visual search which are limited to training periods (Kerkhoff et al., 1994; Pambakian et al., 2004). Furthermore, the pattern of improvement with regards to achieving a plateau in performance cannot be determined for this task at present either, and further research in which both attention and exploration training are provided but the order is randomised would be useful in determining the contribution of each type of training.

With regards to the 'visuomotor search' task the additional component of general motor function should be considered. It is possible that the training led to increases in motor responses and manual dexterity which translated to improvements in this task, which may have been falsely attributed to searching gains. Pambakian et al. (2004) controlled for manual reaction time in their ADL visual search tasks (i.e. sequential bead location and threading), showing that improvements in visuomotor search behaviours were not the consequence of generic motor improvements. This suggests that perhaps such factors would be unlikely to account for the results obtained here, although future work should aim to confirm the absence of motor effects from such improvements in performance.

4.4.4 Reading

4.4.4.1 Method

The reading ability of the patients was assessed with regards to both text and numbers. For the details of the reading assessment tasks see Chapter 2 (pp. 82-83).

4.4.4.2 Results and discussion

Within-subjects comparisons:

The reading of text and of numbers was analysed separately and the results of the text reading are shown in Figure 4.10. The reading speed did gradually increase over the sessions. However the increase after the attention training was non-significant ($z = -0.87$, $p = 0.382$, $r = 0.17$) as was the increase after the exploration training ($z = -0.94$, $p = 0.345$, $r = 0.18$).

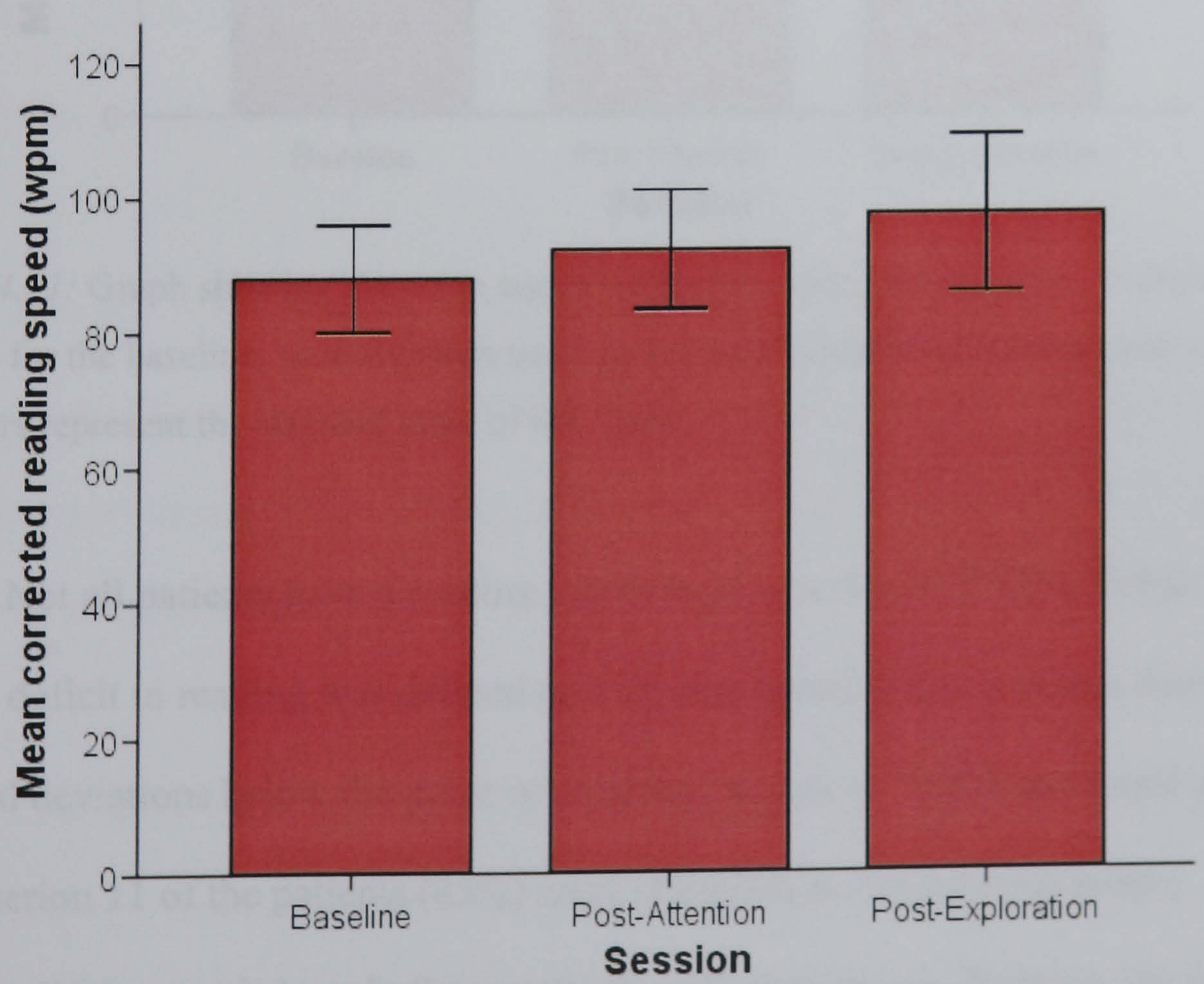

Figure 4.10: Graph showing the mean corrected reading speed for text (in words per minute) for the baseline, post-attention training and post-exploration training sessions. The error bars represent the standard error of the mean.

The mean corrected reading speed for numbers also gradually increased across the assessment sessions (see Figure 4.11). However, the difference in reading speed after the attention training was not significant (z = -1.50, p = 0.133, r = 0.29) and nor was the increase after the exploration training (z = -1.50, p = 0.133, r = 0.29).

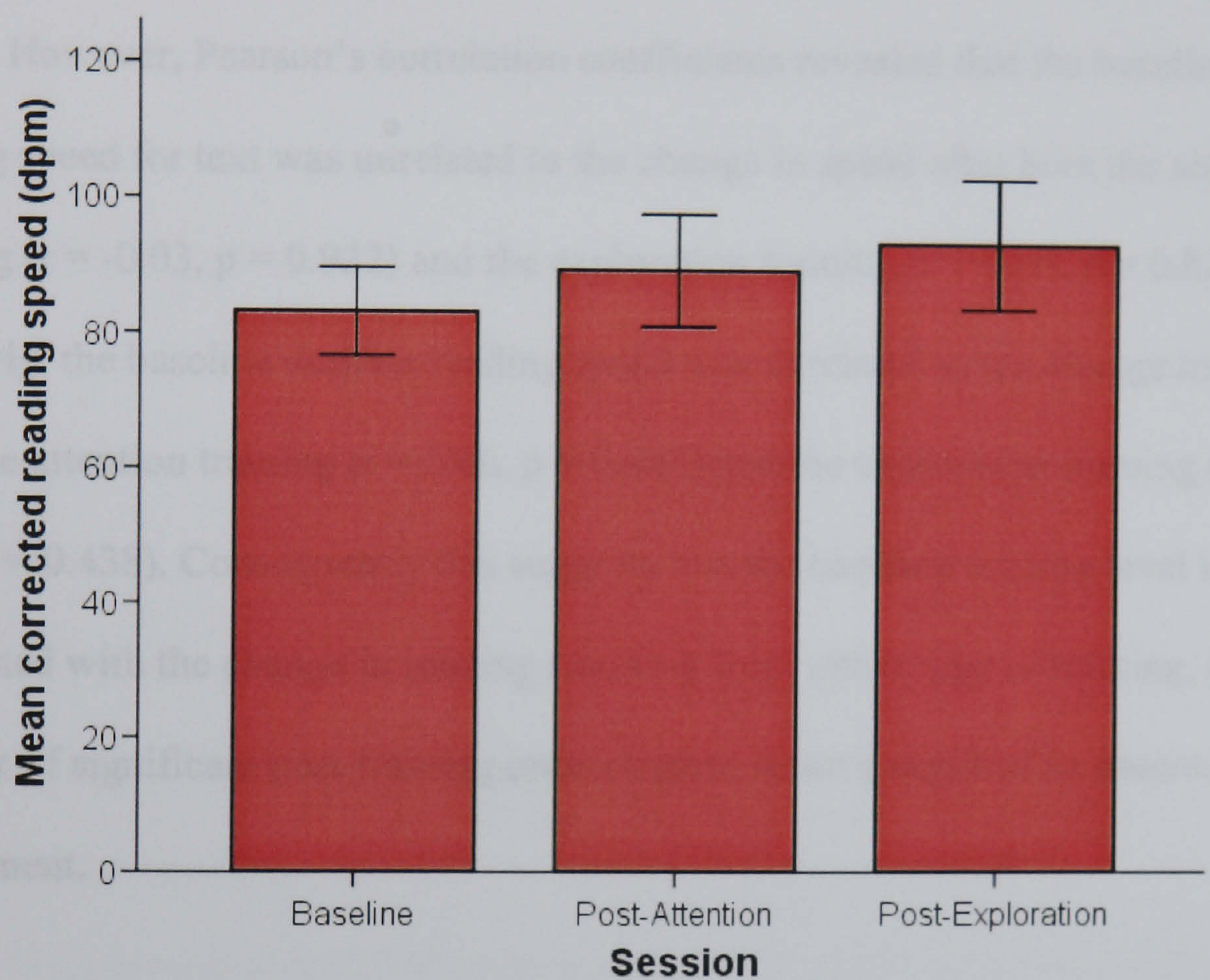

Figure 4.11: Graph showing the mean corrected reading speed for numbers (in digits per minute) for the baseline, post-attention training and post-exploration training sessions. The error bars represent the standard error of the mean.

Not all patients have a reading impairment as a result of their HVFD. In this study a deficit in reading was defined as a reading speed which was less than two standard deviations below the mean of a control sample (< 114.8wpm), and using this criterion 11 of the patients (85%) were classified as having hemianopic dyslexia. With regards to only those patients with hemianopic dyslexia, the mean reading speed for text did not change significantly after the attention training (*z* = -

0.27, $p = 0.790$, $r = 0.08$) or the exploration training ($z = -1.42$, $p = 0.155$, $r = 0.43$). Similarly, the mean reading speed for numbers did not change significantly after the attention training ($z = -1.16$, $p = 0.248$, $r = 0.35$) or the exploration training ($z = -1.78$, $p = 0.075$, $r = 0.54$). However, given the large effect size for the post-exploration training improvement in number reading speed, this effect may possibly be the result of reduced statistical power.

However, Pearson's correlation coefficients revealed that the baseline reading speed for text was unrelated to the change in speed after both the attention training ($r = -0.03$, $p = 0.922$) and the exploration training ($r = 0.07$, $p = 0.820$). Similarly, the baseline number reading speed was unrelated to the change in speed after the attention training ($r = 0.06$, $p = 0.847$) and the exploration training ($r = 0.24$, $p = 0.438$). Consequently this suggests that the baseline reading level is not associated with the change in reading resulting from either type of training, and that the lack of significant post-training improvement is not a result of an absence of impairment.

Between-subjects comparisons:

Given that neither the attention training nor the exploration training were found to significantly affect reading performance the relative benefit of each type has not been compared.

In summary, the results in Chapter 2 revealed that the exploration training did not improve reading performance for either text or numbers. The data reported in this chapter confirmed this observation and also revealed that the attention training did not affect reading ability. Furthermore, whilst not every patient has a reading problem as a consequence of their HVFD it appears that the level of reading impairment does not predict whether or not a patient will benefit from training.

Overall, the results suggest that the same processes required to improve visual exploration do not translate to reading, and the results also indicate that general increases in visual attention cannot transfer to improvements in this task either. Consequently, an enhancement of attention is not sufficient to overcome all behavioural difficulties which can result from an HVFD. Given that neither attention training nor exploration training improve reading it seems reasonable to conclude that a reading-specific training is necessary to successfully help patients compensate for hemianopic dyslexia. Such a reading training has been developed and found to be more beneficial than a search-based placebo therapy (Spitzyna et al., 2007).

4.4.5 Activities of daily living questionnaires

4.4.5.1 Method

Questionnaires designed to assess subjective quality of life and ADLs were completed at each assessment session. The questionnaires included the FIM+FAM, EQ-5D and the visual impairments questionnaire. For the details of the methods relating to these tests see Chapter 2 (pp. 88-89).

4.4.5.2 Results and discussion

Visual ability

Figure 4.12 shows the mean rating of subjective impairment for the ten behaviours assessed using the visual impairments questionnaire. A larger score indicates more impairment than a smaller score. No significant effects were observed for any of the behaviours assessed (p > 0.083; see Appendix 20). A non-significant trend was found for use of public transport, which declined after the attention training (z = -2.00, p = 0.046, r = 0.58).

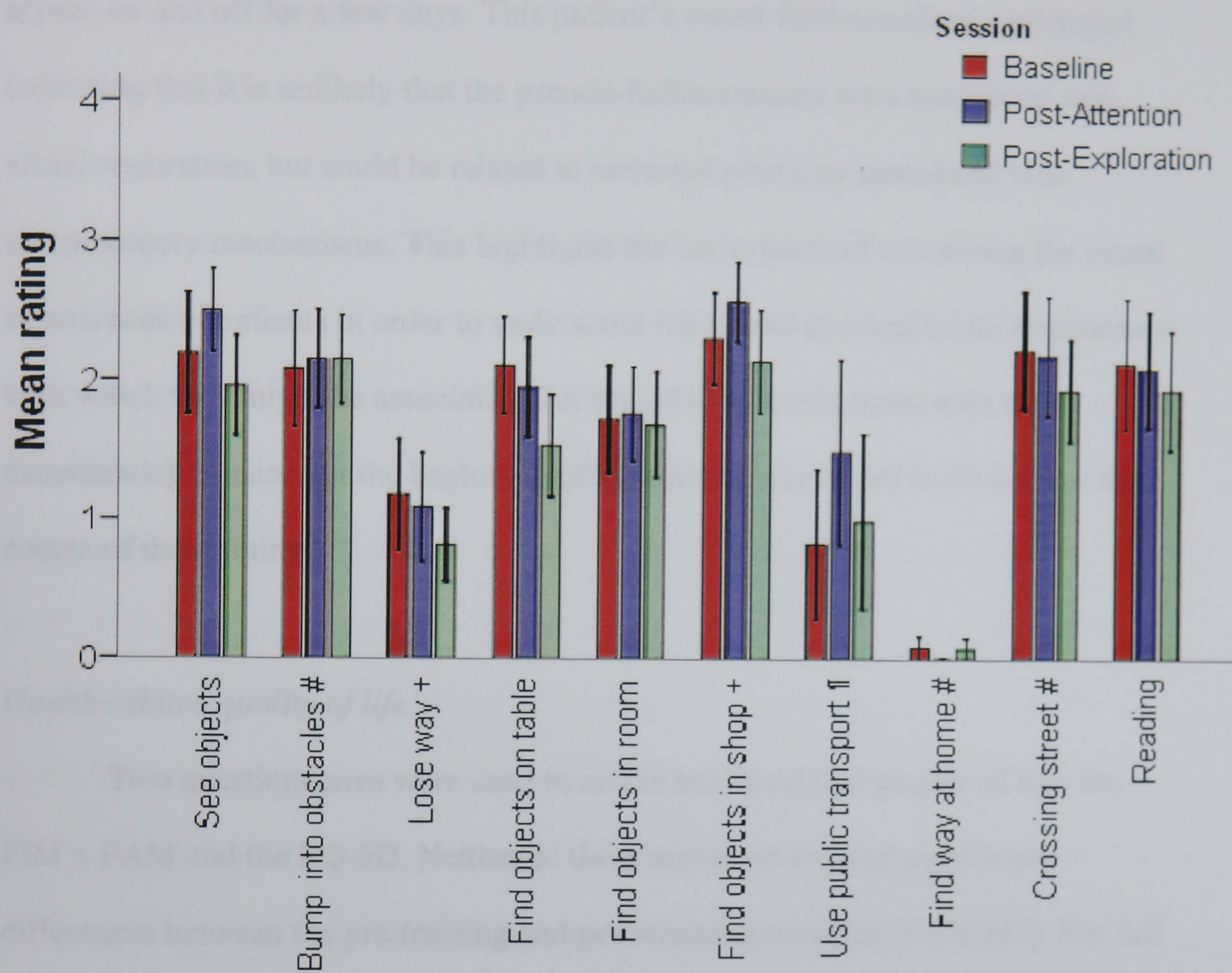

Figure 4.12: The mean ratings of subjective impairment for each item of the visual impairments questionnaire before training, after attention training and after exploration training. The error bars represent the standard error of the mean. Data are missing for some items: # based on 12 patients, + based on 11 patients, ¶ based on 6 patients.

In addition to this questionnaire patients were asked if they had noticed any change in their ability to see. Seven of the patients (54%) reported an improvement in their ability to see after the attention training, whilst eight patients (62%) reported an improvement after the exploration training which followed.

Furthermore, one patient (14) reported the onset of basic visual illusions ('bright twinkling lights') in the blind hemifield during the training which he had not experienced previously. These were noted specifically during the course of the exploration training, and persisted for only a few minutes at a time, although did appear on and off for a few days. This patient's visual field remained unchanged indicating that it is unlikely that the pseudo-hallucinations were associated with visual restoration, but could be related to neuronal plasticity associated with compensatory mechanisms. This highlights the importance of examining the visual experiences of patients in order to understand the neural and functional mechanisms with which they might be associated. For the other patients, those who were experiencing illusions at the beginning of the training continued to do so over the course of the training.

Health-related quality of life

Two questionnaires were used to assess health-related quality of life: the FIM + FAM and the EQ-5D. Neither of these measures showed significant differences between the pre-training and post-training sessions ($p \geq 0.317$). For full details of the results of these questionnaires see Appendix 21. The EQ-5D also involved a rating of overall health state by the patients. At the baseline session the mean overall health score was 57.2% (SD = 28.1) which increased to 58.2% (SD = 28.6) after the attention training, and then to 68.5% (SD = 24.2) after the exploration training. However, the change after the attention training was not significant ($z = -0.70$, $p = 0.481$, $r = 0.14$) and neither was the change after the exploration training ($z = -1.71$, $p = 0.088$, $r = 0.34$). No significant improvements were found for any of the questionnaire items after either training type and subsequently between-subjects comparisons have not been conducted.

Subjective reports overall

Overall the subjective ADLs questionnaire data showed relatively few changes as a result of both the attention training and the exploration training, and this further highlights the need to select such measures with great consideration. Many quality of life measures which assess ADLs are too general to detect any training or placebo related changes due to ceiling effects. Furthermore, the scale used to report difficulty needs to be extensive enough to provide adequate scope for improvement to be detected.

The visual impairments questionnaire was the most suitable questionnaire used for assessing subjective ADLs. In this study none of the items improved significantly, which is similar to the findings reported in Chapter 2, although contradictory to previous studies. Previously researchers have reported significant post-training improvements for all items assessed (Kerkhoff et al., 1994; Nelles et al., 2001), although Pambakian et al. (2004) found improvements for only three items. An almost significant decline in the ability to use public transport was found in this study after the attention training. Whilst this could reflect a true decrease in patient ability for this task it could also be the result of patients becoming more aware of their behavioural problems. This is one problem associated with subjective report; simply being involved with research forces patients to think about their vision and their impairments. Increased awareness of certain problems may bias personal subjective responses and could also possibly influence patient behaviour.

Overall, patients did generally report an improvement in their ability to see, although this occurred after both the attention training and the exploration training. This indicates that the perceived visual abilities of patients can be modified regardless of the intervention provided, indicating that placebo effects may underlie the psychological benefits of the training. Details of the nature of the improvement were not collected and as such it is not possible to determine what people meant by 'ability to see', and whether or not the two types of training produced different effects.

4.4.6 Perimetry

4.4.6.1 Method

In Chapter 2 it was concluded that the changes in the visual field that occurred after the exploration training could possibly be explained as a consequence of enhanced attention. If visual field changes are driven by attention, it is plausible that the attention training could increase the visual field. To test this possibility visual field size, as assessed using perimetry, was compared before and after both the attention training and the exploration training. For the details of the perimetric method see Chapter 2 (pp. 95-97).

4.4.6.2 Results and discussion

Within-subjects comparisons:

Figure 4.13 illustrates the mean amount of visual field sparing at each assessment session. There was no significant increase in the amount of visual field sparing after attention training ($z = -0.45$, $p = 0.655$, $r = 0.09$), or after exploration training ($z = -1.84$, $p = 0.066$, $r = 0.36$).

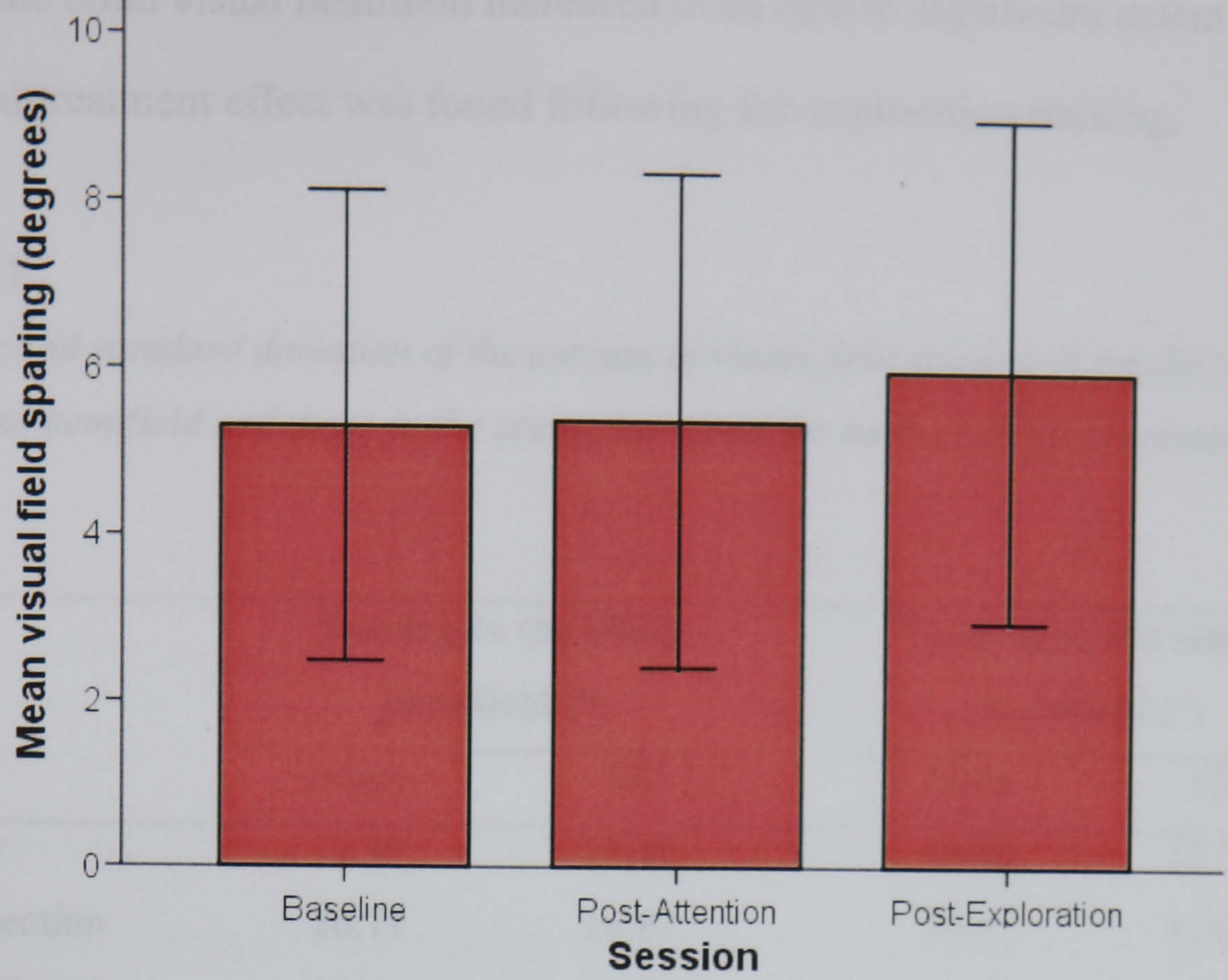

Figure 4.13: Graph showing the mean amount of visual field sparing along the most impaired meridian (in degrees) for the baseline, post-attention training and post-exploration training sessions. The error bars represent the standard error of the mean.

The effect of the training on the mean amount of sparing along all of the meridians in each hemifield was examined to see if changes occurred in locations other than the most impaired meridian. Data from patient 06 was removed from this analysis because she had bilateral defects and therefore both hemifields were defined as blind. After the attention training the visual field increased by 2.74º in the blind field and by 1.82º in the seeing field (see Table 4.11). There was a non-significant trend towards a field increase after the attention training for the blind hemifield (z = -2.14, p = 0.033, r = 0.46), as based on a corrected alpha-level of p = 0.025 (as described above). A lesser effect was found for the seeing hemifield (z = -1.69, p = 0.092, r = 0.34). The additional increase after the exploration training was non-significant both for the blind hemifield (z = -0.78, p = 0.433, r = 0.17) and the seeing hemifield (z = -0.31, p = 0.754, r = 0.07). Therefore, whilst after the attention training the blind visual hemifield increased to an almost significant extent no additional treatment effect was found following the exploration training.

Table 4.11

The mean and standard deviation of the amount of visual field sparing along the meridians in the blind hemifield and those in the seeing hemifield for each of the three assessment sessions.

	Sparing in the blind hemifield (°)		**Sparing in the seeing hemifield (°)**	
	Mean	*SD*	*Mean*	*SD*
Baseline	17.97	14.42	58.05	10.22
Post-Attention	20.71	14.87	59.87	11.09
Post-Exploration	21.40	14.54	60.40	9.78

However, these reported increases in the visual field are not large enough to rule out the possibility that changes in eye-movements may underlie the effects. As mentioned previously in Chapter 2 (pp. 99), eye-movements could only be detected by the experimenter if they were at least 3° in amplitude. As such it is possible that small changes in fixation could account for the increases in the visual field found here.

Between-subjects comparisons:

As described in Chapter 2 the blind and the seeing hemifields both increased significantly after the exploration training (pp. 98). Since the blind hemifield increased to an almost significant extent after the attention training (see above) the effects on the blind hemifield of both types of training were compared using a between-subjects analysis. The mean increase in the blind hemifield after each training type is shown in Table 4.12, along with the increase as a proportion of the baseline in order to take into account any baseline variability.

Table 4.12

Mean change in the blind hemifield (and standard deviation) after each training type separately. The proportional change is also reported as a percentage of the baseline measure.

	Change in the blind hemifield (°)		Proportional change in the blind hemifield (%)	
	M	*SD*	*M*	*SD*
Attention training (n = 13)	+2.74	3.91	+29.74	57.22
Exploration training (n = 21)	+4.61	4.84	+76.95	201.74

Although the results in Table 4.12 suggest a far greater increase in the blind hemifield after the exploration training than after the attention training, there is a large degree of variability in the finding. The results of a Mann-Whitney U test revealed that the treatment effect on the blind hemifield of each of the training types was not significantly different ($U = 102$, $p = 0.369$, $r = 0.16$). The same non-significant difference was also found for the proportional effects ($U = 110$, $p = 0.549$, $r = 0.10$). Since both the exploration and the attention training produced comparable increases in the blind hemifield this result supports the concept that enhanced attention may underlie the supposed restorative effects.

Restorative therapies are controversial, as is the claim that compensatory training can lead to visual restoration. Kerkhoff and colleagues (1992b, 1994) found significant visual field increases after compensatory exploration-based training. Conversely, such results have not been observed in other studies examining compensatory therapy (Nelles et al., 2001; Pambakian et al., 2004; Pommerenke & Markowitsch, 1989; Zihl, 1995a), and in accordance with this the findings from this study revealed no significant effect of either the exploration or the attention training on the degree of visual field sparing along the most impaired meridian. This is in contrast to the finding from Chapter 2 where a significant increase was found after the exploration training. The fact that this same effect was not observed here does question the reliability of such increases. The ability to conduct manual perimetry (as was used in these studies) improves with both practice and intuition (Simpson & Crompton, 2008). It could perhaps be assumed that the later measurements (Chapter 4) are more reliable and accurate than the earlier ones (Chapter 2) since the ability to perform perimetry could have improved with practice. Overall, the results imply that visual restoration is not an achievable outcome of compensatory therapy for the majority of patients with HVFDs.

However, further examination of the data in this study did uncover an almost significant increase in the blind hemifield as a whole after the attention training, whereas no significant increase was observed in the seeing hemifield. This increase was comparable to that reported after the exploration training as revealed in a between-subjects analysis, which implies that the type of training which a patient receives is not important for this outcome to be achieved.

There is no way of determining if the increase in the blind hemifield observed in this study was training-induced or natural. Spontaneous recovery seems unlikely since the time between onset of the HVFD and the start of the training was at least three months, which is the maximum period in which spontaneous recovery is typically expected (Pambakian and Kennard, 1997). Additionally, Kerkhoff et al. (1994) reported increases in the visual field after compensatory training whereas there had been no change after a waiting period in which no therapy was provided, which does suggest that spontaneous recovery is unlikely to mediate the effects found.

It is possible that the increase in the blind hemifield did not reflect visual restoration. As discussed in relation to the findings of Chapter 2, the field increase could be explained by an enhancement of visual attention or criterion-shifts. In line with this proposition is the evidence that both hemifields increase after exploration training, and the finding that exploration training and attention training produce comparable decreases in the size of the blind field. It is a possibility that patients may use different decision criteria for the various assessment sessions which could feasibly account for the field increase (Campion, Latto & Smith, 1983). Furthermore, it is also possible that small eye-movements could account for the enlargement observed. The mean increase in the blind hemifield was 2.7° after the attention training and 4.6 ° after the exploration training. Given that eye-movements could only be detected by the researcher if they were 3° or greater, then such field enlargements as these could be the product of small saccades towards the blind region. The results at present do not allow one to distinguish between these various possibilities, and future research should attempt to determine the contributions of each to the pseudo-visual restoration which results from compensatory training.

Overall, the results do show that a reduction of the blind hemifield was detectable after training, although this was regardless of the type of training provided, which suggests that type of intervention might be arbitrary for such an effect to be found. Given the controversy surrounding restorative approaches to HVFD rehabilitation the same stringent criteria need to be used when attempting to establish the restorative effects of compensatory techniques. A plausible explanation at present for the increase in the visual field reported is enhanced attention.

4.5 Overall discussion

4.5.1 Is exploration training more effective than a placebo condition?

The primary aim of this study was to examine whether the improvements found in various visual search tasks after compensatory exploration training are training-specific benefits or if they are a consequence of placebo effects. The results of this study reveal that many of the assessment tasks showed a significant improvement after both the attention training and the exploration training. Whether or not the exploration training produced a superior effect over the attention training for each of the assessment tasks is shown in Table 4.13.

Table 4.13

Description of which of the assessment tasks showed a specific effect of the exploration training relative to the attention training, as revealed both by the within-subjects and between-subjects analyses.

Task	Is there a specific effect of the exploration training?	
	Within-subject comparisons	*Between-subject comparisons*
Count the dots	Yes	No
Find the number	p = 0.028	Yes
Count the numbers	p = 0.027	No
Projected search	No	No
Visuomotor search	No	No
Reading	No	-
Subjective ADLs	No	-
Perimetry	No	No

Only for the 'find the number' visual search task was the effect of the exploration training revealed conclusively to be significantly greater than that found after the attention training. Contradictory results were found for the other two visual search tasks ('count the dots' and 'count the numbers'), whilst the remainder of the tasks showed comparable effects after the two types of training.

One possible explanation as to why the 'find the number' visual search task showed a training-specific effect whilst for the remainder of the tasks the attention training appeared to be equally effective, could be the extent of similarity between this assessment task and the training itself. As discussed in Chapter 2, the 'find the number' task benefited more than the other visual search tasks from the exploration training, perhaps indicating a greater degree of transferability. Associated with this is the fact that the 'find the number' task and the training require similar attentional, exploration and procedural strategies, and it is this similarity which could explain the training-specific enhancement. The exploration training enhances particular skills above and beyond those acquired as a consequence of the attention training. It could be expected that tasks for which these skills are most applicable would show a greater improvement after the exploration training, whilst the less similar tasks which do not require these same skills would show a reduced effect. However, other skills resulting from the attention training could still be used. For the majority of tasks comparable effects were found after either training type which provides the first evidence that compensatory exploration training is no more effective than a placebo therapy at alleviating some of the deficits associated with HVFDs.

Establishing the efficacy of an intervention relative to a placebo condition is important when considering the clinical value of any treatment. There is no conclusive evidence from this study that the exploration training is superior to the attention training, at least not with regards to improving performance on the majority of tasks. The only exception to this is for the visual search task which is almost identical to those tasks which formed the basis of the exploration training, and thus training specificity could be assumed for only for those tasks which share particular components of the training.

4.5.2 What explanation can be provided for the placebo effects?

The results reported here do not confirm that compensatory exploration training is more effective than a placebo condition which trains attention in the absence of exploration, at least not for the majority of the transfer tasks. This therefore leads one to question by what manner the placebo training was yielding an effect.

It is important to note that although for many of the transfer tasks the attention training and the exploration training produced similar effects, spontaneous effects cannot be reliably dismissed. Since the improvement for the 'find the number' task was only observed after the exploration training this shows that the benefit for this task was not spontaneous and nor was it the result of general enhanced attention. However, for the remaining tasks, the extent to which the benefits are the result of intervention cannot be concluded. Previous research has established improved visual search behaviour only during periods of training (Kerkhoff et al., 1994; Pambakian et al., 1992b) which would suggest that it is perhaps unlikely that spontaneous compensation underlies the effects. Furthermore, the results from the study reported in Chapter 3 revealed that no further significant benefit was found at the follow-up session, indicating that the results are unlikely to be an effect of repeated testing for example.

However, if spontaneous improvements are discounted as being responsible for the effects reported, it is necessary to explain the mechanisms which are responsible for the benefits produced by the attention training. One candidate factor is enhanced attention, as already considered in the discussion of Chapter 2. Both the exploration training and the attention training require visual attention. Consequently a general enhancement of visual attention resulting from either training type could explain why both types of training were found to significantly improve performance on various tasks, including not only visual search but also perimetry. Zihl (2000) proposed that spatial shifts in attention associated with visual search training were likely to enhance the therapeutic benefit and the process of oculomotor modification. It appears that the effect of enhanced attention on compensatory rehabilitation may have been underestimated. The fact that the patients demonstrated an improvement with regards to the attention training task over the course of the training period suggests that they did experience an improvement in attention, namely in selective and sustained attention which were the relevant components of the task. However, this effect is confounded by the fact that the measure of attention was used as the training task. Future research should assess attention as an independent outcome measure in order to establish the effect of both the exploration training and the attention training on attentional processes.

Research involving patients with comorbid HVFDs and hemispatial neglect has revealed that such patients can benefit from compensatory training, although more extensive training is required in order for them the achieve the same gains as patients with HVFDs in the absence of neglect (Kerkhoff et al., 1992b). This could be explained by the inability of patients with neglect to direct attention as effectively as patients without neglect in order to compensate for their impairments, in line with an attention-based theory of HVFD rehabilitation. Alternatively patients with a comorbid neglect also typically experience much less insight into their defects than patients with a HVFD only (Celesia et al., 1997), and this could contribute to the reduced therapeutic efficacy for these patients. This second possibility raises another potential factor which may contribute to the effects found in this study; disorder awareness.

Many patients have no insight into, or limited awareness of, their visual loss immediately after onset the onset of their HVFD (Celesia et al., 1997; Townend et al., 2007). As such, patients may not compensate spontaneously because they are unaware of their deficit, and therefore it is important that they recognise their need to compensate in order to do so. Awareness of the visual loss is associated with functional outcomes such as employment in patients with HVFDs, with patients who show greater insight typically also demonstrating better outcomes (Sherer et al., 1998). Drawing a patient's attention to their impairment could potentially be sufficient for the patient to then naturally improve. Simply being involved in the training programmes (regardless of the specific content of the training) may have led to the patients becoming more aware of their HVFD and spending more time thinking about their impairments. It is possible that this led to them altering their behaviour in response to this, and thus it is possible that disorder awareness is a mechanism by which improvements in search behaviour are obtained.

Knowledge and understanding of the visual impairment and the neurological substrate increase rehabilitation motivation and ability, which are crucial aspects with regards to the success of rehabilitation (Anderson & Rizzo, 1995). The first step of rehabilitation should be assessment (Nair & Taly, 2002), which in this study included not only a visual field measurement (which was then discussed with the patient), but also an assessment of the resulting disability and the needs of the patient. Being provided with the opportunity to receive a detailed assessment of their visual abilities may have increased the patients' understanding of their deficits, which consequently may have contributed to their ability to compensate for their visual loss. Therefore, this could be associated with the placebo effects found in this study.

Furthermore, it is possible that the improvement in the different visual search tasks was affected by a variety of alternative placebo factors such as changes in response criteria. For example, patients may have become more trusting of their own judgement after training and therefore become faster at dismissing distractors and responding to targets; a lower response threshold. The results at present do not allow one to distinguish between the possible mechanisms which may underlie the placebo effects reported in this study. However, it appears likely that enhanced attention resulting from either type of training could explain not only the improved performance for various visual search tasks, but also the increases in the visual field. Furthermore, awareness and insight in the HVFD also appear to be important factors that may contribute to the improvements found.

4.5.3 Clinical implications of the research

The only task for which there was conclusive evidence that the exploration training was more effective than attention training was the 'find the number' visual search task. This was the task which shared the most in common with the training tasks in terms of exploration, attention and procedure. Consequently, this indicates that the largest transfer of training benefits occurs for tasks which are very similar in their requirements to the training. Therefore, in order to achieve maximum rehabilitation then particular tasks which are deficient need to be trained, specifically those identified by the patient as being problematic. This finding is in accordance with the field of clinical neuropsychology as a whole; there is a feeling that generalisation of neuropsychological therapy is not achievable for the most part. If training does not generalise beyond the trained task then therapy is needed which trains a variety of skills, rather than focusing on one deficient area and hoping for transfer across all. According to Sohlberg and Mateer (2001):

> *"...therapists should not 'expect' generalization, rather they should 'program' for generalization. It has become abundantly clear that spontaneous generalization of skills is improbable if not impossible for many clients with acquired brain injury." (pp. 20).*

Consequently the best clinical approach would seem to be one which encourages patients to develop specific skills in a variety of deficient areas. Some previous compensatory exploration training has involved teaching patients to use saccadic search strategies in everyday situations such as crossing the street (Kerkhoff et al., 1992b, 1994). The results suggest that this should be encouraged, and perhaps the skills taught should extend beyond just saccadic searching (i.e. organise one's own environment methodically in order to make it easier to find things). It may also be possible to improve the driving ability of patients using a search therapy which trains those scanning strategies that are necessary for driving scenarios using a driving simulator (Kooijman et al., 2004; Tant et al., 2002). Whilst such training was found to improve some patients driving ability to such a level that they then passed on the road driving tests, this was only for a small proportion of the sample (two out of seventeen patients). As such driving may not be a realistic goal for the majority of patients with HVFDs.

The results of this study confirm the earlier finding from Chapter 2 that exploration training does not significantly affect reading performance, and further extend this result by showing that the attention training does not affect reading either. This result suggests that in order for a patient with hemianopic dyslexia to improve their reading a therapy specifically tailored towards this is required. As such, patients with reading impairments should be offered compensatory reading training, such as that developed by Spitzyna et al. (2007), to alleviate the difficulty experienced in this task.

The results reported in this study (and as discussed in the section above) highlight that both awareness of the visual field loss and visual attention are important factors contributing to the rehabilitation of HVFDs. Since training attention may improve visual search performance to a comparable extent as exploration training, a therapy which enhances attention may prove an effective intervention for patients with HVFDs. Attentional deficits are a common problem generally for patients following brain injury (McKinley, Brooks, Bond, Martinage & Marshall, 1981), although the precise number of sufferers is unknown (Lincoln, Majid & Weyman, 2008), and a therapy designed to enhance attention may be a useful starting point for many neurological patients, not only those with HVFDs. Attention training is easier to complete since the patients are not required to make the searching eye-movements which can become tiring, and is therefore favourable alternative to exploration training on a practical level. These practicalities might encourage the uptake of rehabilitation training by patients.

Additional training practicalities have been highlighted by the research. It is obvious that training on a small screen is less costly because it means that the training can potentially be performed by the patient in their own home, and the findings reported show that training can be successfully performed using a practical and portable system. On a practical level the reading training provided by Spitzyna et al. (2007) exceeds even a portable training system; their reading training was available free of charge over the internet, and this should be set as the benchmark for which future therapies should aim.

4.5.4 Open research questions

One of the main questions to address in future research is whether or not the training does actually enhance attention. Patients' performance of the attention training did improve over the course of the intervention, indicating an improvement in attention. However, this effect is confounded by the fact that the measure of attention used also formed the training. The impact of the exploration training on attention cannot be established at present either, and thus it cannot be reliably concluded that either training type does influence visual attention. As such, future research should assess attention as an independent outcome measure in order to establish the effect of both the exploration training and the attention training on attentional processes. Doing so would further allow researchers the opportunity to assess the contribution of such a factor to the rehabilitation of HVFDs.

It is important to establish how much training may be required in order to achieve an improvement in performance on the transfer tasks. The results for the attention training revealed that patients' performance appeared to plateau after two blocks of training, which might imply that this is sufficient training for the patients to benefit. However, since the transfer tasks were not repeatedly assessed during the course of the therapy it is not known if the three blocks of training were required in order to achieve the generalisable benefits. Establishing the time-course of training would ensure that time and resources are utilised to their best advantage. However, this could also contribute to the lack of significance observed between the effects of the two training types. It is possible that extending the duration of the exploration training (which did not plateau within the current time-course) could improve the effects found using this method. Examining this possibility could help to establish the superiority of the exploration training over the placebo condition.

If the training does increase attention then it is necessary to explain why enhanced attention may lead to improvements in visual search. Since the attention training only involves presentation of stimuli to foveal regions of the visual field it could be assumed that the training does not induce an orientation bias towards the blind hemifield. As such, the mechanism by which attention training could be thought to increase exploration of the blind hemifield is uncertain. It could be that increased selective attention enables faster item recognition (or dismissal) which subsequently makes patients faster at searching a display and selecting the target. The ability to dismiss items more quickly could imply less fixation duration on these items, and thus faster scan-paths may result. More organised search strategies could also possibly result from slight increases in visual detection. The increase in the visual sparing in the blind hemifield, even though it may only be small (<3°), may allow patients to detect items which they would previously not have seen. The enhanced detection could provide targets to direct attention towards, which may thus lead to more efficient searching strategies. This possibility is perhaps unlikely given that increases in the visual field are not correlated with improvements in visual search behaviour (Kerkhoff et al., 1992b). Since there is no evidence of the effect of the attention training on oculomotor behaviour one cannot conclude the effect that attention is having on such processes. Further research is required to determine if attention training is sufficient to influence oculomotor modification.

However, whilst examining oculomotor behaviour as a training outcome would be desirable, researchers should be aware of some of the practical issues surrounding this. Many people wear glasses which can interrupt the path of reflection to the video-camera and thus can interfere with the ability to monitor eye-movements reliably using a video-based eye-tracker. Secondly patients with HVFDs are often elderly, which increases the chance of them having ptosis of the eyelid (Sridharan, Tallis, Leatherbarrow & Forman, 1995), or rather 'droopy' eyelids. In such cases the eyelid obscures part of the pupil which complicates the tracking process. Finally, there is also the issue of trying to examine the saccadic behaviour of patients with acquired brain injury, who often present with problems in attention and concentration (Lincoln et al, 2008; McKinlay et al, 1981). This can make it difficult to perform eye-tracking since it can be challenging for such patients to sit relatively still for the duration of the assessment. This may be less of a problem if head-mounted eye-tracking systems were used. Therefore, whilst examining the effect of attention training on oculomotor behaviour would be useful for trying to establish the mechanism by which it leads to improvements in the performance of visual search tasks, one should be aware of the difficulties which might be encountered in trying to do so. Techniques such as electrooculography, which could be used to measure eye-movements along the prime meridians, may prove valuable in extending the research in this area.

The results of this study provide the first evidence that although compensatory exploration training can lead to some significant transferable benefits, it is not the case that these are specific to the training. For some of the assessment transfer tasks it is difficult to interpret whether the benefits of the exploration training are greater than those found after the attention training, although for at least the 'projected search' and the 'visuomotor search' tasks the effects of the two types of training appear to be comparable. It is unlikely that reduced statistical power explains the lack of significance between the effects of the training types as revealed in the between-subjects analyses. If one considers the effect sizes for such comparisons (<0.20) this indicates that the difference between the effects of the two training types is small. However, research using a larger sample is required in order to increase the statistical power of the analyses such that the effects of the exploration training and the attention training can be more reliably established. Furthermore, it is important that the results of this study be confirmed using a robust design in which the same patients receive both types of training in a randomised order. Such research is needed to try and help choose between different alternatives such as the results being purely attentional, or if in fact some improvement is possible with enhanced attention but that further gains can only be achieved if exploration training follows.

Even if the exploration training were to be more beneficial than a training based purely on attention, the extent to which additional attention may be beneficial warrants further investigation. Exploration training involves the patient voluntarily attending to their blind-hemifield, but Bolognini et al. (2005) found that using an auditory stimulus to shift attention exogenously could significantly improve visual search and lead to transferable benefits, including improving reading performance. Perhaps emphasising the attentional element within exploration training could lead to the most effective training. Therefore, further research is needed to determine if the training program can be developed in order to produce maximal and transferable training benefits beyond placebo effects. Such methods may include integrating attention and exploration and possibly extending the duration of training.

4.5.5 Conclusion

The results of this study suggest that exploration training can improve performance on a variety of tasks which require visual search. However, the compensatory training is not more effective than an attention-based placebo therapy, except for the task which was the most comparable to the training itself. This result indicates that training-specific effects are most likely for activities which are very similar to the practiced tasks. The mechanism by which the placebo training improved performance in visual search is not known, but it is possible that enhanced attention may underlie the behavioural improvements, suggesting a greater role for attention in the rehabilitation of HVFDs than previously proposed. If this is the case then training attention on its own may prove to be an effective first phase of rehabilitation for patients with HVFDs.

Chapter 5: Does extending the arm into the blind hemifield improve visual performance for patients with HVFDs?[2]

5.1 Introduction

5.1.1 Multisensory integration and HVFD rehabilitation

The main approaches used in the rehabilitation of homonymous visual field defects (HVFDs) include vision restoration therapy (VRT), compensation via oculomotor modification and the use of optical aids. The relative advantages and disadvantages of these methods have been described previously (see Chapter 1) with most researchers agreeing that compensatory therapies offer the most promising approach to HVFD rehabilitation (Bouwmeester et al., 2007; Lane et al., 2008; Pambakian et al., 2005; Pelak et al., 2007). However, there is an alternative restorative approach based on multisensory integration which may offer practical advantages over the other comparatively mainstream methods.

A multimodal integration rehabilitation technique was proposed by Schendel and Robertson (2004) who found, in one patient (WM) with a left-sided hemianopia, that visual detection could be enhanced in the blind hemifield by extending the patient's contralesional arm into this area. This simple manipulation appeared to have restored vision (at least partly and momentarily) to the blind hemifield. Schendel and Robertson explained this observation by referring to the existence of bimodal, visuo-tactile neurons. These multisensory neurons have been found in the dorsal regions of the visual cortex in monkeys (Graziano, Gross, Taylor & Moore, 2004a; Graziano, Gross, Taylor & Moore, 2004b), and there is

[2] The data presented in this chapter has been previously published (Smith, Lane & Schenk, 2008) and this thesis chapter is based upon said article. I collaborated on this study with Thomas Schenk and Daniel Smith, the latter of whom was the first author of the published paper. The design of the experiments was a joint process, as was the analysis and interpretation of the data. Daniel Smith completed the technical aspects of the experimental set-up and I assisted with recruitment and testing.

also some neuroimaging evidence to suggest that comparable neurons may exist in human parietal and frontal areas (Bremmer et al., 2001). Schendel and Robertson interpreted their data as providing support for the existence of such neurons in humans. They proposed that positioning the patient's arm into his blind hemifield activated these bimodal neurons and that this provided a sufficient enhancement to the visual signal from this area to bring it above the threshold for conscious perception. In the context of rehabilitation multisensory integration refers to the use of information from one modality (such as tactile) to enhance the processing of information from a second, impaired modality (in this case vision).

Schendel and Robertson's conclusion that arm manipulation may ameliorate visual field loss may have therapeutic value, since it could provide a new rehabilitation method for patients with HVFDs. Reducing visual loss would hopefully also improve everyday functioning and a therapeutic approach based on arm manipulation would be preferable to others, such as VRT, due to the comparable ease and low cost of the technique. Therefore, replicating the findings of Schendel and Robertson could be a first step for radically modifying HVFD rehabilitation practices.

5.1.2 Concerns regarding the Schendel and Robertson (2004) study

Given the possible advantages of an approach to HVFD rehabilitation which is based on manipulating arm position it is worth examining this further, especially since the findings of Schendel and Robertson (2004) do need to be interpreted with some caution. The first feature of the study which is of concern is the fact that the finding was observed in only one patient (WM). Additionally, the patient's performance at baseline showed that he had some spared visual ability in various areas within his so-called blind hemifield, rather than a dense HVFD as is common.

Ensuring that the patient does not make any eye-movements during the assessment of the visual field is essential for obtaining an accurate and reliable measurement. Rather than monitoring eye-position Schendel and Robertson instead used a second central task to try and ensure central fixation from their patient. The use of a second task introduces additional attentional load to the main visual detection task, which could impair performance (Cartwright-Finch & Lavie, 2007). Furthermore, the fixation task may also have been inadequate at preventing eye-movements. A central task is only capable of acting as a fixation control measure if the features of the task are small enough that they are not recognisable when presented in the periphery of the visual field. It is unclear whether or not the fixation task used by Schendel and Robertson was effective at controlling for eye-movements since details of the stimuli used in the task were not provided in the paper. However, the accuracy for the fixation task was not perfect (95 – 98.5%), indicating that perhaps eye-movements may have contributed to the effect found.

Previous studies which have examined the preserved visual abilities of patients with HVFDs have shown that it is important to try and account for the possibility that patients may just guess or use different decision criteria for various task conditions (Campion et al., 1983). Schendel and Robertson tried to correct for the possibility of guessing by measuring the false-alarm rate in catch trials in which no visual target was presented, and then using a simple formula to correct the obtained hit-rate on the basis of the measured false-alarm rate. Their formula calculated the guess-corrected hit-rate by multiplying the original hit-rate with the correct-rejection rate (1 minus false-alarm rate) obtained in the catch trials. The problems with this approach are that it does not control for criterion-shifts between task conditions and it does not fully discount guessing effects. To illustrate this problem assume that there are two conditions (A and B) and that the patient sees nothing in either one of these. However, in condition A the patient expects stimuli in 50% of all trials (guess-rate 50%) and in condition B they expect stimuli in 20% of the trials. The uncorrected hit-rate will be 50% (0.5) and 20% (0.2) respectively, and the corrected hit-rates according to the above formula (hit-rate x (1 – false-alarm rate)) will be 25% in condition A and 16% in condition B. If the correction process would work properly then the corrected hit-rate should be identical in the two conditions. In fact, the corrected hit-rate should be 0% since no genuine detection took place in either one. Therefore, the process for correction used in the Schendel and Robertson study is not suitable for controlling for the contribution of guessing.

Thus, whilst the observation by Schendel and Robertson (2004) suggests that positioning the arm into the blind hemifield can enhance detection of visual stimuli presented in this location, the finding needs to be interpreted with caution. Consequently, the effect of arm position on visual function needs to be examined further in order to determine whether or not it may provide an exciting new route to HVFD rehabilitation.

5.1.3 Aims of the study

This study was conducted in order to examine the possibility proposed by Schendel and Robertson (2004) that manipulating arm position can influence visual detection in the blind hemifield of patients with HVFDs. The aim was to investigate this in such a manner as to avoid some of the difficulties associated with the previous research. In order to try and address some of the concerns regarding the Schendel and Robertson study several amendments to the method were made. Firstly, a group of five patients with HVFDs participated in this study rather than a single case, and all had a dense HVFD with no evidence of spared vision in their blind hemifield. Manual Tübingen perimetry was used to measure the visual fields which allowed the patients' fixation during the visual field assessment to be monitored using a telescope. Additionally, a video-based eye-tracker was used during the experimental tasks in order to overcome the problem of inadequate monitoring of fixation. A two-alternative forced-choice task (2AFC) is an example of a criterion-free method of assessing detection (Gescheider, 1997). During 2AFC tasks the participant is always required to make a response (they must choose between two possible options) regardless of their conscious experience. As such this method allows the researcher to control for the possibility of participants guessing or shifting criteria between conditions. The disadvantage of this approach is that it cannot discriminate between implicit (unconscious) detection and explicit (conscious) detection. In order to try and overcome these problems two different tasks were used in this study. The first of these was an explicit detection task in which participants had to state whether or not they perceived the visual target. This task examined whether manipulating arm position could affect conscious experience as was predicted based on the findings by Schendel and Robertson. The second task was an implicit task in which participants were asked to state whether a visual target appeared above or below a reference line regardless of their conscious perception of the stimulus.

5.2 Method

5.2.1 Design

The study included two experiments, one designed to assess the effect of manipulating arm position on explicit target detection, and the other to examine the effect of the same manipulation on implicit target localisation. Both of the experiments used a within-subjects repeated-measures design. The independent variables in both experiments included arm position (arm-in-lap and arm-extended), probe location (seeing and blind hemifield) and probe eccentricity (4.5°, 9° and 13.5°). The dependent variable in experiment 1 was probe detection accuracy and in experiment 2 it was probe localisation accuracy. For the group analyses accuracy was determined as the percentage of trials in which the correct response was provided, and for the individual participant analyses accuracy was the number of trials in which the correct response was given.

5.2.2 Sample

The sample consisted of five patients with post-chiasmatic HVFDs. These patients had previously participated in one of the visual rehabilitation training studies outlined in Chapters 2 and 4, and were selected for their ability to maintain fixation during perimetry. Table 5.1 contains details of the individual demographic and HVFD characteristics of the participants. Medical imaging was available for three of the patients (RE, FP and VH), and images which demonstrate their lesions are located in Figure 5.1. HVFDs were established using binocular, kinetic Tübingen perimetry and the maximum amount of visual field sparing observed in any of the patients was 2°. None of the patients showed signs of neglect as examined using the star-cancellation task (Halligan et al., 1991), or as indicated in their medical notes. Two of the patients (VH and FP) presented with mild hemiparesis of their contralesional arm when first diagnosed, although their medical notes revealed that this had resolved in both cases by the time of participation in this study.

All of the patients gave informed consent to participate in accordance with the Declaration of Helsinki (International Committee of Journal Medical Editors, 1991), and the study was granted approval from the departmental ethics committee at Durham University and from the local NHS multi-centre research ethics committee.

Table 5.1

Characteristics of each of the five patients. Details include gender, age, visual field defect location (HVFD), amount of visual field sparing (sparing), lesion site and aetiology (lesion), and time since onset (onset).

Participant	Gender	Age (yrs)	HVFD[a]	Sparing (degs)	Lesion	Onset (months)
CL	M	62	LH	0	Right occipital ischaemic infarct	32.0
LM	M	78	LH	2	Right occipital ischaemic infarct	3.5
RE	M	73	LIQ	2	Right occipital ischaemic infarct	16.0
FP	M	74	LH	0	Right occipital ischaemic infarct	5.0
VH	F	71	RH	0	Left thalamic and intraventricular haemorrhage	4.5

Note: [a] LH = left hemianopia, RH = right hemianopia, LIQ = left inferior quadrantanopia.

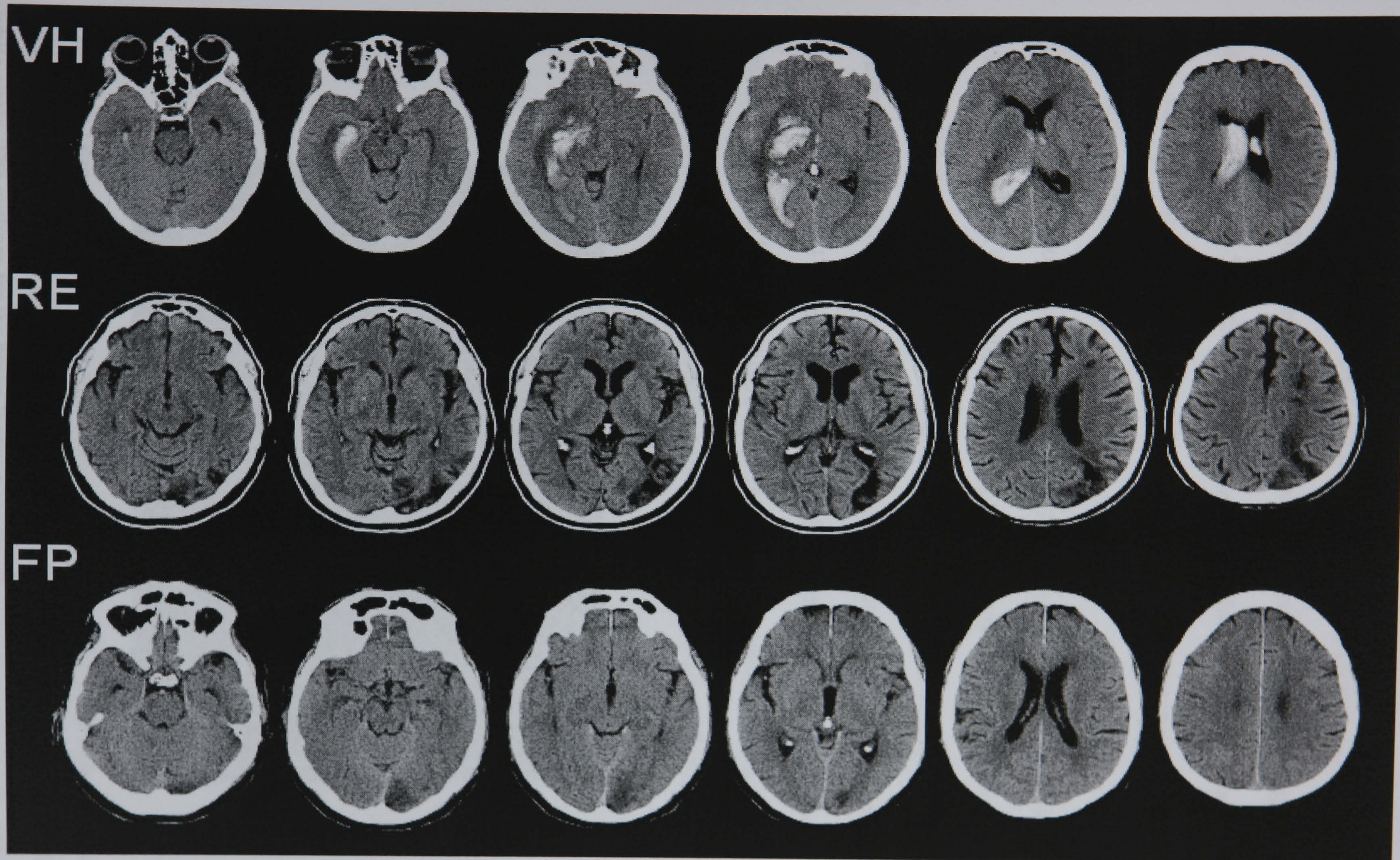

Figure 5.1: Neuroimaging slides showing the lesion locations for three of the participants (VH, RE and FP).

5.2.3 Materials and stimuli

The stimuli were generated using a VSG 2/5 graphics card (Cambridge Research Systems, Rochester, UK) and displayed using a 21-inch Sony Trinitron monitor with a 100Hz refresh rate. Eye-movements were recorded using a Cambridge Research Systems Video Eyetracker Toolbox (2.1) with a sample rate of 50Hz. The participant responses were recorded by the experimenter using a standard computer keyboard.

The display consisted of a black screen with a central fixation point (a 0.7° by 0.7° white cross). Across the width of the screen there was a horizontal white reference line located 7.5° below the fixation point. The probe target was a white circular dot with a 0.3° diameter. The probe could appear at one of 12 possible locations: 4.5°, 9° or 13.5° to the left or right of fixation, and either 2.2° above or below the reference line (see Figure 5.2). The size and relative positions of the stimuli are based on a viewing distance of 57cm (such that 1cm subtends 1°).

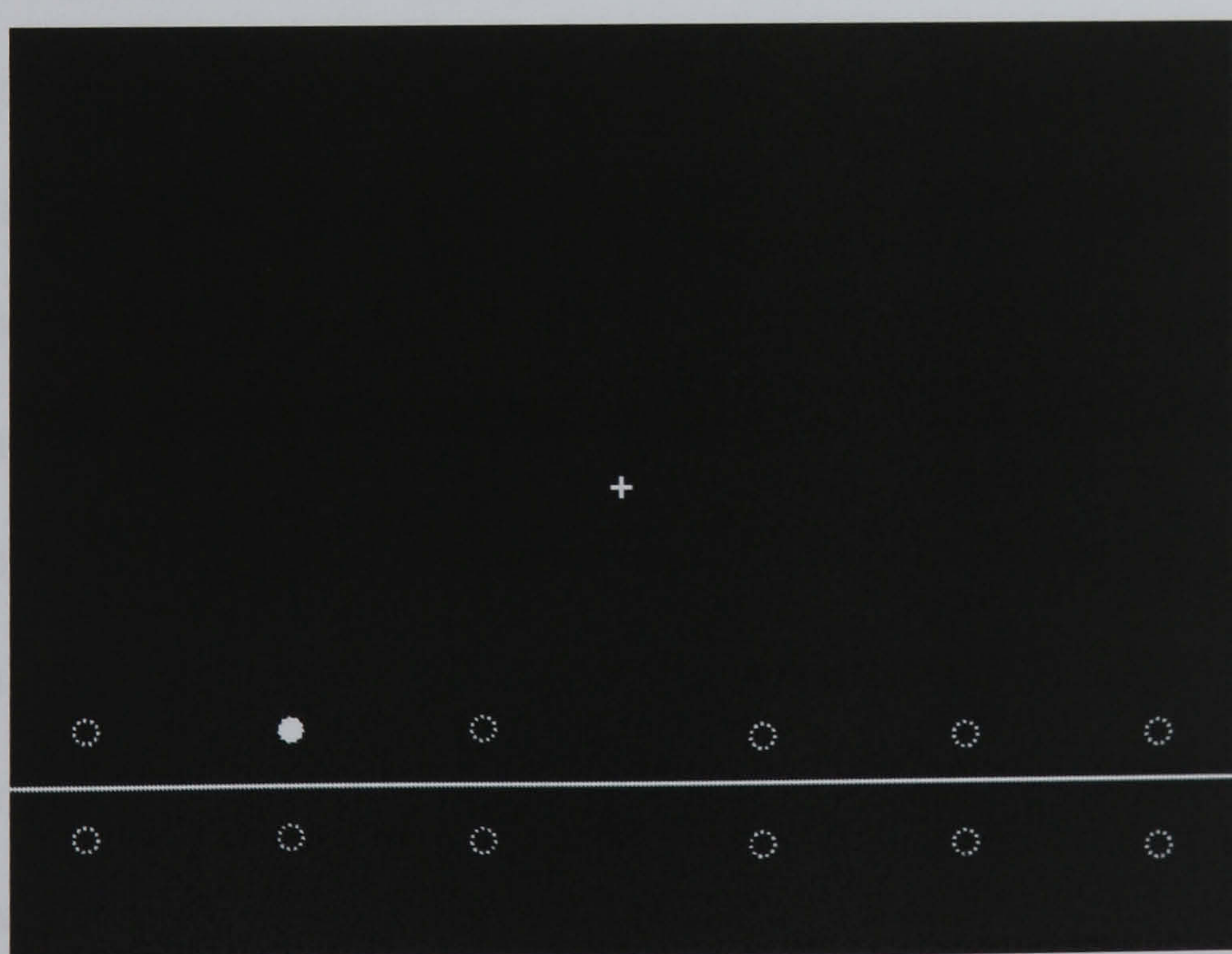

Figure 5.2: Diagram of the experimental set-up (not to scale). The white reference line was always present. The dotted circles illustrate the potential locations of the probe, which is the white circle. The outlines for the probe location are for illustration purposes only and were not visible during the experiment.

5.2.4 Procedure

5.2.4.1 Experiment 1

Experiment 1 used a standard detection paradigm, designed to assess explicit visual ability in the blind hemifield. For each trial the participants were asked to report whether or not they had seen the probe, whilst always maintaining central fixation.

Each trial began with the presentation of a black screen with the central fixation cross and white reference line displayed. This screen was presented for 1500ms. The probe then appeared at one of the 12 possible locations. The probe was presented at each location in a random order (such that the participant could not predict the location), although the probe did appear at each location an equal number of times. The probe was presented for 150ms after which time it disappeared and the fixation cross turned red, prompting participants to verbally report whether or not they had seen the probe. The experimenter recorded the participant's response with the appropriate key press. The central cross then turned white signalling the start of the next trial. Participants were instructed to maintain fixation on the cross throughout trials and not to search for the probe. Fixation compliance was monitored using the eye-tracker and trials in which fixation was not adequately maintained were omitted during the data-analysis stage.

There were two conditions for the arm position manipulation. In the arm-in-lap condition both arms were positioned comfortably in the participant's lap, whilst in the arm-extended condition the contralesional arm (ipsilateral to the HVFD) was extended forward into the blind hemifield. The extended arm was positioned such that the fingertips were level with, and just inside the edge of, the computer monitor. When fixating straight ahead the participants could not see the extended arm. Head position (and thus also viewing distance) was maintained using a head-rest atop which the eye-tracker was mounted. For four of the participants the monitor was positioned 57cm away. For participant RE when the monitor was at this distance the screen was more than 20cm from the end of his extended arm. Therefore, for RE the monitor was brought forward to a viewing distance of 37cm. No other aspect of the display was changed, which meant that for participant RE the probe was 0.46° in diameter and appeared at eccentricities of 6.9°, 13.6° and 20° from the vertical midline.

For experiment 1 participant CL completed two blocks of 96 trials, starting with the arm-in-lap condition (i.e. the probe appeared eight times at each location for each condition of arm position). Participant RE completed two blocks of 120 trials beginning with the arm-extended condition (the probe appeared at each location 10 times for each condition). The remaining three participants each completed two blocks of 120 trials for the arm-in-lap condition, and two blocks of 120 trials for the arm-extended condition (the probe appeared at each location 20 times in each arm position condition). The blocks of different conditions were interleaved, and the order of the conditions was counter-balanced across the participants.

5.2.4.2 Experiment 2

Experiment 2 used a 2AFC target localisation paradigm. The set-up was the same as used in experiment 1 except that in this task the participants were asked to report whether the probe appeared above or below the horizontal reference line, and if they did not know then they were required to guess. This experiment was designed to assess the implicit ability of patients with HVFDs to respond to visual stimuli presented in the blind hemifield. For this task participant CL completed 192 trials (96 trials for each condition of arm position), and the remaining participants completed 240 trials (120 trials for each condition).

5.2.5 Statistical analyses

Statistical tests were performed using SPSS, were two-tailed and the alpha-level was set at 0.05. Repeated-measures ANOVAs were performed on the group data in order to examine the effect of arm position, probe location and probe eccentricity on detection/localisation accuracy. The association between arm position and accuracy was also examined on an individual participant level, and this was done using Fishers exact test when there were fewer than 40 observations in three or more cells, otherwise Chi-Square was used.

5.3 Results

5.3.1 Experiment 1

5.3.1.1 Fixation control

Technical issues prevented the collection of fixation data from one participant (RE). However, previous Tübingen perimetry assessment had established that this individual was able to maintain fixation when required. Consequently none of RE's trials were excluded from the statistical analyses. The eye-tracking data for the remaining four participants was analysed offline. Trials were excluded if they contained an eye-movement which exceeded 2° in magnitude and which occurred within 1650ms of the trial onset (i.e. before the offset of the probe). Using these criteria, 75 trials were excluded from a total of 1632 trials from the four participants (4.6%), of which 51 trials were excluded from CL, 16 trials from LM, six trials from FP and two trials from VH. Of the trials which were excluded, 30 occurred when the probe was in the blind hemifield and 45 when the probe appeared in the sighted hemifield.

5.3.1.2 Detection accuracy

The data was collapsed across the vertical position (i.e. for probes presented at the same eccentricity but which were above or below the reference line). Mean probe detection accuracy scores were calculated for each horizontal position and for each arm position individually (see Table 5.2).

Table 5.2

Mean detection accuracy scores (in percent) for each eccentricity (4.5°, 9°, 13.5° for both the blind and seeing hemifields) for each condition of arm position. The standard deviation is shown in the brackets.

	Seeing hemifield detection accuracy (%)		
	4.5°	*9.0 °*	*13.5 °*
Arm-in-lap	96.75 (3.49)	93.25 (8.17)	92.25 (8.22)
Arm-extended	96.25 (4.33)	96.50 (4.87)	92.00 (9.59)
	Blind hemifield detection accuracy (%)		
	4.5 °	*9.0 °*	*13.5 °*
Arm-in-lap	1.50 (3.35)	0.50 (1.12)	0.00 (0.00)
Arm-extended	0.50 (1.12)	0.00 (0.00)	1.50 (2.24)

A 3 (*probe eccentricity*: 4.5°, 9° or 13.5°) x 2 (*probe location*: seeing hemifield or blind hemifield) x 2 (*arm position*: arm-in-lap or arm-extended) repeated-measures ANOVA was performed on the mean accuracy scores. The results revealed that there was a significant main effect of probe location ($F_{(1,4)}$ = 1903.72, $p < 0.001$) and as can be seen from the data in Table 5.2, accuracy was always greater when the probe appeared in the seeing hemifield than when it was presented in the blind hemifield. The analysis further revealed that there was no main effect of arm position ($F_{(1,4)} = 0.46$, $p = 0.537$), and no interaction between arm position and probe location ($F_{(1,4)} = 0.33$, $p = 0.595$).

As these results show there was no significant effect of manipulating arm position on the accuracy of probe detection in either the blind or the seeing hemifield, nor at any eccentricity of probe presentation. However, it is possible that arm position produced significant effects on detection accuracy for individual participants which were masked in the group analysis. To assess the possibility that arm position did influence target detection for individuals, analyses were performed separately for each participant.

For the individual analyses trials from within each hemifield were collapsed (i.e. those from different eccentricities and vertical positions but on the same side of the screen). The number of trials in which the probe was correctly detected in the blind hemifield for the arm-in-lap and arm-extended conditions were compared and the results are presented in Table 5.3. Statistics were conducted only for participants CL, FP and VH, since for the other two participants there was no difference in detection between the two conditions; they never detected any probes displayed in the blind hemifield. The results show that for none of the participants was probe detection significantly associated with arm position.

Table 5.3

The number of correct detections for probes presented in the blind hemifield for the two conditions of arm position for individual participants. The numbers presented in the brackets are the number of trials included after the data had been filtered to remove eye-movements. The table shows the Fishers exact test or Chi-Square result (as appropriate).

Participant	Number of correct probe detections		χ^2		Fishers exact test (p)
	Arm-in-lap	Arm-extended	χ^2	p	
CL	0 (36)	1 (39)	-	-	0.520
LM	0 (57)	0 (57)	-	-	-
RE	0 (120)	0 (120)	-	-	-
FP	3 (119)	2 (120)	0.21	0.644	-
VH	0 (119)	1 (119)	1.00	0.316	-

Overall, the results of experiment 1 reveal that manipulating arm position (placing the arm in the lap or extending it in front of the patient) had no significant effect on the explicit visual detection of targets presented in the blind hemifield of patients with HVFDs. The absence of a significant effect was found at both the group and individual participant level.

5.3.2 Experiment 2

5.3.2.1 Fixation control

As with the previous experiment technical issues prevented the collection of fixation data from participant RE, and thus no trials were excluded for this individual. The eye-tracking data for the remaining participants was analysed in the same manner as in experiment 1, resulting in the exclusion of 163 trials from a total of 912 trials for the four participants (17.9%). Specifically 79 trials were excluded from CL, 52 trials from LM, 18 trials from FP and 14 trials from VH. Of the excluded trials 80 involved saccades which were made towards the seeing hemifield, and 83 involved eye-movements towards the blind hemifield.

5.3.2.2 Localisation accuracy

The data was collapsed across the vertical position (i.e. for probes presented at the same eccentricity but which were above or below the reference line). Mean target localisation accuracy scores were calculated for each horizontal position and for each condition of arm position individually, and are presented in Table 5.4. A 3 (*probe eccentricity*: 4.5°, 9° or 13.5°) x 2 (*probe location*: seeing hemifield or blind hemifield) x 2 (*arm position*: arm-in-lap or arm-extended) repeated-measures ANOVA was performed on the mean localisation data. The results revealed that there was a significant main effect of probe location ($F_{(1,4)} = 155.46$, $p < 0.001$). As can be seen from the scores outlined in Table 5.4, accuracy was significantly greater when the probe appeared in the seeing hemifield than when it was presented in the blind hemifield.

Table 5.4

Mean localisation accuracy scores (in percent) for each eccentricity (4.5°, 9°, 13.5° for both the blind and seeing hemifields) for each condition of arm position. The standard deviation is shown in the brackets.

	Seeing hemifield localisation accuracy (%)		
	4.5°	*9.0 °*	*13.5 °*
Arm-in-lap	95.78 (4.26)	98.28 (2.45)	99.33 (1.49)
Arm-extended	85.24 (14.16)	93.24 (8.16)	93.02 (13.83)
	Blind hemifield localisation accuracy (%)		
	4.5 °	*9.0 °*	*13.5 °*
Arm-in-lap	61.96 (15.87)	52.82 (13.88)	45.75 (6.53)
Arm-extended	57.73 (14.06)	52.75 (10.33)	43.14 (7.86)

The analysis also revealed a significant interaction effect between probe location and probe eccentricity ($F_{(2,8)} = 5.50, p = 0.031$). Figure 5.3 shows the probability of participants correctly localising the probe (above or below the reference line) for each eccentricity, separately for probes which appeared in the seeing and blind hemifields. This graph suggests that the significant interaction effect between probe location and probe eccentricity was the product of facilitated localisation rates for those probes presented in the blind hemifield which were closest to fixation.

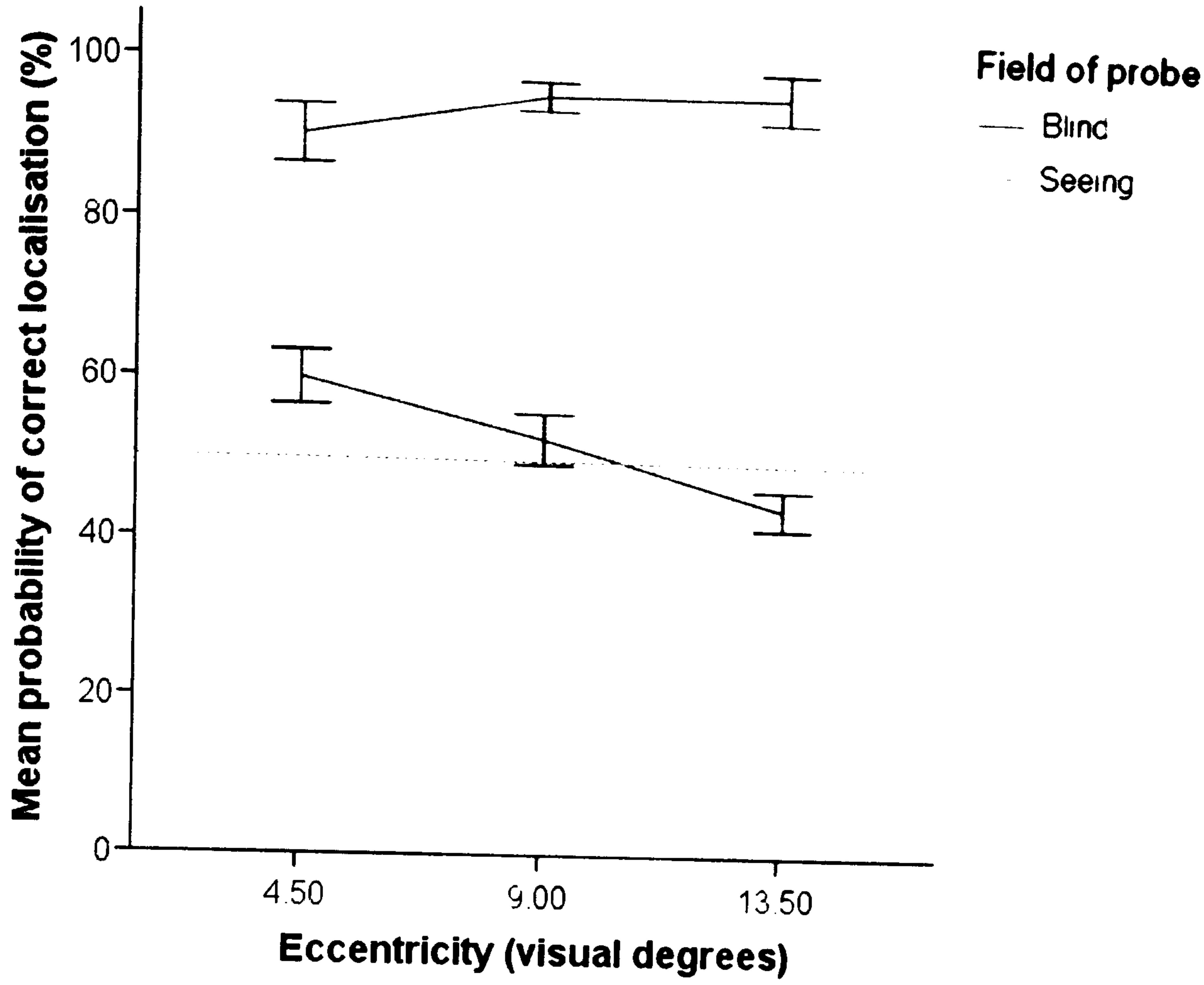

Figure 5.3: Graph showing the probability of correctly localising the probe at each horizontal eccentricity for probes in the blind and seeing hemifield. Error bars show the standard error of the mean and the reference line shows chance level of performance.

The ANOVA further revealed that there was no main effect of arm position on localisation ($F_{(1,4)} = 1.03, p = 0.369$), and no interaction effect between arm position and probe location ($F_{(1,4)} = 1.03, p = 0.368$).

It is possible that the arm position manipulation did affect probe localisation for individual participants but that the effect was masked by the group analysis. To test this possibility analyses were performed separately for each participant. For the individual analyses trials from within each hemifield but from the different eccentricities were collapsed. The number of correct localisations for the arm-in-lap and arm-extended conditions were compared and the results are shown in Table 5.5. For none of the participants was there a significant association between arm position and localisation accuracy. However, for participant VH there was a non-significant trend ($p < 0.1$) towards improved localisation in the arm-in-lap condition relative to the arm-extended one.

Table 5.5

The number of correct localisations for probes presented in the blind hemifield, for the two conditions of arm position for individual participants. The numbers presented in the brackets are the number of trials included after the data had been filtered to remove eye-movements. The table also shows the Fishers exact test or Chi-Square result (as appropriate).

Participant	Number of correct probe detections		χ^2		Fishers exact
	Arm-in-lap	Arm-extended	χ^2	p	test (p)
CL	16 (26)	12 (26)	-	-	0.404
LM	23 (50)	29 (47)	-	-	0.419
RE	24 (60)	33 (60)	1.81	0.232	-
FP	31 (52)	29 (58)	-	-	0.850
VH	35 (58)	27 (56)	-	-	0.095

The results from this experiment show that manipulating arm position did not significantly affect implicit target localisation for visual probes presented in the blind hemifield of patients with HVFDs. Although the localisation of targets presented in the blind hemifield was more accurate for those probes which appeared closest to fixation, this effect was not mediated by arm position. The absence of a significant effect of arm position on target localisation was found at both the group and the individual level.

5.4 Discussion

5.4.1 Interpretation of the results

In this study none of the participants showed any improvement in their ability to detect visually-presented stimuli in their blind hemifield when their arm was extended into this location relative to the condition in which their arm was placed in their lap. This result was observed not only for explicit target-detection but also for implicit target-localisation, suggesting that arm position does not influence either conscious or unconscious visual perception for patients with HVFDs. This finding has failed to replicate the earlier observation by Schendel and Robertson (2004) that extending the arm into the blind hemifield could enhance explicit detection of visual stimuli.

There are various possibilities as to why this study failed to find a significant effect of manipulating arm position on visual performance, whereas Schendel and Robertson had previously found this. One possibility lies in the bimodal visuo-tactile neurons which Schendel and Robertson had hypothesised as mediating the visual improvement which they had observed. If these neurons are damaged in our sample of patients then this could explain the difference in results. These bimodal neurons are located in the frontal and parietal brain areas of monkeys (Graziano et al., 2004a; Graziano et al., 2004b) and are proposed to lie in the same locations in humans (Bremmer et al., 2001). In three of the participants in this study (CL, LM and FP) the lesions appear to be restricted to the medial occipital lobe, very similar to the lesion described for patient WM in the Schendel and Robertson paper. However, it should be noted that neuroimaging data is available for only one of these patients (FP). For the other two cases (CL and LM) lesion localisation is based solely on medical records. Therefore, it is unlikely that damage to visuo-tactile neurons explains the lack of a significant arm manipulation effect, at least not for all of the participants in this study.

It could be speculated that a lack of statistical power may underlie the inability to obtain significant effects in this study. Two of the patients (LM and RE) did show improved implicit localisation of visual targets presented in the blind hemifield for the arm-extended condition relative to the arm-in-lap condition, although the other three patients showed the reverse effect. None of the changes in accuracy were statistically significant, possibly due to insufficient statistical power. However, it is worth noting that the largest improvement for any patient in explicit visual detection was only 2.6%, which is substantially lower than the 11.2% improvement reported by Schendel and Robertson. This implies that the differences in the methods used are the more likely explanation for the discrepancy between the findings.

The differences in method between the studies were outlined in the introduction to this chapter. Notable differences between the two studies are the amount of visual field sparing of the study participants (islands of visual sparing were found in the visual field of WM, Schendel and Robertson's patient), the method of fixation control and controls for criteria-shifting between conditions. For example, extending the arm may have increased WM's awareness of his blind hemifield leading him to expect more stimuli in this location. WM may have made more eye-movements into his blind hemifield, or adjusted his decision criterion or guessing strategy on the basis of this increased awareness. Whilst such confounding variables cannot be excluded in the case of the Schendel and Robertson study, these strategies were not available to the participants in this study, specifically not in experiment 2. Consequently these factors could explain the absence of the effect in this study which was previously obtained by Schendel and Robertson.

The results of this study imply that manipulating the position of the arm within the blind hemifield does not lead to improved implicit or explicit visual perception for patients with HVFDs. Consequently this suggests that extending the arm into the blind hemifield does not provide a successful means of rehabilitation for such patients.

5.4.2 Attention and visual detection

Attention provides a plausible means of explaining the improvement in visual perception reported by Schendel and Robertson (2004) when their patient extended his arm into his blind hemifield. It is proposed that the extended arm acts as a spatial attention attractor: attention is shifted to the location of the arm thereby enhancing the processing of any near-threshold sensory information in this area. As such, this would mean that manipulating arm position does not restore the lost portions of the visual field but rather enhances the ability to detect preserved yet degraded visual information. In accordance with this proposal Bestmann, Ruff, Blakemore, Driver and Thilo (2007) found that phosphenes (which are perceptual experiences of light in the absence of light stimulation) could be generated using a lower intensity of transcranial magnetic stimulation directly applied over the visual cortex when the participant consciously attended to the perceived location than when they did not direct attention in such a manner. As such it appears that spatial attention can modify the excitability of visual cortex, and this could underlie the improved visual detection effect observed by Schendel and Robertson.

The modulation of attention can not only explain the findings of this study, but can also explain the differences between the results obtained here and those previously reported by Schendel and Robertson. Recent research has shown that attending to a specific location enhances the detectability of stimuli which are visually presented in or near to the attended location (Smith & Schenk, 2008). Reed, Grubb and Steele (2006) showed that positioning the arm into one visual hemifield shifts spatial attention to the same location, specifically if there is additional movement of the fingers. Furthermore, the visual abilities of healthy participants can be modified by the position of the hands; people take more time to disengage their attention when objects of interest are positioned close to the hand (Abrams, Davoli, Du, Knapp, & Paull, 2008). In fact, patients with neglect are routinely offered therapy in order to increase attention to the neglected side by positioning the arm into the affected side and using finger manipulation (Robertson, McMillan, MacLeod, Edgeworth & Brock, 2002). As such, it is perhaps not too surprising that extending the arm into the impaired portion of the visual field may benefit patients with partial visual loss.

The explanation based on the modulation of attention does however assume that visual functioning is not completely destroyed in the patient's blind hemifield. The visual field assessment of Schendel and Robertson's patient (WM) revealed that he had islands of degraded but preserved vision in his blind hemifield, and these measurements may even have underestimated the true extent of WM's spared vision due to the method of fixation control. Previous studies using both healthy participants and patients with neglect have shown that dual-tasks which increase the attentional load at fixation disrupt processing of the periphery of the visual field, thereby reducing the detection of peripheral visual targets (Cartwright-Finch & Lavie, 2007; Lavie, 2005; Lavie & Robertson, 2001; Russell et al., 2004; Santangelo & Belardinelli, 2007). Since Schendel and Robertson used a central fixation task they therefore turned the visual field assessment into a dual-task and, as such, WM's true ability to detect stimuli in his blind hemifield may have been substantially greater than observed. Consequently, it may be the case that extending the arm shifted attention towards the blind hemifield thereby counteracting the attentional pull towards the centre which was induced by the second task conducted at fixation. The improvement in detection found for the arm-extended condition may then be interpreted as reflecting the true state of preserved vision in the blind hemifield compared to the artificially induced suppressed state resulting from the central task in the standard condition.

In this study there was no significant effect of manipulating the arm position on the explicit detection of visual stimuli. This is in accordance with the findings of another study recently published (Brown, Kroliczak, Demonet & Goodale, 2008) which also attempted to replicate the findings of Schendel and Robertson. Using a case study Brown et al. failed to observe a significant improvement in conscious visual detection when the arm was placed near the visual target, although this study also suffered from some of the same weaknesses associated with the Schendel and Robertson study. This included as a single patient design (at least for some of the experimental tasks), an additional task at fixation (although they did directly monitor eye-movements as well) and the inability to account for criterion-shifts. As already mentioned the attention modulation account assumes that vision is not completely destroyed in the blind areas of the visual field. The patients who participated in this study, and also the patient studied by Brown et al., did not show any evidence of notable preserved vision in their blind areas. This could explain why the increase in attention provided by placing the arm into the extended position did not lead to improved visual detection as it did for WM in Schendel and Robertson's study.

Schendel and Robertson also observed an improvement in visual detection when the display was positioned 180cm away and WM held a tennis racket which extended his reach towards the monitor. They attributed this improvement to the expansion of the receptive fields of the visuo-tactile neurons centred on the arm. However, this explanation is unlikely since WM simply held the racket and did not actively use it. Maravita and Iriki (2004) have previously shown that passively holding a tool is not sufficient to expand the visual receptive fields. Furthermore, in the Schendel and Robertson study WM's reach when holding the racket was approximately 120cm, and the stimuli were presented 180cm away from the tool. However, bimodal receptive fields extend to an approximate maximum distance of 20cm from the hand (Graziano, Hu & Gross, 1997). With reference to WM, his receptive fields would have to have extended at least 60cm beyond the end of the tool in order for them to influence visual processing. An extension to the receptive fields of this magnitude in the absence of any active reaching practice seems highly improbable. An alternative, more plausible explanation is that the tool biased attention towards this spatial location and consequently improved visual detection.

The previous results on multisensory audio-visual integration from Bolognini et al. (2005) also fit with a theory based on the modulation of attention. Bolognini et al. observed improvements in visual detection following systematic audio-visual stimulation training, although only when eye-movements were permitted. These findings can be interpreted as demonstrating that information from one modality (for example auditory) can increase visual attention to a spatial location which then enables more efficient eye-movements to this position, thereby enhancing visual perception. In other words, the auditory tone may provide a guide as to the direction and amplitude of saccade required to detect the visual target. Therefore, with regards to arm position it may be that this manipulation could enhance visual processing in the blind hemifield of patients with incomplete HVFDs, but potentially also those with dense HVFDs if saccades are allowed. Repositioning the arm could increase awareness of the specific location thereby increasing oculomotor searching and improving perception. Recently Thura, Boussaoud and Meunier (2008) found that positioning the hand into a specific location (even if the hand cannot be seen) influenced the onset of saccades to the same location. The authors propose that non-visual signals from the hand can influence the oculomotor system and thereby affect saccades, and it is possible that such an influence is attentional. These results demonstrate the interaction between modalities via oculomotor behaviour, which fit with an attentional account of multisensory integration.

An account based on the modulation of attention can not only explain the observations of Schendel and Robertson, but can also explain the differences between studies. If the findings of Schendel and Robertson are explained in terms of attention then it is unclear whether or not bimodal neurons are involved. Therefore, the existence of attentional effects resulting from arm manipulation is insufficient to prove the existence of bimodal neurons in the human cortex.

5.4.3 The future of HVFD rehabilitation

It is important to note that the lack of any statistically significant effect in this study does not prove that manipulating arm position does not enhance visual performance. It might be the case that manipulating arm-position proves a successful means of enhancing visual processing in specific cases (i.e. those patients with HVFDs who have degraded but preserved residual vision in the blind hemifield).

In this study the largest improvements were observed for the implicit visual localisation task, although even these changes were non-significant. However, Brown et al. (2008) did observe a significant arm-manipulation effect on unconscious visual function, namely grip-scaling size estimation. They also determined that this effect could not be entirely attributed to shifts in spatial attention since extending the ipsilesional arm into the blind hemifield did not produce the same result. However, even if unconscious visual functioning can be enhanced in the blind hemifield by manipulating arm position, this is a different ability to the improved conscious vision claimed by Schendel and Robertson (2004). Previous research has shown that it is possible to increase blindsight abilities with repeated practice (Sahraie et al., 2006), but the clinical and rehabilitation relevance of this improvement relative to that for conscious vision remains unclear.

Rather than trying to restore the lost visual abilities of patients with HVFDs, research efforts should instead focus on trying to help patients to adapt to their visual loss using compensatory therapies, the approach to HVFD rehabilitation for which there is the most promising evidence (Lane et al., 2008). Whilst it appears that multisensory integration may not lead to restorative effects this is not to imply that multisensory approaches should be dismissed entirely. It is possible that cross-modal integration may facilitate behavioural adaptation. Visual stimuli presented in the blind hemifield which are not consciously detected can improve the localisation of sounds (Leo, Bolognini, Passamonti, Stein & Làdavas, 2008) and similarly auditory stimuli spatially aligned with visual targets can improve visual processing in the blind hemifield for patients with HVFDs (Bolognini et al., 2005; Frassinetti, Bolognini, Bottari, Bonora & Làdavas, 2005). Bolognini et al. (2005) found that systematic audio-visual stimulation could ameliorate visual field loss in HVFD patients, although only when patients were allowed to make eye-movements. Therefore, this implies that audio-visual integration may mediate the effect on visual detection via improvements in oculomotor behaviour, and highlights the importance of ensuring that patients are fixating adequately when assessing visual performance. Bolognini et al. propose that adding auditory stimulation to visual stimulation orients attention to the blind hemifield and improves visual exploration by enhancing the responsiveness of the oculomotor system. These findings suggest that not only is it possible to combine information across different modalities, even when one is impaired, but that this may be beneficial for patients with HVFDs by assisting compensation.

Whilst manipulating arm position may not directly improve visual detection, it is possible that it indirectly orients attention to the blind hemifield and subsequently facilitates visual processing. As outlined in the previous chapter, enhancing attention can improve the visual functioning of patients with HVFDs and therefore there is clearly a role for attention in compensating for visual field loss. It is worth examining whether or not extending the patient's arm could improve their visual functioning if saccades are allowed.

Given the lack of significant effects observed in this study the future of HVFD rehabilitation should focus on the therapy for which there is the greatest evidence: compensatory exploration training. The evidence from Bolognini et al. (2005) does however suggest that multisensory integration may be useful for enhancing the process of compensation, and therefore perhaps should be incorporated into compensatory HVFD rehabilitation. Research needs to explore the relationship between attention, cross-modal integration and compensation. Perhaps cross-modal associations can be used to maximise compensation, using information from different modalities to increase attention and facilitate adaptation.

5.4.4 Conclusion

The results of this study do not replicate the previous findings of Schendel and Robertson (2004), instead implying that manipulating arm position does not improve either explicit or implicit target detection in the blind hemifield of patients with dense HVFDs. Consequently this finding suggests that arm manipulation may not provide a successful means of rehabilitation for the majority of patients and, as such, efforts should be focussed towards more promising rehabilitation approaches, for example behavioural compensation.

Chapter 6: General discussion

Homonymous visual field defects (HVFDs) are a relatively common consequence of acquired brain injury (Kerkhoff, 1999), the chance of extensive and meaningful spontaneous recovery of the visual field is unlikely (Pambakian & Kennard, 1997), and the behavioural consequences are extensive and very disabling. These issues highlight the importance of helping patients to rehabilitate their visual deficit. Three main approaches to HVFD rehabilitation have been developed: restorative, optical aids and compensatory. The efficacy of these interventions has not previously been established. This chapter will firstly consider the evidence relating to restorative approaches, including a technique based upon the manipulation of arm position (as introduced in Chapter 5), and will then consider the implications of the research reported in this thesis for compensatory approaches to HVFD rehabilitation (Chapters 2 to 4).

6.1 Restoration of the visual field

The aim of restorative approaches is to increase the visual field of patients with HVFDs and the main technique available is visual restoration training (VRT). Whilst the early evidence relating to this approach appeared promising (Kasten et al., 1998, 2001), more recent research into the efficacy of VRT has failed to conclusively show that the intervention leads to significant visual restoration (Reinhard et al., 2005; Sabel et al., 2004; Schreiber et al., 2006). The inconsistency in the results appears to be associated with the method used to control fixation during the perimetry, indicating that changes in fixation or small undetectable saccades may underlie any supposed visual restoration. Given the time, effort and cost associated with VRT it does not seem worthwhile pursuing this as an intervention for the majority of patients with HVFDs.

However, Schendel and Robertson (2004) proposed an alternative avenue for visual field restoration. They found that extending a patient's arm into their blind hemifield could improve the detection of visual stimuli presented in this location. If manipulating arm position could alleviate visual field loss then this would provide a simple, cheap and effective means of visual rehabilitation for patients with HVFDs. The reliability of the study by Schendel and Robertson was limited by several factors; a single patient was examined (WM) who had islands of degraded but remaining vision within his blind hemifield, the method of assessment used could not reliably exclude shifts in fixation from the results, and confounds such as criteria-shifts between task conditions could also not be dismissed. Therefore, a study was conducted to examine whether or not the arm-manipulation effect was reliable and robust (Smith et al., 2008 and Chapter 5). The results showed that manipulating arm position could not increase visual detection in the blind hemifield for the majority of patients with HVFDs. The results were interpreted as indicating that extending the arm into the blind hemifield biases orientation towards this location, but only if there are areas of residual vision within the blind hemifield that can be utilised by the patient. This attention bias in turn enhances the processing of any near-threshold information located in this area, thus bringing previously undetected stimuli presented in areas of degraded vision above the threshold for conscious detection. However, if the patient cannot draw upon such resources then manipulating arm position is unlikely to enhance visual detection.

The results further revealed that the same manipulation of arm position could not improve the implicit ability to localise targets presented in the blind hemifield. This finding indicates that biasing orientation does not enhance unconscious visual processing for patients without residual vision. However, this is in opposition to the results of Brown et al. (2008) who found an improvement in implicit visual functioning (grip scaling size estimation) when the patient extended their contralesional arm into the blind hemifield, although extending the ipsilesional arm into the same position did not lead to the same effect. It is difficult to compare the results of Chapter 5 with those of Brown et al., since the two tasks used to assess implicit processing were very different. In the study reported in Chapter 5 the implicit task involved patients verbally reporting the location of a visual target, whilst Brown et al. investigated the effect of manipulating arm position on the action of grip scaling. The findings of Brown et al. were based upon only one patient and thus the results of the study reported in Chapter 5 are more robust. However, the clinical relevance of such unconscious, implicit abilities in terms of rehabilitation remains unclear, unlike improvements in conscious visual detection which could be expected to improve the functioning of the patients. Therefore, the results overall indicate that there is little clinical potential of using arm-extension for HVFD rehabilitation.

In summary, it appears that the modulation of attention account may explain the increase in visual detection reported by Schendel and Robertson. Such an account may also explain the findings from other studies which have examined changes in the visual field. The evidence from both restorative (Poggel, Kasten, Müller-Oehring, Sabel & Brandt, 2001) and compensatory training research (Kerkhoff et al., 1994), including the results outlined in Chapter 2, reveal that some patients do show visual field recovery which extends beyond the expansion possible with a change in fixation. It is possible that enhanced attention reduces the threshold for visual detection in areas of residual vision, thereby increasing the visual field.

Kasten et al. (2007) observed an increase in the visual field after VRT which was not specific to the trained location, and which was correlated with an increase in visual spatial attention. After one month of VRT Marshall et al. (2008) found no significant increase in the visual field of the patients in their sample. However, they did observe altered neuronal activity in areas such as the right dorsolateral prefrontal cortex and posterior parietal cortex associated with a shift in attention. Additionally, Poggel and colleagues (2004, 2006) found that patients can attend to the transition zones stimulated during VRT whilst fixating centrally, and that this can improve target detection in these areas. However, long-term improvements in the detection of visual stimuli presented in the blind hemifield can only be achieved with repeated training.

The importance of selective attention on visual restoration was highlighted by Zihl and von Cramon (1979), who stated that selective attention forced the patients to use their blind hemifields, which increased activity in the remaining areas of visual cortex. Visual field size varies with the time of day suggesting that neuronal sensitivity associated with visual detection can be modulated (Zihl et al., 1977). In accordance with this observation, Bestmann et al. (2007) found that shifting attention to a specific location can enhance the excitability of visual cortex which represents that area of the visual field. This finding lends support to the notion that attention may moderate the thresholds for conscious visual detection, and that altering attention could possibly provide a long-term effect for some patients.

Chapter 2 revealed a significant post-exploration training increase not only in the blind hemifield but also in the seeing hemifield, and a general enhancement of attention provides a plausible explanation for such findings. In further support of this is the observation that the attention training could lead to comparable increases in the blind hemifield as the exploration training (Chapter 4). Therefore, it appears that the effects on the visual field of both VRT and compensatory training could be explained in relation to enhanced attention.

In support of the argument that attention may mediate the pseudo-restorative effects, Trexler (1998) reported upon a patient with a HVFD who was capable of reducing the extent of their field loss voluntarily from a hemianopia to a quadrantanopia via an attentional mechanism. Perhaps the majority of patients are unable to naturally shift attention and create this effect but instead require training to do so and to retain the improvement. It is feasible that patients with areas of relative defect within the blind visual field could therefore achieve greater improvement, which could explain the variable field increases reported after both restorative and compensatory approaches.

The evidence for the efficacy of VRT indicates that the therapy is unlikely to induce significant restoration, at least not for the majority of patients. The results reported in this thesis show that manipulating arm position does not influence visual detection, at least not for patients without areas of preserved yet degraded visual functioning, indicating that the technique would not provide a new route for visual field restoration. However, it is possible that extending the arm in the blind hemifield could help improve compensation if eye-movements were permitted, since this could help patients to shift their attention to this location, thus facilitating visual exploration. For those patients with areas of residual vision, increasing attention to these locations may also increase visual detection. Overall, the evidence suggests that attempts to restore the visual field should be dismissed and efforts concentrated on establishing the efficacy of compensatory behavioural interventions.

6.2 Compensatory training

The compensatory therapies for the rehabilitation of HVFDs acknowledge that significant restoration of the visual field is not a likely outcome for many patients, and instead focus on helping the patient to function at an improved level despite persistent visual loss. Compensatory training aims to facilitate oculomotor modification such that patients can use intentional, directed eye-movements to compensate for their loss of vision. Whilst this is the approach to HVFD rehabilitation which is generally accepted as the most promising (Bouwmeester et al., 2008; Lane et al., 2008; Pambakian et al., 2005; Pelak et al., 2007), in order to establish the clinical efficacy it is important that the intervention meets three criteria. Firstly the therapy should lead to improvements which are transferable, secondly the training should lead to stable improvements, and lastly it is important to demonstrate the efficacy of the therapy over a placebo condition. The following sections will address each of these criteria in turn.

6.2.1 The transferability of the benefits of compensatory training

It is important that the compensatory exploration training should lead to improvements which extend beyond the training itself. Demonstrating such transfer of training benefits would mean that one intervention would be sufficient to alleviate general impairment and disability, without every individual task of daily life having to be trained independently. This issue was addressed in Chapter 2 of this thesis. The findings revealed that the exploration training led to significant improvements in the performance of three visual search tasks which used different stimuli and search strategies to those involved in the training. This observation indicates that the improvement in visual search is not restricted to particular visual stimuli and, thus, that it is not the detection of specific items which has improved post-training. Rather since the benefit generalised across various displays this implies an improvement in the general search process as a result of the exploration training. This confirms previous findings with regards to compensatory training (Pommerenke & Markowitsch, 1989; Kerkhoff et al., 1994), and demonstrates such generalisation for the specific exploration training and the parameters employed.

An important finding from the study was that training 30° of the horizontal visual field led to generalised improvements in visual search extending beyond this trained area. This means that the exploration training can be performed on a standard computer monitor in the patients' own homes (as previously done by Pambakian et al., 2004). Therefore, the training is a portable and practical rehabilitation option, which can still lead to improvements in visual search that extend across the wider visual field. Previous researchers used exploration training which extended across the entire visual field (Nelles et al., 2001), and the results of this study suggest that this is not necessary in order to achieve benefits in large display search.

It is more typical in everyday life to search for three-dimensional objects and quite often an overt motor response is required (for example, picking up the target item when you have located it). Therefore, an important aspect of generalisation is whether or not the benefits of the training transfer to such scenarios. The results from Chapter 2 demonstrated effective transfer of the exploration training to a 'visuomotor search' task which involved visually-guided search actions using three-dimensional displays. Thus, the training can improve visual search using a more typical behavioural response. In accordance with this finding, Kerkhoff et al. (1994) reported that after the exploration training the patients' performance at a search task using real everyday items improved, although generalisation to some everyday situations had been included in the training program which the patients received in that study. Pambakian et al. (2004) found that patients improved at visuomotor activity of daily living (ADL) tasks (such as sequentially searching for and threading beads) following training in the absence of additional transfer training. Furthermore, Pambakian et al. found the effect to be greater than could be obtained by a motor improvement alone. The results reported here confirm that post-training improvements can be found for visual search tasks which involve the visuomotor domain, without the need to include such transfer as part of the training procedure itself.

However, the exploration training did not improve the reading performance of the patients, a finding confirmed in the study described in Chapter 4. The benefits of exploration training on objective reading ability had not been previously reported, and this study implies that reading requires specific intervention. However, Bolognini et al. (2005) did find that a form of compensatory training which involved combining auditory stimuli with saccadic localisation tasks did improve reading ability, and it is possible that the type of saccades acquired during the course of the training influences whether or not the benefits transfer to this task. Reading requires a very particular pattern of saccades (Rayner, 1998) and training which encourages similar horizontal eye-movements (like that used by Bolognini et al.) may generalise to such tasks, whilst a training which encourages more general searching saccades may not benefit reading. Subjective assessment of reading had been previously reported to improve after exploration training (Nelles et al., 2001), and this effect was supported by the findings in Chapter 2, although not by those reported in Chapter 4. Of course the reliability of such subjective measures of ADLs is questionable since the results of the study reported in Chapter 2 revealed a significant post-exploration training subjective improvement in the absence of an objective change in reading performance. Therefore, caution should be exercised when interpreting subjective measures of ADLs.

Overall, the results suggest that the compensatory exploration training utilising small-scale visual search can meet the first evaluative criterion, which is generalisation. Whilst not every task can benefit (specifically not reading), it appears that the training benefits do transfer to those tasks which require some exploration of the visual scene. This generalisation is regardless of the additional requirements of the search tasks, for example the use of a different behavioural response or the need to search across more of the visual field than involved in the training. This indicates therapeutic transfer to more realistic search tasks without the need to directly train transfer to such scenarios. As such, the portable exploration training system is capable of leading to significant improvements in performance.

6.2.2 The stability of the post-compensatory training improvements

It is clinically important that the compensatory exploration training should induce long-lasting improvements in behaviour, since this would mean that training would not have to be ongoing in order to achieve improved functioning. This is an essential issue to consider since rehabilitation does need to be practical and cost-effective.

The results reported in Chapter 3 showed that the visual search improvements obtained after the exploration training for several of the tasks were stable for six months in the absence of any additional intervention. This is in accordance with previous research, which revealed that the improvement in visual search obtained after compensatory training can be maintained over a follow-up period of at least one month (Kerkhoff et al., 1992b; Kerkhoff et al., 1994; Nelles et al., 2001; Pambakian et al., 2004; Zihl, 2000). Kerkhoff et al. (1992b) even observed this stability over a follow-up period of 22 months.

For several of the tasks ('count the dots', 'count the numbers' and 'projected search') the effects were difficult to interpret reliably as a consequence of the reduced statistical power associated with sample attrition, and therefore, it would be worth further examining this issue using a larger sample. Despite this, the results do provide evidence that the improvements in at least some transfer tasks, such as 'visuomotor search' and 'find the number' visual search, can persist after the cessation of the training. Furthermore, the results for the remainder of the tasks do suggest stability of improvement as well, despite the lack of statistical significance. Significant long-term effects of the training have been observed for visual search tasks involving three-dimensional objects randomly presented atop a table

(Kerkhoff et al., 1994) in accordance with the results reported here, although the study reported in Chapter 3 is the first evidence for the stability of post-training improvements for a variety of tasks. Although post-training improvement for some tasks proposed to represent ADLs had previously been demonstrated (Pambakian et al., 2004) the long-term benefit was not examined in that study.

The results of Chapter 3 further revealed that those tasks which did not benefit initially after training (for example reading) did not change significantly across the follow-up period either. This indicates that the transferable benefits of the training are seen relatively quickly (within the time course of the training itself) and that if performance of a task does not improve within this time then it is unlikely to improve as a later consequence. This at least appears to be the case for the assortment of tasks assessed in this thesis.

Overall, in relation to the evaluation criterion of the stability of therapeutic effects, the evidence indicates that the benefits of the training found for the various visual search tasks extend for at least six months in the absence of any additional intervention. This is of practical importance since the presence of persistent transferable benefits indicates that the therapy can have a significant effect on functioning which lasts substantially longer than the course of the training.

6.2.3 The efficacy of the compensatory training compared to a placebo therapy

It is important to demonstrate the efficacy of an intervention as compared to a placebo condition, in order to determine the specific effects of the treatment, and to justify its use over an alternative with regards to the cost and effort required. No previous placebo controlled research has been conducted to examine the efficacy of exploration training for patients with HVFDs. The study reported in Chapter 4 addressed this issue. The study compared the effectiveness of the compensatory exploration training to a placebo therapy which trained attention in the absence of searching eye-movements. A placebo training based on attention was selected since it is possible that the exploration training benefits could be explained as a consequence of enhanced attention as opposed to improved exploration. Therefore, this condition also allowed the examination of the relative contribution of exploration over a purely attentional effect.

The results of the study showed that for the majority of the tasks there was no significant difference between the effects of the attention training and those of the exploration training. For one visual search task ('find the number') the exploration training was conclusively found to be superior to the attention training, however, training-specific effects were not reliably observed for any of the other assessment tasks. The 'find the number' task was very similar to the exploration training itself with regards to the task requirements, and this similarity between the two could explain why training-specific effects were observed for this task but not for the others. It is likely that specific skills are acquired as part of the training and if the same combination of skills is required in the transfer task then there appears to be a greater enhancement in performance, whereas tasks which rely upon only a subset of the skills show less benefit. This indicates that there may be both general and specific components of the training, which is in accordance with other areas of cognitive rehabilitation (Sohlberg & Mateer, 2001). In the field of clinical neuropsychology generalisation of training is not achievable for the most part, and subsequently it is believed that therapy should train a variety of skills rather than focusing on one deficient area.

It is important to understand what might explain why, for most tasks, the exploration training and the attention training did not produce significantly different outcomes. It is possible that the duration of the exploration training was not sufficient to achieve maximal gains, especially if one considers that performance did not plateau across the course of the training as it did with the attention training.

Therefore, it may be the case that extending the duration of the exploration training would increase the efficacy of the intervention, and thereby increase the likelihood of establishing the superiority of the technique over the placebo condition.

If the effects of the two training types are accepted as comparable then the question arises as to what may account for the placebo effects. Previously researchers have demonstrated improvements in visual search which are training-specific in so far as the therapy led to increased search performance to a greater extent than when no intervention was provided in a repeated baseline condition (Kerkhoff et al., 1994; Pambakian et al., 2004). This allows one to determine that the improvement in visual search is the result of the exploration training rather than being the product of repeated testing effects for example. As such, it seems likely that spontaneous improvements can be disregarded since the attention training effects are more pronounced than those observed in the waiting groups.

Currently the mechanism by which the attention training mediates the improvement in search is unknown, although two likely contributing factors are the patients' awareness of their HVFD and visual attention (as discussed in Chapter 4). These factors may be considered to be related or independent. Greater awareness of the HVFD is associated with improved functional outcome (Sherer et al., 1998) and it is likely that being involved in therapy increases the patients' insight of their impairments, which may then lead to improved performance on a variety of tasks. In daily life, patients become more aware of their HVFD with time and as they experience behavioural problems as a consequence of their visual loss (for example, bumping into obstacles). Perhaps being involved in training which encourages patients to consciously think about their visual field loss also encourages them to alter their behaviour in an appropriate compensatory manner. Visual attention is involved in both the attention training and the exploration training and subsequently a general enhancement in attention may underlie the comparable improvements found with each. The fact that the patients demonstrated an improvement with regards to the attention training task over the course of the training period suggests that they did experience an improvement in attention. Modulation of attention may not only account for the improvements in visual exploration but can also potentially explain the pseudo-restoration of the visual field (as discussed earlier). It appears that the effect of the attentional enhancement on compensatory and restorative rehabilitation may have previously been underestimated.

The results reported show that the exploration training does not meet the final criterion applied to the evaluation of the intervention: the efficacy of the therapy is not greater than can be achieved with a placebo. Consequently the transferable and stable benefits of the exploration training may also be a result of placebo effects.

6.3 Conclusion

Developing effective rehabilitation approaches for patients with HVFDs is important in order to improve functioning for a relatively numerous portion of patients with brain injury. The results show that visual restoration can be dismissed as a likely outcome for the majority of patients following any rehabilitation approach (except possibly those with extensive areas of residual vision). Instead rehabilitation should focus on the compensatory approach.

In summary, the results show that the compensatory exploration training can lead to transferable and stable improvements in various tasks which include an element of visual exploration, including tasks that are more representative of search in everyday scenarios. However, for only the visual search task most similar to the training was the benefit reliably established over a placebo condition which trained attention in the absence of exploration. The results further revealed that neither the attention training nor the exploration training could improve reading performance significantly. As such, this indicates that rehabilitation should be task specific in order to achieve maximum gain. Since the improvements in various visual search tasks can be achieved with an attention training it is possible that enhancing attention may ameliorate some functional impairment for patients with HVFDs, although the training is also likely to increase the patients' awareness of their visual loss and this too may contribute to the success of the therapy.

The main theme that has become apparent through the studies reported in this thesis is that the importance of attention in HVFD rehabilitation has previously been underestimated (both in visual restoration and compensation). Establishing the role which attention has to play in such approaches may offer new avenues for understanding HVFDs and improving rehabilitation processes.

6.3.1 Clinical implications of the research findings

It is important to note that, since the exploration training is not more effective at improving visual search behaviour (for the most part) than the general attention training, attention may have a more integral role in the rehabilitation of HVFDs than previously acknowledged. The finding that training attention may improve visual search supports the statement by Cole (1999), who interpreted his own HVFD-related exploration problems as a "deficit of visual attention rather than of vision" (pp. 173). Subsequently, training attention may be a good starting point for rehabilitation for many patients with HVFDs. Furthermore, it is perhaps not just patients with HVFDs who should be offered attention training, since deficits in attention are a pervasive problem amongst patients with brain damage (Lincoln et al., 2008; McKinlay et al., 1981). It is possible that all such patients could benefit from an intervention which aims to improve processes of attention. There are therapies which have been developed to enhance attention for neuropsychological patients, including Attention Process Training (Sohlberg & Mateer, 1987) which involves various training tasks aimed at enhancing a range of different types of attention including sustained, selective and divided. For a summary and evaluation of this training see Sohlberg and Mateer (2001). It is important to establish whether or not enhancing attention through training could help patients to rehabilitate successfully following brain injury.

Many patients have no insight into, or limited awareness of, their visual loss immediately after the onset of their HVFD (Celesia et al., 1997; Townend et al., 2007). As such patients may not compensate spontaneously because they are unaware of their visual loss, and therefore, it is important that they recognise their need to compensate in order to do so. This factor may contribute to the placebo effects reported. The clinical implications of this are that patients should be provided with information in order to increase their awareness, knowledge and understanding of their visual loss, in order to improve the chances of them compensating and improving their functional outcomes.

It is possible to achieve specific effects of the exploration training over a placebo therapy, although this was found only for the visual search task which was most similar to those which had been repeatedly practiced as part of the training. This implies that maximal benefit is obtained for the tasks which have been specifically developed as part of the intervention provided. In other words, the patient learns particular skills with repeated practice which are most useful for tasks which require this same particular combination of skills. With regards to less similar transfer tasks the benefit seems to be no greater than can be obtained using a placebo condition, suggesting that the intervention is of little specific benefit to these activities. In accordance with this, compensatory reading training improves reading but not general exploration (Schuett et al, 2008b). This finding supports the concept that training on a particular task can benefit that activity but has little effect on other behaviours. Therefore, for maximal rehabilitation success therapy is required which provides practice for specific everyday activities directly. The goals of rehabilitation need to be functional and relevant to the individual patient. For example, not all patients have problems with reading and therefore it would not seem worthwhile to provide reading training if a patient does not present with hemianopic dyslexia. The same is true for activities such as crossing the street and shopping. Therefore, rehabilitation should focus on the identifying, setting and training of specific therapeutic goals. In accordance with this, setting goals is a well-acknowledged component of the rehabilitation process (Wade, 2000). Part of the compensatory training used by Kerkhoff and colleagues (1992b, 1994) involved teaching patients to utilise their newly acquired saccadic strategies in ADL tasks which they had identified as being deficient (i.e. crossing the street). The evidence described here suggests that, in order to maximise the therapeutic benefit for such activities, specific training for these should be provided and future research should attempt to confirm the value of task-specific training.

Finally, it is also worth stating the importance of examining all three of the criteria for therapeutic evaluation together, as has been done in this thesis. If the placebo condition had not been performed one could have concluded effective transfer of the exploration training benefits to many exploration based tasks. Also, if the effect of the placebo condition had not been examined on the various transfer tasks and instead focused on only the 'find the number' visual search task for example, then the efficacy of the exploration training over the placebo could have been confirmed. This highlights how important it is that the three criteria (generalisation of training benefits, stability of effects, and efficacy of a therapy versus a placebo) are considered in conjunction when a rehabilitation approach is evaluated. This approach allows the researcher to examine the interplay between these different elements, all of which are crucial for understanding the clinical efficacy of an intervention.

6.3.2 Limitations of the research and open research questions

One of the main areas of research which it is important to conduct is the reliable establishment of the difference (or lack thereof) between attention and exploration training. The results from Chapter 4 showed that the exploration training had a significant effect on two visual search tasks ('count the dots' and 'count the numbers') when the attention training did not, and yet the magnitude of the two training effects were not found to be significantly different from one another. The current evidence does not allow us to determine which of three possible explanations for this pattern is accurate: that exploration training does not affect the performance of these tasks, that the attention training does have an effect or that the effects of the two types of training are actually different. Therefore, trying to confirm the findings using a larger sample could hopefully elucidate which of these options reflects the effects of the attention training as compared to those of the exploration training.

An additional element to examine would be whether or not the exploration training is currently maximally effective. The most recent evidence (from both Chapters 2 and 4) show that performance of the exploration training does not plateau within the current time course of the therapy (15 sessions). Therefore, it is possible that extending the duration of the exploration training could increase the efficacy of the approach and that this could subsequently lead to improvements which are distinguishable from the effects of the attention training (for which a plateau in performance was found within the current duration). Consequently a longer training duration may help to establish the clinical efficacy of the exploration training as compared to a placebo.

Another way to examine whether or not the attention training is equally as effective as the exploration training would be to evaluate the stability of the training benefits. If the attention training can improve transferable visual search performance immediately, but the improvements are not maintained, then this would suggest that the exploration training may be the more effective approach with regards to rehabilitation (since stability is clinically important). The stability of the exploration training effects would also need to be confirmed however, since the results of Chapter 3 were hindered by reduced statistical power.

Furthermore, future research should address the explicit effects of the potential placebo factors, namely that of attention and awareness, since the mechanism underlying the placebo effect which was reported is not known. Knowledge of the mechanisms which underlie visual compensation is important for determining the most effective way to help patients with HVFDs rehabilitate their defects. Research is required which assesses attention as an independent outcome. It can be assumed that since exploration training necessarily involves aspects of attention that this would be improved by the training also, however, no research has explicitly demonstrated the effect of the training on attention processes. The fact that performance on the attention training task improved over the duration of therapy indicates an enhancement of attention, although it is important to assess this using an independent measure. Furthermore, there are various subtypes of attention including focussed, sustained, selective, alternating and divided (Sohlberg & Mateer, 2001). It would be beneficial to establish the type of attention which can be enhanced by the training and therefore which is most likely to be of benefit with regards to rehabilitation. Kasten et al. (2007) observed that both spatial attention and alertness increased significantly after VRT, and these were also found to be associated with the increase in the visual field, which highlights the importance of assessing attention as an outcome measure.

At present, the results do not allow one to distinguish between the possible mechanisms by which the placebo training might operate. Future research could compare attention training to an alternative such as HVFD education training (whereby the patient receives information about their HVFD in order to increase their understanding of their impairment). This may help to evaluate the efficacy of the attention training, and to examine the contribution of patient insight and alternative placebo effects.

It is possible that the attention training modifies oculomotor function and that this leads to the improvements in visual search performance. The data available currently does not allow one to conclude if attention training is mediating oculomotor behaviour, and therefore it would be valuable to assess if attention training does have any effect on the saccades of patients with HVFDs or not. If it can be established that attention training improves oculomotor function, as has been demonstrated with exploration training (Zihl, 1995a), then it could be determined that the training is influencing visual exploration and not only enhancing attention.

6.3.3 Concluding remarks

Overall, the findings of this thesis confirm that visual restoration is not an achievable outcome for the majority of patients with HVFDs, regardless of the rehabilitation approach used. Whilst the behavioural improvements which can be obtained using compensatory exploration training suggest that transferable and stable benefits are possible with this approach, one needs to bear in mind that these are for the most-part not training-specific effects. Only for the visual search task most similar to the exploration training was the benefit reliably established over a placebo condition which trained attention in the absence of exploration. This suggests that the training has both specific and general components, and that, in order to maximise rehabilitation, specific intervention is required for the particular tasks for which improvement is necessary. The research further highlights the importance of studying the training transfer, stability, and relative efficacy of an intervention versus a placebo within the same study, in order to consider interactions between these components. However, the main element to emphasise is the contribution of attention in the rehabilitation of HVFDs, a role which may previously have been underestimated.

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Appendices

Appendix 1

Details of the data which is missing from the analyses of the exploration training (Chapter 2).

Patient number	Session(s) for which data is missing
1	Dropout
2	
3	5, 6, 7, 8, 9, 10
4	12
5	2, 3, 4, 5, 12, 13, 14, 15
6	
7	
8	
9	6
10	10
11	
12	
13	3
14	Excluded: completed 10 sessions
15	
16	
17	15
18	Dropout
19	
20	12
21	
22	2, 4
23	

Appendix 2

The results of the exploration training for the target-absent condition.

	Mean accuracy (%)		Mean search time (ms)	
	M	*SD*	*M*	*SD*
Block 1	97.20	3.62	2944.92	1111.26
Block 2	97.45	2.69	2544.47	994.18
Block 3	94.40	8.23	1768.24	549.40

Search time:

The search time in block 3 was significantly decreased relative to block 1 ($z = -3.88$, $p < 0.001$, $r = 0.61$).

The search time was significantly decreased in block 2 relative to block 1 ($z = -2.99$, $p = 0.003$, $r = 0.47$).

Accuracy:

The accuracy in block 3 was not significantly different relative to block 1 ($z = -1.85$, $p = 0.065$, $r = 0.29$).

The accuracy was not significantly different between blocks 1 and 2 ($z = -0.24$, $p = 0.811$, $r = 0.04$).

Appendix 3

The results of the projected search task for the target-absent condition (Chapter 2).

	Mean accuracy (%)		Mean search time (ms)	
	M	*SD*	*M*	*SD*
Pre-Training	87.33	21.88	8267.77	6984.52
Post-Training	92.78	18.25	4822.23	1944.87

Search time:

The difference in search time between the two sessions was significant ($z = -3.506$, $p < 0.001$, $r = 0.58$).

Accuracy:

The difference in accuracy between the two sessions was non-significant ($z = -1.520$, $p = 0.130$, $r = 0.25$).

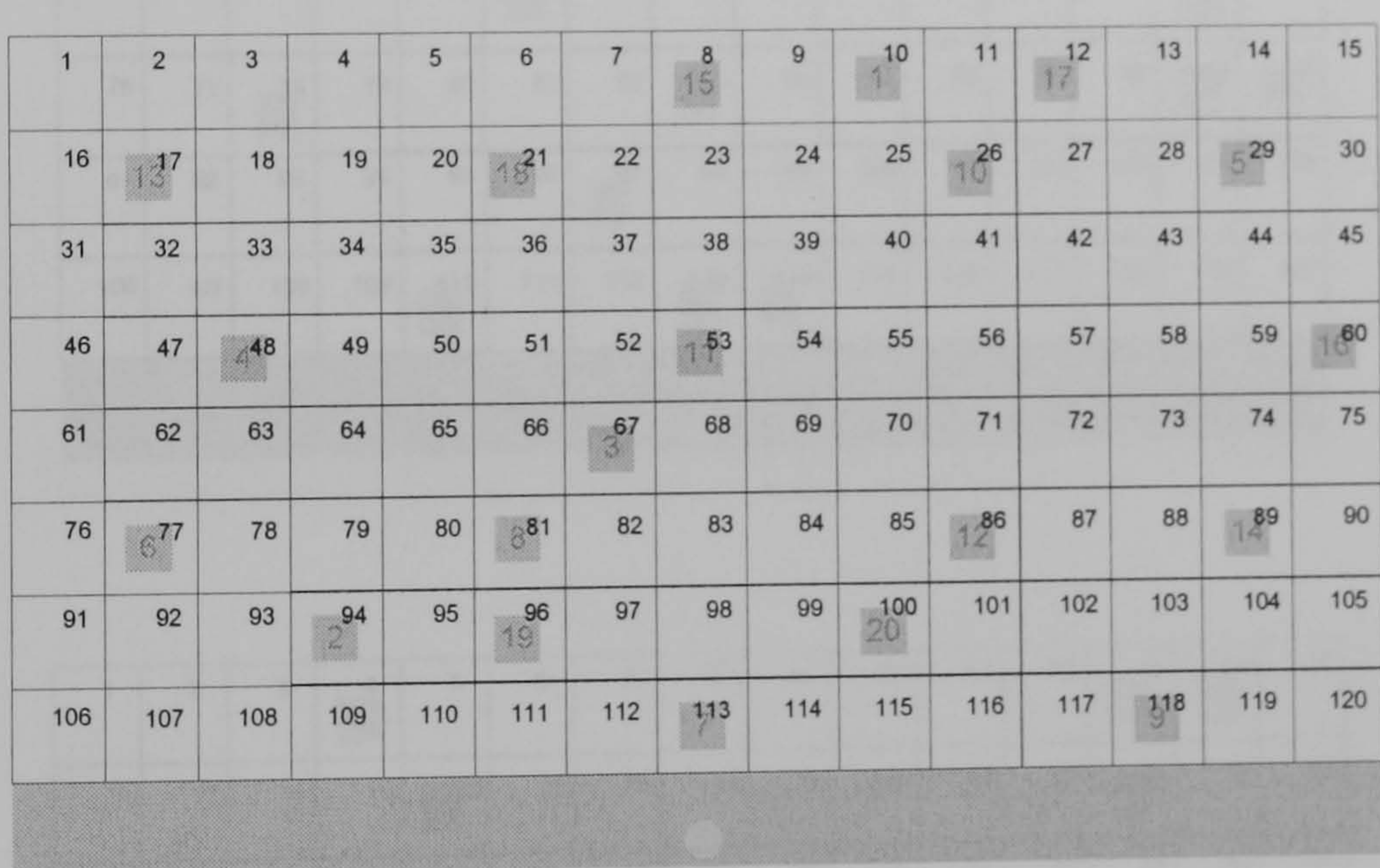
Appendix 4

Details of the arrays generated for the visuomotor search task.

The grid used to position the search items for this task contained 112 numbered square holes, each of which was 3.5cm by 3.5cm, and which were organised in eight rows of 15. The ten layouts were created in a pseudo-random manner. A random number generator (restricted from one to 120) selected the positions for each of the 20 numbered blocks in turn. There were to be five blocks in each quadrant of the grid, and those that fell along the midline belonged to one or other of the quadrants that it was within, but not both. If a coordinate was generated which would violate this arrangement another was chosen until all the numbers were positioned in the array.

Diagrams showing the layout for the numbers in each of the ten trials for the visuomotor search task.

1)



2)

1	2 12	3	4	5	6 15	7	8	9	10	11	12 19	13	14	15
16	17	18	19	20	21	22	23 11	24	25	26	27	28	29	30
31	32	33	34 10	35	36	37	38 17	39	40	41	42	43	44 4	45
46 6	47	48	49	50	51	52	53	54	55 1	56	57	58	59	60 3
61 18	62	63	64	65	66 2	67	68	69 9	70	71	72	73	74	75 7
76	77	78	79	80	81 8	82 20	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100	101	102 5	103 13	104	105 14
106	107 16	108	109	110	111	112	113	114	115	116	117	118	119	120

3)

1	2	3	4	5	6	7 6	8	9	10	11 4	12	13	14	15
16 10	17 5	18	19	20	21	22	23	24	25	26	27	28 20	29	30
31	32	33	34	35	36	37 19	38	39	40	41	42	43	44 7	45
46 15	47	48	49	50	51	52	53	54	55	56 13	57	58	59	60 16
61	62	63	64	65	66 18	67	68	69	70	71	72	73	74 3	75
76	77	78 17	79	80	81	82	83 14	84	85	86	87	88	89 8	90 2
91	92	93	94	95	96	97 9	98	99	100	101	102	103	104	105
106	107	108	109	110 1	111	112	113 12	114 11	115	116	117	118	119	120

4)

1	2	3	4 19	5	6	7	8	9	10	11	12	13 1	14 3	15
16	17	18	19	20 20	21	22	23	24	25	26	27	28 7	29	30
31	32 18	33	34	35	36	37 14	38	39	40	41	42	43	44	45
46	47	48	49	50	51	52 6	53	54	55	56	57 17	58	59	60 5
61	62	63	64 13	65	66	67	68 2	69	70	71	72	73	74	75
76	77	78	79 4	80 9	81	82	83	84	85	86 12	87	88	89 8	90
91	92	93	94	95	96	97	98 10	99	100	101 16	102	103	104	105
106	107	108	109	110 15	111	112	113	114	115	116	117 11	118	119	120

5)

1	2	3	4	5 18	6	7 12	8	9	10	11 7	12 3	13	14	15 20
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
31 5	32	33	34	35 16	36 13	37	38	39 11	40	41	42 17	43	44	45
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68 8	69	70	71	72	73	74	75
76	77	78	79	80 10	81 19	82 6	83	84 15	85 9	86	87	88 14	89	90
91	92	93 4	94	95	96	97	98	99	100	101	102 2	103	104	105
106	107	108	109	110	111	112	113	114	115 1	116	117	118	119	120

6)

1	2	3	4 6	5	6	7	8	9	10	11	12	13	14	15
16	17	18 5	19	20	21	22	23	24	25	26	27	28	29	30
31	32 7	33	34	35	36 18	37	38	39	40	41 15	42	43 3	44 20	45
46	47	48	49	50	51	52 13	53 11	54	55	56	57	58	59 17	60
61	62	63	64	65	66	67	68	69	70	71	72	73	74 8	75
76	77	78	79	80	81 19	82	83	84 2	85	86	87	88	89 14	90
91	92	93	94	95	96	97 16	98	99	100	101	102	103	104 1	105
106 10	107 4	108	109	110 9	111	112	113	114	115	116 12	117	118	119	120

7)

1 11	2	3	4	5	6	7 2	8	9	10	11	12	13	14	15 5
16 1	17	18	19	20	21	22	23	24	25	26 19	27 7	28	29	30
31	32 20	33	34	35	36	37	38	39	40	41	42	43	44	45
46	47	48 4	49	50	51	52	53	54 9	55	56	57	58	59 15	60
61	62	63	64	65	66	67	68 13	69 3	70	71	72 17	73	74	75
76	77	78	79	80	81	82	83 6	84	85	86	87	88	89	90
91	92 16	93 18	94	95	96	97	98 8	99	100	101	102	103	104	105
106 10	107	108	109	110	111	112 12	113	114	115	116	117 14	118	119	120

8)

1	2 (10)	3	4	5	6	7	8 (6)	9 (4)	10	11	12	13	14 (12)	15
16	17	18	19	20	21	22 (14)	23	24	25	26	27	28 (13)	29	30
31	32	33	34	35	36	37	38	39	40	41	42 (9)	43	44	45
46	47	48	49 (8)	50	51	52 (18)	53	54	55	56	57	58	59	60 (5)
61	62 (7)	63 (2)	64	65	66 (15)	67	68	69 (16)	70	71	72	73	74	75
76	77	78 (20)	79	80	81	82	83	84 (1)	85 (11)	86 (19)	87	88	89	90
91	92	93	94 (17)	95	96	97	98	99	100	101	102	103	104	105
106	107	108	109	110	111	112	113	114	115 (3)	116	117	118	119	120

9)

1	2	3	4	5	6 (19)	7 (13)	8	9	10	11	12 (17)	13	14	15
16	17 (10)	18	19 (11)	20	21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40	41 (15)	42	43	44 (2)	45
46	47	48	49	50	51	52	53 (1)	54	55 (7)	56	57	58	59	60 (6)
61 (5)	62	63	64	65	66	67 (3)	68	69	70	71	72 (4)	73	74	75
76	77 (16)	78	79	80 (12)	81	82	83	84 (18)	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100	101	102 (9)	103 (8)	104	105
106	107	108	109	110	111	112 (20)	113	114	115 (14)	116	117	118	119	120

10)

1 (11)	2 (16)	3	4	5	6	7	8	9	10	11	12	13	14	15
16	17	18	19	20	21 (5)	22	23	24	25 (7)	26	27	28 (14)	29	30
31	32	33	34 (4)	35	36 (3)	37	38	39	40 (18)	41	42	43	44 (10)	45
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60 (1)
61	62	63	64 (2)	65	66 (6)	67	68	69 (12)	70	71	72	73	74 (17)	75
76	77	78	79	80	81	82	83	84	85	86 (8)	87	88	89	90
91 (20)	92	93	94	95	96	97	98	99	100	101 (19)	102	103	104	105
106 (13)	107	108	109	110	111	112 (9)	113	114 (15)	115	116	117	118	119	120

Appendix 5

Details of the material used for the reading task. This includes the material for both the text and the number reading tasks.

The passages of text were modified from '*The Grey Gentlemen*' (Ende, 1974) whilst the numbers were generated using a random number generator. All of the reading material was produced using an Arial, type 14 font and was double-spaced. The text passages were one side of A4 in length, and the numbers were approximately half a side of A4 and were positioned such that they filled the central portion of the page. The materials used for these tasks are shown below.

<u>*Text:*</u>

1)

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.

2)

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.

3)

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.

4)

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.

Numbers:

1) 742 935621 83 4067 2592 184053 726015 9441 687932 51493 3018824 967321 54 026841 946 297385 59732 492 110785 638741 31207 84559 2852 66910

2) 634 908215 73 1092 5238 401273 921815 8556 869723 76239 2104495 243976 45 620148 621 946053 97231 013 557024 867429 14295 20914 1741 55809

3) 597 568823 98 7421 6732 990017 413628 3212 795452 85609 7456845 977410 86 382954 328 707865 44875 872 945356 405102 43271 05526 6342 60364

4) 957 865507 36 4217 4598 441104 905229 3784 524841 24393 2458936 833408 14 179542 29 704285 26937 484 934203 650412 74036 21007 9163 59419

Appendix 6

Short answer questionnaire on subjective complaints.

This questionnaire was translated by Thomas Schenk from the German assessment questionnaire developed by Kerkhoff et al (1990). The ten questions (and any sub-questions which were relevant) were read aloud by the researcher and the answers of the patient noted in the space provided. A copy of the questionnaire is provided below.

1. Have you noticed any changes in your ability to see since the start of your neurological condition?
( ) No
( ) Yes
If yes, could you please list those changes?

Could you please indicate when you first noticed these changes?

What do you think is the cause of these changes or how would you explain those changes?

2. Do find reading more difficult than before the start of your neurological condition?
( ) No
( ) Yes

If yes, how would describe those difficulties?
( ) Do you miss words to the left?
( ) Do you miss words to the right?
( ) Do you find it difficult to find the beginning of a line?
( ) Do you find it difficult to remain within a line during reading?

When did you first notice these difficulties?

3. Do you find it difficult to avoid bumping into people, objects or other obstacles? Do you sometimes bump into people or against doorframes?
( ) No
( ) Yes
If yes, which side causes you more problems?
( ) Left
( ) Right

How long have you had these problems?

4. Do you find it difficult to assess the depth of steps when climbing stairs?
( ) No
( ) Yes
If yes, can you describe what you find difficult?

When did you first notice this problem?

5. Are you more easily blinded by bright light than you were before the onset of your neurological condition?
( ) No
( ) Yes
If yes, since when?

6. Do you feel that everything appears now to be darker than before the onset of your neurological condition?
( ) No
( ) Yes
If yes, since when?

7. Do you have the feeling that you need more light for comfortable reading than you did before the onset of your neurological condition?
( ) No
( ) Yes
If yes, since when?

8. Do you have the feeling that your vision is more blurred than before?
( ) No
( ) Yes
If yes, since when?

How would you describe your vision now? (For example, does it feel as though you are looking through dirty glasses or frosted glass? Does it appear as if you are engulfed by fog? Does everything appear blurred?)

Is your vision always blurred or does it become blurred after long periods of exposure to visual stimuli (e.g. reading, working in front of a computer screen)?

How long can you read before the text becomes less distinct?

............minutes.

9. Do colours appear to be as bright and distinct as before?
( ) No
( ) Yes
If yes, do colours now appear to be paler, less saturated, or brighter or somehow different or strange?
If yes, since when?

10. Have you seen light spots (flashes, lines, stars, fog etc.), coloured patterns, people or scenes?
( ) No
( ) Yes
If yes, when did you have these experiences?
( ) Before the onset of your neurological condition
( ) During onset of your neurological condition
( ) After the onset of your neurological condition

For how long did you perceive those visual sensations?

On which side did you experience those visual sensations?
(Did you experience the sensations on the same side as your visual deficit?)
Did you think at the time that these sensations were illusions or did you think they were real objects?

How did you respond to those visual sensations?

---

11. Assessment of the patient's responses by the investigator.
How are the responses?
( ) sufficient and appropriate
( ) lacking in detail
( ) inappropriate and the patient digresses from the topic

Appendix 7

FIM+FAM (UK FIM+FAM Users Group, 1999).

Patients were classified by the researchers on each of the items assessed with a score ranging from one (total dependence) to seven (complete independence). When the behaviour assessed was not witnessed by the researchers (i.e. 'transfer to the shower'), the score was determined based on the comments provided by the patient and their family or carer, or when this was not possible was inferred from what was known about the patient's other abilities. The overall score for the dimension was based on the sum of the score for the individual items which it was comprised of.

List of the sub-sections (and the specific items) of the UK FIM+FAM examined in this study. This is then followed by a general description of the items and the scoring criteria.

Mobility: Transfers: bed / chair / wheelchair; Transfers: toilet; Transfers: tub / shower; Transfers: car; Locomotion: walking / wheelchair; Locomotion: stairs; Community mobility

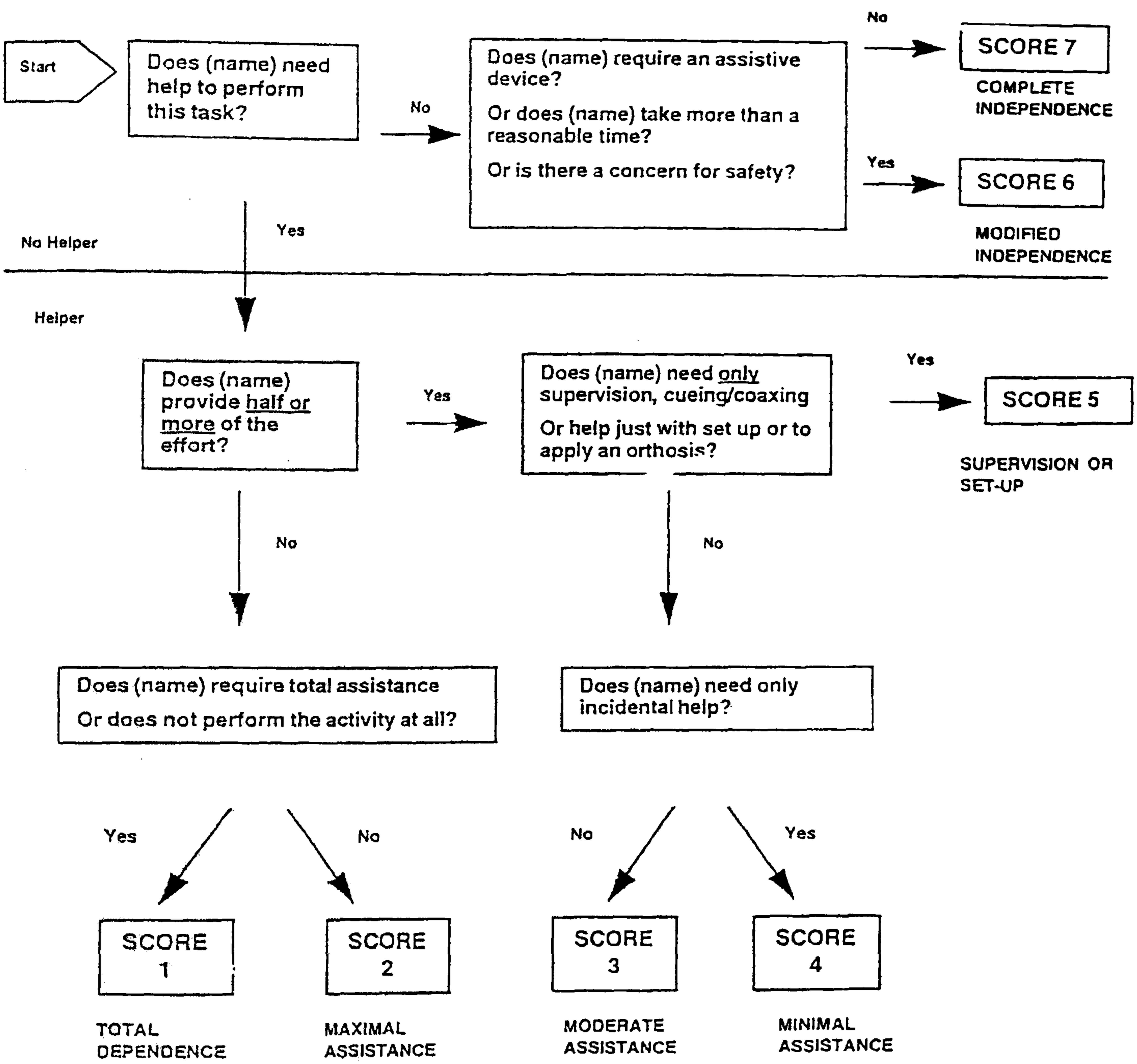
Communication: Expression; Comprehension; Reading; Writing; Speech intelligibility

Psychosocial Functioning: Social interaction; Emotional status; Adjustment to limitations; Use of leisure time

GENERAL DESCRIPTION OF ITEMS

Item includes:	At level 7, the subject :
Various components included in the task	Description of complete independence

Start at the top left hand corner
Follow the tree down



NOTES

Level 7 : Complete independence: Performs independently and safely

Level 6 : Modified independence: Requires an assistive device, or there is consideration for time / safety

Level 5 : Supervision or set-up: Requires only curing or coaxing but no physical contact - or help just with set-up

Level 4 : Minimal assistance: Requires incidental help but performs more than 75% of the task themselves

Level 3 : Requires moderate assistance: but still performs more than half the task themselves

Level 2 : Maximal assistance: provides less than half of the effort to complete the task

Level 1 : Requires total assistance - contributes less than 25% of the effort. Or does not perform the activity at all.

Appendix 8

Euroqol EQ-5D questionnaire (The EuroQol Group, 1990).

This questionnaire contains five dimensions: mobility, self-care, performance of usual activities, pain/discomfort and anxiety/depression. For each dimension there are a set of three statements reflecting the level of severity of impairment (no problems / some or moderate problems / extreme problems), and the participant had to select which of these they perceived as best applying to them at the current time. The second section contains a scale with zero at the bottom to represent the worst possible health state and 100 at the top to represent the best possible health state. The participant was required to mark on the scale their current perceived health state. A copy of the questionnaire is shown below.

By placing a tick in one box in each group below, please indicate which statements best describe your own health state today.

Mobility

I have no problems in walking about ☐

I have some problems in walking about ☐

I am confined to bed ☐

Self-Care

I have no problems with self-care ☐

I have some problems washing or dressing myself ☐

I am unable to wash or dress myself ☐

Usual Activities *(e.g. work, study, housework, family or leisure activities)*

I have no problems with performing my usual activities ☐

I have some problems with performing my usual activities ☐

I am unable to perform my usual activities ☐

Pain/Discomfort

I have no pain or discomfort ☐

I have moderate pain or discomfort ☐

I have extreme pain or discomfort ☐

Anxiety/Depression

I am not anxious or depressed ☐

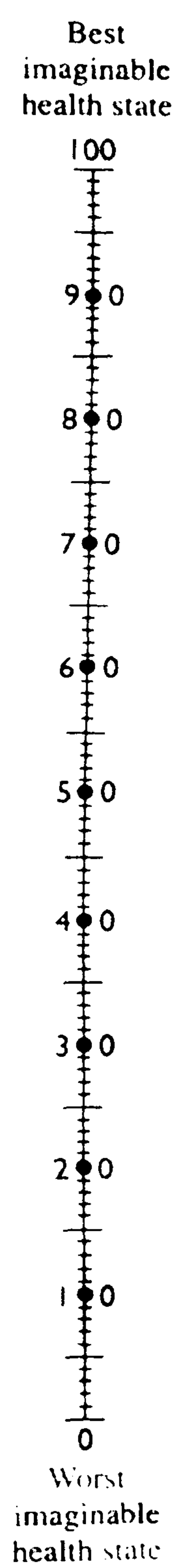
I am moderately anxious or depressed ☐

I am extremely anxious or depressed ☐

To help people say how good or bad a health state is, we have drawn a scale (rather like a Thermometer) on which the best state you can imagine is marked by 100 and the worst state you can imagine is marked by 0.

We would like you to indicate on this scale how good or bad is your health today, in your opinion. Please do this by drawing a line from the box below to whichever point on the scale indicates how good or bad your current health state is.

Your own health state today



Appendix 9

Visual impairments questionnaire.

This questionnaire was adapted from that developed by Kerkhoff et al (1994). The questionnaire was read aloud to the participants who had to rate on a five-point scale the extent to which they had a problem with each item. The scale was as follows: 0, no problem; 1, rare problem; 2, occasional problem; 3, frequent problem; 4, very frequent problem. From the original Kerkhoff version the items 'finding way to clinic' and 'finding way to therapist's room' were removed. This was because the majority of patient's were either brought to the assessment sessions by family or carers, or else were collected by the researcher, and thus these were not deemed to be suitable questions. The item 'reading' was however added. A copy of the questionnaire is shown below.

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 10

The results for the visual impairments questionnaire. The table contains the results of the Wilcoxon signed ranks tests used to compare the two training sessions (pre-training and post-training) for each of the items.

	Wilcoxon: post-pre	
	z	*p*
See Objects	-0.57	0.569
Bumping in Obstacles	-1.42	0.156
Losing Way	-1.00	0.317
Finding Objects on a Table	-0.81	0.417
Finding Objects in a Room	-1.85	0.064
Finding Objects in a Shop	-1.22	0.221
Using Public Transport	-1.00	0.317
Finding Way at Home	-1.34	0.180
Crossing the Street	-1.27	0.204
Reading	-2.51	0.012

Appendix 11

Results from the EQ-5D and the FIM+FAM which were used to assess health-related quality of life.

The table below contains details relating to each of the five dimensions of the EQ-5D. For this questionnaire a score of one indicates 'no problem' whilst the maximum score of three indicates 'extreme difficulty'.

The mean score and standard deviation for the five dimensions of the EQ-5D. Outcomes of the Wilcoxon signed ranks tests performed to compare the pre-training and post-training scores on these dimensions are also shown.

	Pre-Training		**Post-Training**		**Wilcoxon: Post-Pre**	
	M	*SD*	*M*	*SD*	*Z*	*P*
Mobility	1.71	0.46	1.62	0.50	-1.41	0.157
Self-Care	1.24	0.44	1.19	0.40	-1.00	0.317
Performance of Usual Activities	1.43	0.51	1.43	0.51	0.00	1.000
Pain/Discomfort	1.33	0.58	1.43	0.60	-0.82	0.414
Anxiety/Depression	1.33	0.48	1.24	0.44	-1.00	0.317

The following table contains details relating to the dimensions of the FIM+FAM which were assessed: mobility (which had a maximum score of 49), communication (35) and psychosocial functioning (28).

The mean sum score (and standard deviation) for the three dimensions of the FIM+FAM assessed. Outcomes of the Wilcoxon signed ranks tests performed to compare the pre-training and post-training scores on these dimensions are also included.

	Pre-Training		**Post-Training**		**Wilcoxon: Post-Pre**	
	M	*SD*	*M*	*SD*	*Z*	*P*
Mobility	43.48	8.85	43.76	8.75	-1.00	0.317
Communication	34.10	1.18	34.24	1.09	-1.00	0.317
Psychosocial Functioning	27.57	0.75	27.57	0.75	0.00	1.000

Appendix 12

Comparisons of the baseline characteristics of the patients seen at the follow-up session and those patients who were not followed-up.

Age:

	Age (years)	
	M	*SD*
Followed-up	68.21	9.18
Not followed-up	56.57	15.43

The mean age of the patients who were followed-up was not significantly different to the mean age of the patients who were not followed-up (U = 24, p = 0.062, r = 0.41).

Gender:

	Male	*Female*
Followed-up	12	2
Not followed-up	4	3

The proportion of males and females who were followed-up did not differ significantly to those patients not followed-up (Fisher's exact test, p = 0.334).

Time since onset:

	Onset (months)	
	M	*SD*
Followed-up	28.43	71.68
Not followed-up	16.50	18.74

The mean time since the onset of the HVFD did not differ significantly between those patients who were and were not followed-up (U = 38, p = 0.411, r = 0.18).

Side of homonymous visual field defect:

	Left	*Right*
Followed-up	11	3
Not followed-up	5	2

The proportion of patients with left-sided and right-sided HVFDs did not differ significantly between those patients who were and were not followed-up (Fisher's exact test, p = 1.000).

Aetiology:

	Ischemic Stroke	*Haemorrhage*	*Trauma*
Followed-Up	10	3	1
Not followed-up	6	3	0

The proportion of patients whose HVFDs were a consequence of the various aetiologies did not differ significantly between those patients who were and were not followed-up (Monte Carlo Exact test, CI = 99%, p = 0.787).

Visual field sparing:

	Visual field sparing (degrees)	
	M	*SD*
Followed-up	3.14	3.48
Not followed-up	5.43	4.16

The mean amount of visual field sparing did not differ significantly between those patients who were and were not followed-up (U = 30, p = 0.139, r = 0.32).

Appendix 13

Results of the assessment tests comparing the pre-training, post-training and follow-up sessions.

Perimetry

Results of the perimetric assessments for the pre-training, post-training and follow-up sessions. Of the 14 patients who were successfully followed-up, perimetry data is missing for two of these due to technical difficulties.

This table shows the details for the visual field sparing along the most impaired meridian.

	Visual field sparing (degrees)	
	M	*SD*
Pre-Training	3.00	3.63
Post-Training	5.58	5.66
Follow-Up	5.00	4.94

The mean amount of visual field sparing did not differ significantly between the pre-training and follow-up sessions (z = -0.85, p = 0.394, r = 0.17), nor did it differ between the post-training and follow-up sessions (z = -1.73, p = 0.084, r = 0.35).

This table shows the data with regards to the mean amount of sparing along the meridians in each hemifield.

	Sparing in the blind hemifield (°)		**Sparing in the seeing hemifield (°)**	
	M	*SD*	*M*	*SD*
Pre-Training	21.78	14.55	50.47	12.54
Post-Training	26.08	12.85	54.15	10.15
Follow-Up	24.57	12.67	53.54	13.29

The mean amount of visual field sparing in the whole of the blind hemifield did not differ significantly between the pre-training and follow-up sessions (z = -1.80, p =

0.071, r = 0.37), nor did it differ between the post-training and follow-up sessions (*z* = -0.94, p = 0.347, r = 0.19). The mean amount of visual field sparing in the whole of the seeing hemifield did not differ significantly between the pre-training and follow-up sessions (*z* = -1.65, p = 0.099, r = 0.34), nor did it differ between the post-training and follow-up sessions (*z* = -0.16, p = 0.875, r = 0.03).

Reading

These results are based on the 11 patients for whom reading data was available for all three sessions.

Table containing the mean corrected reading speed for text in words per minute and for numbers in digits per minute for each of the three testing sessions.

	Corrected text reading speed (wpm)		**Corrected number reading speed (dpm)**	
	M	*SD*	*M*	*SD*
Pre-Training	112.11	38.56	99.82	28.27
Post-Training	110.95	39.40	97.54	24.95
Follow-Up	114.42	42.74	100.01	29.24

For the text material the difference in reading speed between the pre-training and follow-up sessions was non-significant (*z* = -1.067, p = 0.286, r = 0.23) as was the difference between the post-training and follow-up sessions (*z* = -0.800, p = 0.424, r = 0.17). For the numbers the difference in reading speed between the pre-training and follow-up sessions was non-significant (*z* = -0.445, p = 0.675, r = 0.09) as was the difference between the post-training and follow-up sessions (*z* = -0.178, p = 0.859, r = 0.04).

Activities of daily living questionnaires

EQ-5D

The mean score and standard deviation for the five dimensions of the EQ-5D for each session.

	Pre-Training		Post-Training		Follow-Up	
	M	*SD*	*M*	*SD*	*M*	*SD*
Mobility	1.71	0.47	1.57	0.51	1.79	0.43
Self-Care	1.21	0.43	1.14	0.36	1.21	0.43
Usual Activities	1.43	0.51	1.43	0.51	1.64	0.63
Pain/Discomfort	1.43	0.65	1.43	0.65	1.64	0.63
Anxiety/Depression	1.36	0.50	1.21	0.43	1.36	0.50

Wilcoxon signed ranks tests.

	Follow-up – Pre-Training		Follow-Up – Post-Training	
	Z	*p*	*z*	*p*
Mobility	-1.00	0.317	-1.73	0.083
Self-Care	0.00	1.000	-1.00	0.317
Usual Activities	-1.34	0.180	-1.34	0.180
Pain/Discomfort	-1.34	0.180	-1.13	0.257
Anxiety/Depression	0.00	1.000	-1.41	0.157

The results of the health state scale of the EQ-5D.

	Health state (%)	
	M	*SD*
Pre-Training	67.21	21.52
Post-Training	69.43	20.91
Follow-Up	57.36	16.80

The difference in the mean health state between the pre-training and follow-up sessions was non-significant (z = -0.63, p = 0.066, r = 0.12) as was the difference between the post-training and follow-up sessions (z = -2.38, p = 0.017, r = 0.45).

FIM+FAM

The mean score and standard deviation for the three dimensions of the FIM+FAM.

	Pre-Training		Post-Training		Follow-Up	
	M	*SD*	*M*	*SD*	*M*	*SD*
Mobility	43.07	10.34	43.14	10.35	43.00	10.29
Communication	34.00	1.18	34.00	1.18	34.00	1.18
Psychosocial functioning	27.57	0.76	27.57	0.76	27.57	0.76

Wilcoxon signed ranks tests.

	Follow-up – Pre-Training		Follow-Up – Post-Training	
	Z	*p*	*z*	*p*
Mobility	-0.45	0.655	-1.00	0.000
Communication	0.00	1.000	0.00	1.000
Psychosocial functioning	0.00	1.000	0.00	1.000

Visual Impairments Questionnaire

The mean rating (and standard deviation) for the ten behaviours of the visual impairments questionnaire.

	Pre-Training		Post-Training		Follow-Up	
	M	*SD*	*M*	*SD*	*M*	*SD*
Seeing objects	1.93	1.45	1.57	1.30	1.46	1.05
Bumping into obstacles	1.75	1.53	1.50	1.22	1.43	1.28
Losing way	0.36	0.84	0.29	1.07	0.43	0.76
Finding objects on a table	1.25	1.40	1.18	1.32	1.11	1.18
Finding objects in a room	1.64	1.29	1.07	1.21	0.96	0.97
Finding objects in a shop	1.69	1.65	1.62	1.50	1.62	1.45
Using public transport	0.75	1.49	0.50	1.41	0.88	1.46
Finding way at home	0.14	0.36	0.25	0.58	0.00	0.00
Crossing the street	1.27	1.48	1.00	1.29	1.00	1.47
Reading	2.21	1.31	1.25	1.55	1.00	1.47

Wilcoxon signed ranks tests.

	Follow-Up - Pre-Training		**Follow-Up – Post-Training**	
	Z	*p*	*z*	*p*
Seeing objects	-0.96	0.339	-0.05	0.964
Bumping into obstacles	-1.44	0.151	-0.45	0.655
Losing way	-0.58	0.564	-0.56	0.577
Finding objects on a table	-0.60	0.547	-0.30	0.763
Finding objects in a room	-1.55	0.122	-0.26	0.797
Finding objects in a shop	-0.43	0.666	-0.18	0.861
Using public transport	-0.45	0.655	-1.34	0.180
Finding way at home	-1.41	0.157	-1.60	0.109
Crossing the street	-0.86	0.389	0.00	1.000
Reading	-2.70	0.007	-0.95	0.340

Appendix 14

Statistical analyses comparing the demographic and lesion characteristics of the patients in the attention then exploration training sample and the exploration training only sample.

Age: The mean age of the two samples of patients was not significantly different (U = 117, p = 0.478, r = 0.12).

Visual field sparing: The mean amount of visual field sparing was not significantly different between the two samples of patients (U = 127, p = 0.731, r = 0.14).

Time since onset: The amount of time since HVFD onset was not significantly different between the two patient samples (U = 114, p = 0.414, r = 0.14).

Gender: The proportion of males and females in the two samples was not significantly different (Fisher's exact test, p = 1.000).

Side of homonymous visual field defect: The proportion of patients with left-sided and right-sided HVFDs did not differ significantly between the two samples (Monte Carlo Exact test, CI = 99%, p = 0.540).

Aetiology: The proportion of patients with HVFDs as a consequence of the various aetiologies did not differ significantly between the two samples (Monte Carlo Exact test, CI = 99%, p = 1.000).

Appendix 15

Details of the data which is missing from the analyses of the attention training (Chapter 4).

Patient number	Session(s) for which data is missing
1	2, 6, 8, 9
2	Excluded
3	5
4	2, 7, 8, 9, 10
5	2, 14
6	3, 5, 6, 7, 8, 9, 10, 13
7	9, 10, 11, 12, 13, 14, 15
8	1, 2, 3, 4, 7
9	
10	
11	
12	
13	Excluded
14	
15	8

Appendix 16

The results for the target-absent condition of the attention-based placebo training.

	Mean accuracy (%)		Mean search time (ms)	
	M	*SD*	*M*	*SD*
Block 1	95.16	4.83	1276.82	397.57
Block 2	96.17	2.86	928.04	265.15
Block 3	93.57	5.48	962.25	463.07

Search time:

The search time in block 3 was significantly decreased relative to block 1 ($z = -2.83$, $p = 0.005$, $r = 0.55$).

Accuracy:

The accuracy in block 3 was not significantly different relative to block 1 ($z = -1.33$, $p = 0.182$, $r = 0.26$).

Appendix 17

Details of the data which is missing from the analyses of the exploration training which followed the attention training (Chapter 4).

Patient number	Session(s) for which data is missing
1	6, 7
2	Excluded
3	
4	8, 9, 10
5	13
6	13
7	8
8	6, 7, 10, 12, 15
9	
10	
11	
12	
13	Excluded
14	14, 15
15	

Appendix 18

The results for the target-absent condition of the exploration-based training.

	Mean accuracy (%)		Mean search time (ms)	
	M	*SD*	*M*	*SD*
Block 1	97.82	2.06	2470.70	1540.48
Block 2	98.54	0.83	2081.40	805.62
Block 3	96.67	3.01	1735.69	797.07

Search time:

The search time in block 3 was significantly decreased relative to block 1 ($z = -3.18$, $p = 0.001$, $r = 0.62$).

Accuracy:

The accuracy in block 3 was not significantly different relative to block 1 ($z = -1.86$, $p = 0.064$, $r = 0.36$).

Appendix 19

The results for the target-absent condition of the projected search task.

	Mean accuracy (%)		Mean search time (ms)	
	M	*SD*	*M*	*SD*
Baseline	80.00	27.46	10681.37	16443.03
Post-Attention	87.31	20.78	5012.19	4308.17
Post-Exploration	90.77	13.05	4313.39	2562.32

Search time:

The search time post-attention training was significantly faster than baseline (z = -2.34, p = 0.019, r = 0.46). The search time after the exploration training was not significantly different to the post-attention training session (z = -0.45, p = 0.650, r = 0.09).

Accuracy:

The accuracy post-attention training was not significantly different to the baseline (z = -1. 55, p = 0.121, r = 0.30). The accuracy after the exploration training was not significantly different to the post-attention training session (z = -0.61, p = 0.546, r = 0.12).

Appendix 20

The results of the Wilcoxon signed ranks tests for the ten behaviours assessed as part of the visual impairments questionnaire.

	Wilcoxon: Post-Attention - Baseline			**Wilcoxon: Post-Exploration - Post-Attention**		
	z	*p*	*r*	*z*	*p*	*r*
Seeing objects	-0.64	0.526	0.13	-1.38	0.167	0.27
Avoiding obstacles	-0.26	0.792	0.05	-0.06	0.951	0.01
Losing your way	-0.58	0.564	0.12	-1.00	0.317	0.21
Finding objects on a table	-1.24	0.214	0.24	-1.20	0.229	0.24
Finding objects in a room	-0.12	0.904	0.02	-0.26	0.792	0.05
Finding objects in a shop	-1.05	0.293	0.22	-0.83	0.408	0.18
Using public transport	2.00	0.046	0.58	-1.73	0.083	0.50
Finding way at home	-1.00	0.317	0.20	-1.00	0.317	0.20
Crossing the street	0.00	1.000	0.00	-1.32	0.187	0.27
Reading	-0.06	0.953	0.01	-0.41	0.686	0.08

Appendix 21

Results from the EQ-5D and the FIM+FAM which were used to assess health-related quality-of-life.

The table below contains details relating to each of the five dimensions of the EQ-5D. For this questionnaire a score of one indicates 'no problem' whilst the maximum score of three indicates 'extreme difficulty'.

The mean score and standard deviation for the five dimensions of the EQ-5D.

	Baseline		**Post-attention**		**Post-exploration**	
	M	*SD*	*M*	*SD*	*M*	*SD*
Mobility	1.85	0.38	1.77	0.44	1.69	0.48
Self-Care	1.08	0.28	1.15	0.38	1.08	0.28
Performance of Usual Activities	1.69	0.63	1.69	0.48	1.69	0.48
Pain/Discomfort	1.77	0.73	1.69	0.63	1.54	0.66
Anxiety/Depression	1.69	0.63	1.77	0.73	1.69	0.63

Outcomes of the Wilcoxon signed ranks tests performed to compare the scores from the different sessions on the five dimensions of the EQ-5D.

	Wilcoxon: Post-Attention - Baseline			**Wilcoxon: Post-Exploration - Post-Attention**		
	z	*p*	*r*	*z*	*p*	*r*
Mobility	-1.00	0.317	0.20	-1.00	0.317	0.20
Self-care	-1.00	0.317	0.20	-1.00	0.317	0.20
Usual activities	0.00	1.000	0.00	0.00	1.000	0.00
Pain/discomfort	-0.45	0.655	0.09	-1.00	0.317	0.20
Anxiety/depression	-1.00	0.317	0.20	-0.58	0.564	0.11

The following table contains details relating to the dimensions of the FIM+FAM which were assessed: mobility (which had a maximum score of 49), communication (35) and psychosocial functioning (28).

The mean sum score (and standard deviation) for the three dimensions of the FIM+FAM assessed for each of the assessment sessions.

	Baseline		**Post-attention**		**Post-exploration**	
	M	*SD*	*M*	*SD*	*M*	*SD*
Mobility	46.31	7.94	46.92	5.74	47.38	4.09
Communication	33.85	2.48	33.92	2.36	33.92	2.36
Psychosocial Functioning	27.85	0.38	27.92	0.28	27.92	0.28

The results of the Wilcoxon signed ranks tests for the three dimensions of the FIM+FAM.

	Wilcoxon: Post-Attention - Baseline			**Wilcoxon: Post-Exploration - Post-Attention**		
	z	*p*	*r*	*z*	*p*	*r*
Mobility	-1.00	0.317	0.20	-1.00	0.317	0.20
Communication	-1.00	0.317	0.20	0.00	1.000	0.00
Psychosocial Function	-1.00	0.317	0.20	0.00	1.000	0.00

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