Visual exploration training is no better than attention training for treating hemianopia

Running head: Hemianopia training: exploration vs. attention

Alison R. Lane[1], Daniel T. Smith[1], Amanda Ellison[1] and Thomas Schenk[1]

[1]Cognitive Neuroscience Research Unit, Psychology Department, Durham University, UK.

Corresponding author: Alison Lane

CNRU, Wolfson Research Unit, Durham University Queen's Campus, Stockton-on-Tees, TS17 6BH, UK

Telephone: +44-(0)191-3340431

Facsimile: +44-(0)191-3340006

Email: a.r.lane@durham.ac.uk

The title contains 88 characters and the running head 46 characters (including spaces). The summary contains 200 words and the main body of the manuscript (excluding summary, references, tables and figures) contains 5,224 words.

Summary

Patients with homonymous visual field defects experience disabling functional impairments as a consequence of their visual loss. Compensatory visual exploration training aims to improve the searching skills of these patients in order to help them to cope more effectively. However, until now the efficacy of this training has not been compared to that of a control intervention. Given that exploration training uses the visual search paradigm, which is known to require visual attention, in this study the efficacy of the technique was compared to a training that requires visual attention but not exploration. Participants completed either exploration training (n = 21), or attention training followed by exploration training (n = 21). Assessment of the visual field, visual search, reading and activities of daily living were performed before and after each intervention that the participants completed. The results revealed that both the exploration training and the attention training led to significant improvements in most of the visual tasks. For most of the tasks exploration training did not prove superior to attention training, and for reading both types of intervention failed to yield any benefits. The results indicate that attention plays a large role in the rehabilitation of homonymous visual field defects.

Keywords: compensation; hemianopia; rehabilitation; visual attention

Abbreviations: AT = attention training; ET = exploration training; HVFD = homonymous visual field defect; RT = response time; VIQ = visual impairments questionnaire.

Introduction

A visual deficit is a relatively common consequence of brain injury (Schlageter *et al.*, 1993) and homonymous visual field defects (HVFDs), including hemianopia, are one of the most prevalent problems. The extent of spontaneous visual recovery experienced is variable, it does not occur in all patients and complete recovery is rare (Zihl and Kennard, 1996). Therefore, many patients are left with chronic and disabling visual loss. Patients with HVFDs have difficulties searching their environment, leading to disorientation and problems in avoiding obstacles. HVFDs can impair activities such as reading and driving, and reduce employment opportunities, contributing to feelings of insecurity, isolation and depression (Zihl and Kennard, 1996).

Two main rehabilitative approaches have been examined, and there are numerous reviews available which provide a detailed analysis of each technique (Kerkhoff, 2000; Pambakian *et al.*, 2005; Bouwmeester *et al.*, 2007; Pelak *et al.,* 2007; Lane *et al.*, 2008). Restorative methods, such as vision restoration therapy, aim to partially restore vision through repeated visual stimulation. Whilst controlled studies have found that vision restoration therapy can significantly expand the visual field (Kasten *et al.*, 1998, 2001), the benefits are greater for patients with optic tract lesions rather than cortical damage, and it is the latter that are of interest here. Furthermore, vision restoration therapy is a controversial technique as contradictory findings with regards to visual field expansion have been reported (Kasten *et al.,* 1998, 2001; Sabel *et al.*, 2004; Reinhard *et al.*, 2005; Schreiber *et al.*, 2006; Mueller *et al.*, 2007).

The second, less controversial approach is compensatory visual exploration therapy. Patients with HVFDs often exhibit disorganised oculomotor behaviour (Zihl, 1995a), and consequently the training involves visual search tasks which are designed to encourage more efficient oculomotor exploration. This compensatory training can improve saccadic behaviour, increase the search field (the area of visual space in which stimuli can be detected using eye-movements) and improve visual search performance (Kerkhoff *et al.*, 1992b, 1994; Nelles *et al.*, 2001; Pambakian *et al.*, 2004). Two studies confirmed that the improved search performance was significantly greater than that observed during untrained periods (Kerkhoff *et al.*, 1994; Pambakian *et al.*, 2004), and a recent study reported that the gains are specific to compensatory therapy since they were not found following restorative flicker-stimulation training (Roth *et al.*, 2009). It therefore appears that compensatory training is a promising treatment option for patients with HVFDs. However, what is currently missing is an evaluation study which compares exploration training with an appropriate control intervention.

Visual search tasks require not only efficient exploratory eye-movements, but also visuo-spatial attention – in fact, this paradigm is frequently used to study visual attention (Treisman and Gelade, 1980). No previous study has investigated the relative contribution of these two processes to HVFD compensation, and it is therefore unclear to what extent the improvements are due to specific training of oculomotor exploration or more general improvements in attention. In order to assess the relative effectiveness of these two aspects, the present study compared the efficacy of standard visual exploration training (ET) with visual attention training (AT). All patients were assessed using a variety of outcome measures including perimetry, visual exploration and visuomotor search tasks, reading and a visual disability questionnaire. Furthermore, the study used two intervention groups: one received only ET and the other received both AT and ET. Importantly, assessment on the outcome measures was made both before and after each intervention (including after AT and before ET). Therefore, between-subject and within-subject comparisons could be used to examine whether ET (which incorporates both the elements of attention and exploration) is superior to AT (which involves attention in the absence of exploration).

Methods

Participants

The study was approved by Durham University and the Multi-Centre Research Ethics Committee (05/MRE03/29). Forty-six patients with HVFDs as a consequence of a post-chiasmatic lesion (confirmed by reports from a clinical consultant) participated in the study. The first 23 were assigned to group A (ET), and the last 23 to group B (AT and ET). All gave informed written consent in accordance with the Declaration of Helsinki (International Committee of Medical Journal Editors, 1991). One patient dropped-out from group A through personal choice and another died. One patient dropped-out from group B through illness, whilst another was excluded as a consequence of mid-study neurosurgery. The two groups did not differ with regards to age, gender, aetiology, duration of HVFD or baseline visual search performance (Table 1). All patients had a HVFD, although the extent and laterality of the defect differed on an individual basis (Table 1). Example baseline visual field plots (Figure 1) from two patients demonstrate the individual variability.

Insert Table 1

Insert Figure 1

The exclusion criteria for participant selection included visual field loss as a consequence of pre-chiasmatic or chiasmatic damage, additional eye-movement disorders, photosensitive epilepsy, progressive neurological disorders or insufficient speech, language, cognition or mobility to be able to complete the tasks. Some patients had additional difficulties including hemiplegia or hemiparesis (n = 8), memory and cognitive impairments (n = 4), aphasia (n = 2) and diplopia (n = 2). Four patients (two in each group) had a comorbid neglect as indicated by their medical records and confirmed with the star cancellation task (Halligan *et al.*, 1991). Participants had to be at least 18 years of age. The minimum amount of time that had elapsed since onset was three months in order to minimise confounding by spontaneous recovery (Pambakian and Kennard, 1997).

Study design

Two groups of patients were included in the study. Group A received only ET. Group B received AT followed by ET. This resulted in three training conditions: ET in group A, AT in group B, ET in group B. For each training session patients were assessed on all outcome measures both before and after training. This design allowed within-subject comparisons to be made (AT versus ET within group B), overcoming problems associated with unmatched patient samples by comparing performance within a given patient. However, such comparisons result in possible confounds with order effects – *i.e.* the first training might exhaust training potential thereby reducing the benefit possible with another intervention, potentially underestimating the efficacy of the second therapy. To compensate for this, between-subject comparisons were also made (ET effects in group A versus AT effects in group B).

Training methods

The training programs were created using E-Prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA) and participants conducted the training at home using a laptop computer. Both types of training consisted of 15 sessions and patients completed 288 trials per session (9 tasks with 32 trials each). The computer screen was viewed binocularly at approximately 57 cm. Participants sat comfortably such that they were centrally-aligned with the computer, with their hands resting on the keyboard. Participants were instructed to respond as quickly and accurately as possible. Task difficulty was increased across the sessions by reducing stimulus presentation time. This was modified for each session and for each participant individually, and was determined so that accuracy levels exceeded 80%. Performance feedback ('correct' or 'incorrect') was provided after each trial and at the end of each task. Each trial began with a central fixation cross presented for 1 second, followed by the task display which was presented until the participant made a response using a specific key-press, or until the pre-determined trial duration was reached.

Exploration training (ET)

Each session consisted of nine visual search tasks; three feature searches, four conjunction searches and two comparative searches. The three feature and four conjunction tasks involved the participant deciding whether a specific target was present (50% of occasions) or absent, searching an array of between 9 and 18 items. In feature searches the target was defined by one characteristic (*i.e.* colour, shape or size) whilst in conjunction searches it was defined by two of these characteristics (*i.e.* the target is a blue x, with the distractor items being red x's and blue k's). The two comparative searches involved patients deciding whether two pictures (one on each side of the display), containing a series of between 3 and 9 real-life objects, were the same or different. For each of these tasks the displays subtended ~30º horizontally (15° in each hemifield) and ~21º vertically. Participants were instructed to look at the central fixation cross which was presented at the start of each trial for 500 ms, and could move their eyes freely once the array appeared. Specific instructions for how participants should move their eyes were not provided, and instead they were permitted to develop their own search strategies. The mean duration of the training was 4 weeks (range: 2-9 weeks), with each session typically lasting approximately 40 minutes.

Attention training (AT)

The AT was designed to be as similar as possible to the ET, but the exploration component was removed by positioning all stimuli close to fixation; the displays subtended 1º in each hemifield. For those patients with macular sparing (57%) all stimuli could be perceived whilst fixating centrally, whilst for those patients with macular splitting a slightly eccentric fixation ($\leq$1°) was required to bring all stimuli into view. This was determined at the start of the training. No additional eye-movements were required to view the display throughout the training sessions, and participants were instructed to try and maintain fixation as much as possible. As with the exploration training there were nine tasks; three feature searches, four conjunction searches and two mental rotation tasks. For the feature and conjunction searches four items were presented, each subtending ~0.5° (except for the small letters which subtended half of this height), with the innermost edge of the items ~0.5° from fixation. For the mental rotation tasks one item (a number, letter or symbol) was displayed in the centre of the screen. The item could be facing the normal direction or else could be mirror-reversed, and was presented in one of five different orientations (rotated by 0º, 45º, 135º, 225º or 315º). Participants had to decide whether the standard or mirror-reversed version of the stimulus was presented. The mean duration of the AT was 3.5 weeks (range: 2-7 weeks), with each session lasting ~30 minutes on average.

Visual assessment tests

Binocular visual fields were mapped using manual kinetic Tübingen perimetry (Oculus Inc., Tübingen, Germany) with a standardised background luminance of 3.2cd/m². The target stimulus was a white circle with a 0.25° diameter and a supraliminal brightness of 160cd/m². The target was moved inwards from the peripheral visual field at an approximate speed of 2° per second until detected. Participants placed their head into the chin-rest, were instructed to keep their eyes on the red circle (0.30° in diameter) in the centre of the perimeter and to press the buzzer when they could see the target. The visual field border was measured for 24 meridians (horizontal, vertical and diagonal, each 15° apart; Figure 2) in a pseudo-random order. Fixation was monitored through an oculoscope and a meridian was re-tested when eye-position shifts were detected.

The eccentricity of the border separating the seeing and blind portions of the field was measured along each of the 24 meridians and could vary between 0° and 90°. The amount of visual sparing in each hemifield (blind and seeing) was determined by calculating the mean eccentricity of the border across all 13 meridians (11 on each side plus both vertical meridians) for the left and right sides of the visual field. Figure 2 provides more detail on how the amount of visual sparing was calculated.

Insert Figure 2

Performance on visual search was examined using a *find-the-number* task in which participants had to search for a number (between 1 and 9) hidden amongst four or eight distractor symbols (i.e. &, %, £), and then verbally report the number presented. Participants were instructed to fixate centrally at the start of each trial (a fixation spot was presented for 1 second) and could move their eyes freely once the array appeared. Once the number was reported by the participant, the experimenter used a key-press to end the trial, a blank screen was displayed and the experimenter then typed in the response. For this task participants were positioned in a chin-rest to maintain viewing position. All items were 1° in height and the target appeared with equal frequency in each of the four screen quadrants. The array subtended 40° horizontally and 30° vertically. Participants completed 40 trials per session.

The mean response time (RT) was calculated across the trials, using only the trials in which the correct response was provided.

Visual search performance across a greater area of the visual field than directly trained was assessed using a 16 item conjunction visual search task that was projected onto a wall, such that the array subtended approximately 60° horizontally and 53° vertically (projected search). The target was a red forward slash, with blue forward and red backward slashes as distractors. All items were ~5° in height. The target was present on 50% of trials and appeared in each array quadrant equally. Participants were instructed to fixate the central cross at the start of each trial, but were free to move their eyes once the array was presented. Responses regarding the presence or absence of the target were made using a response box (Cambridge Research Systems, Rochester, UK). Participants completed 40 trials per session. Mean RT was determined for the target-present trials, calculated using only correct-response trials.

Visuomotor search performance was measured using a task in which participants had to search an array of 20 numbered blocks (each 3 cm^3), sequentially pick them up and place them into a container as quickly and accurately as possible. The blocks were displayed in a central array atop a table, and were positioned using a polystyrene grid (54 cm by 88.5 cm) which was removed after the blocks were positioned. The task was repeated for between five and ten trials per session. RT (in seconds) was recorded from the time the participant touched the first block until the final block was placed in the container, and mean RT was calculated across the trials.

Reading ability was assessed using four modified passages taken from 'The Grey Gentlemen' (Ende, 1974) which were matched for difficulty; a group of healthy control participants (n =17) read all passages at a non-significantly different speed (χ^2 (3) = 1.59, p = 0.662). Each passage contained 200 words, presented in a 14-point Arial font with doublespacing and left-alignment. Participants were required to read aloud one passage at each session. Reading time (in seconds) and the number of errors made were recorded. The corrected reading speed in words per minute (wpm) was calculated using the following formula: *(words read – number of errors) / time x 60*.

The participants completed a ten-item rating-scale questionnaire (*visual impairments questionnaire; VIQ*), modified from the version developed by Kerkhoff *et al.* (1994). Participants had to rate the level of impairment they experienced with particular activities, with higher scores indicating more difficulty.

Statistical analyses

For each training condition (ET in group A, AT in group B and ET in group B) two-tailed Wilcoxon signed ranks tests were conducted to compare performance before and after training, to determine if the training was beneficial. Training effects were then calculated for each training condition (post-training performance minus pre-training performance) to compare the relative effects of AT and ET. Within-subject comparisons (AT in group B versus ET in group B) were conducted using Wilcoxon signed ranks tests (dependent samples), whilst the between-subject comparisons (AT in group B versus ET in group A) were performed using Mann-Whitney U tests (independent samples).

Results

For each training condition (ET in group A, AT in group B, ET in group B) Wilcoxon signed ranks tests were conducted for all of the assessment tasks to compare performance before and after the training (Table 2).

Insert Table 2

Perimetry:

Insert Figure 3

The mean visual field border at baseline was comparable for both groups (Figure 3; (U = 184, p = 0.498)). Significant increases were found for both the blind and seeing hemifields, after both ET and AT (Table 2 and Figures 4-5). Figure 5 demonstrates the variability of the change within each hemifield, depicting the mean change for each of the meridians separately. The within-subject analyses revealed that the two types of training had similar effects on the size of the blind (z = -0.04, p = 0.970) and the seeing hemifields (z = -1.12, p = 0.263). The same outcome was found in the between-subject analyses (blind hemifield: U = 148, p = 0.106; seeing hemifield: U = 168, p = 0.273). Therefore, ET does not lead to a greater increase in the visual field than AT.

Insert Figure 4

Insert Figure 5

Find-the-number visual search:

In all conditions mean accuracy exceeded 97.1% and changes in RT cannot be attributed to a meaningful speed-accuracy trade-off effect. For both groups significant improvements in RT were found after ET but not AT (Table 2 and Figure 6). The two types of training had a significantly different effect on find-the-number task performance as revealed by the between-subject analyses (U = 116, p = 0.009). However, this was not confirmed by the within-subject comparison (z = -0.43, p = 0.664), possibly resulting from an order-effect of the training or the slightly faster baseline RT in group B relative to A. For this task ET led to significant improvements whereas AT did not, and the relative benefit of ET compared to AT was significant when each training was completed independently.

Insert Figure 6

Projected visual search:

For all conditions accuracy was between 81% and 86%, and any improvements in RT were not the consequence of a speed-accuracy trade-off effect. Significant improvements in RT were observed for ET in group A and AT in group B, although not for ET in group B (when completed after AT; Table 2 and Figure 7). There was no significant difference between the effects of the two training types as shown by the between-subject analyses (U = 356, p = 0.922). However, the within-subject comparison revealed a significant difference (z = -2.56, p = 0.011): AT was more beneficial than ET. This is most likely the result of an order-effect whereby the scope for improvement was exhausted by the first intervention, as demonstrated by the similarity in the magnitude of the training effects between ET in group A and AT in group B.

Insert Figure 7

Visuomotor search:

Percentage accuracy was determined based on the number of errors made (blocks missed or picked up out of sequence), of which there were 20 possible per trial. Mean accuracy exceeded 97.9% for all sessions and changes in RT cannot be attributed to a speed-accuracy trade-off effect. Both the ET and the AT led to significant improvements in RT (Table 2 and Figure 8). The relative effects of the two interventions were not significantly different as revealed by both the within-subject (z = -0.43, p = 0.664) and the between-subject comparisons (U = 203, p = 0.660). Therefore, for this task ET was not superior to AT.

Insert Figure 8

Reading:

Overall there was a significant effect of defect side on reading performance at the baseline session ($\chi^2(1) = 41.00$, $p < 0.001$) with patients with a right-sided defect being more impaired than those with a left-sided defect (Table 3). Also, patients with macular splitting were significantly more impaired than those with macular sparing (z = -5.58, $p < 0.001$).

Insert Table 3

Neither ET nor AT had a significant effect on reading performance (Tables 2 and 3). The laterality of the HVFD and the extent of macular sparing did not significantly affect the change in reading performance resulting from intervention ($p \geq 0.150$), although the sample size makes it difficult to examine such effects reliably. Since neither training type affected reading the relative effects of the two conditions were not compared.

VIQ:

'Reading' was the only item to show a significant improvement (lower score) after ET in group A (z = -2.51, p = 0.012; Table 4). This effect was not replicated in group B, and AT did not affect this either (Table 4). Neither training had a significant effect on any other item.

Insert Table 4

Since reading was the only item for which a significant effect was observed it was the only item compared. Intervention type proved non-significant both for the within-subject (z = -0.43, p = 0.668) and between-subject analyses (U = 148, p = 0.061). The latter statistic was however nearing significance, indicating that ET might have a somewhat greater effect on increasing patients' subjective assessment of their own reading ability.

Discussion

The present study revealed significant post-training improvements in most outcome measures demonstrating that ET can lead to generalised improvements in visual search. Whilst not every task can benefit (specifically reading), it appears that the training effects do transfer to different tasks requiring visual exploration. However, with the exception of the find-the-number task, comparable effects were always obtained with the attention training, thus questioning the need for specific visual exploration training. The following discussion focuses on why, in general, attention training proved as effective as visual exploration training, and then examines the two exceptions: the find-the-number task and reading.

The most likely explanation for why both types of training yielded similar benefits is that visual attention plays an important role in HVFD compensation, and that both interventions improve the patients' attentional capacities. As mentioned previously the visual search paradigm has been used to examine visuo-spatial attention (Treisman and Gelade, 1980), and therefore one might expect that training involving this paradigm would also act as an attention training. Zihl (2000) proposed that spatial shifts in attention associated with visual search were likely to enhance oculomotor modification resulting from exploration.

However, perhaps the surprising finding reported here is that attention training on its own already conveys most of the benefits which are associated with the more specialised exploration training. This certainly suggests that previously the role of attention in HVFD rehabilitation may have been underestimated.

This attentional account can also explain the somewhat counter-intuitive finding of bilateral visual field enlargements following both interventions, although the perimetry data is susceptible to experimenter bias and subsequently must be interpreted with caution. Visual field increases after compensatory training have sometimes (Kerkhoff *et al.*, 1992b, 1994) but not always (Pommerenke and Markowitsch, 1989; Zihl, 1995a; Nelles *et al.*, 2001; Pambakian *et al.*, 2004) been observed. However, they were reported only for the affected hemifield and were interpreted as signs of training-induced visual restoration. The fact that such increases were also found in the patient's intact visual hemifield and can be achieved with an attentional training suggests that the field enlargement may reflect improved attention. It is plausible that the increased visual detection reflects an enhanced ability to shift visuo-spatial attention: shifting attention enhances the excitability of preserved portions of the visual cortex thereby lowering the detection threshold in the particular corresponding visual field location. This is in line with psychophysical (Carasco *et al.*, 2004), physiological (Reynolds and Chelazzi, 2004), behavioural (Lu and Dosher, 1998; Simons and Chabris, 1999; Smith and Schenk, 2008), functional imaging (Pessoa *et al.*, 2003) and transcranial magnetic stimulation evidence (Bestmann *et al.*, 2007) that attention can modulate perception and cortical excitability. More specifically it has also been demonstrated that the size of the visual field can be significantly improved when patients with HVFDs learn to allocate attention to parts of their visual field (Trexler, 1998; Schendel and Robertson, 2004; Smith *et al.*, 2008). Furthermore, Kasten *et al.* (2007) recently observed a significant post-vision restoration therapy visual field enlargement that was not specific to the trained location, and that was correlated with increased spatial attention and alertness. Finally, it should be noted that the changes in the visual field that we have reported here were measured using manual kinetic perimetry, and the results might therefore be specific to this method. Thus it might be worthwhile to re-examine this question using other forms of perimetry.

Whilst it seems reasonable to associate the benefits with improved visuospatial attention, there are alternative mechanisms to consider. Many patients have limited awareness of their visual loss immediately after onset (Celesia *et al.,* 1997; Townend *et al.*, 2007) and may not compensate spontaneously because of this. Being involved in training may increase patients' awareness of their HVFD, subsequently leading to them altering their behaviour. It is also possible that sustained attention is enhanced by training, which could lead to the observed improvements in functioning across multiple tasks. Sustained attention training can improve symptoms of neglect (Robertson *et al.*, 1995) and it is possible that AT was working in a similar manner by enhancing concentration and thus performance. Furthermore, for those patients with macular splitting, AT involved them adopting a slightly eccentric fixation towards the blind hemifield in order to bring the full array into view, and it is possible that this contributed to their improved performance. The results at present do not allow one to distinguish between the possible mechanisms of compensation.

In principle it is possible that the observed improvements are simply a consequence of spontaneous recovery. This is unlikely for two reasons. Firstly, patients did not participate until at least three months post-onset, and therefore the potential for spontaneous recovery was substantially reduced (Pambakian and Kennard, 1997). Secondly, previous research has established improved visual search to a similar magnitude as reported here only during periods of training (Kerkhoff *et al.*, 1994; Pambakian *et al.*, 2004). It can therefore be argued that the findings from this study are better understood if one assumes that both training types lead to significant attentional gains in patients with HVFDs. However, this does not explain why the find-the-number task benefitted only from ET but not AT, and why reading performance did not improve at all.

These exceptions are best understood in a framework which assumes that ET improves both visual attention and task-specific skills. While many visual tasks will benefit from the improvement in visual attention, only tasks which share essential features with the training tasks will benefit from the acquisition of task-specific skills following ET. The find-the-number task shares one essential aspect with ET: in both cases the stimuli to search are presented on a computer screen. Therefore the set of saccadic amplitudes and search strategies that prove successful during ET will also improve performance in the find-the-number task. While performance in the find-the-number task benefitted from AT, this was not true for projected search. This prompts us to ask why training might be beneficial for one type of visual search and not the other. At the moment we can only offer some speculations. The projected search task requires participants to report the presence/absence of a specified target (red /), whereas the find-the-number task requires participants to report which of 10 possible numbers is present. This type of accurate identification requires that items are foveated, which is perhaps not essential in the projected-search task, especially given the larger item size in the latter task (~5° relative to 1°). Accurate eye-movements may therefore be of greater importance for the find-the-number task possibly explaining why AT on its own did not lead to a significant improvement in this task.

A similar analysis also explains why reading did not improve. During reading the eyes scan in the direction of the text in a step-wise manner (horizontal saccades interspersed with fixations), followed by a large saccade returning the eyes to the beginning of the next line (Rayner, 1998). The compensatory strategies needed for reading not only differ from those used during exploration, but also for left versus right-sided HVFDs (Trauzettel-Klosinski and Brendler, 1998). Little transfer should therefore be expected from the exploration training to reading, and the results from this study further demonstrate that enhanced attention alone cannot replace the teaching of the required reading-specific oculomotor strategies. Kerkhoff *et al.* (1992a) and Zihl (1995b) previously reached similar conclusions and developed specific reading training. The efficacy of a reading training has recently been demonstrated by Spitzyna *et al*. (2007) and such training has been found to improve reading but not visual search (Schuett *et al.*, 2008). Schuett *et al*. (2008) reported that patients' reading ability can be improved using non-word material as effectively as using words. Like the present study, it revealed that that the content of training displays could be simplified. Furthermore, both studies show that the generalisation of training improvements are possible to some extent if the transfer task requires similar (but not content-specific) skills, but that there are also limits to this; reading training does not benefit search, and ET does not benefit reading.

With regards to the questionnaire-item "reading", the difference between pre- and post-training assessment was almost significantly greater for ET than for AT ($p = 0.06$). It should be stressed that this is a purely subjective assessment by the patients, which does not correlate with the objective outcome measure. Similar discrepancies between subjective and objective outcomes for visual training have been reported before (Reinhard *et al.*, 2005), and suggest that self-reports do not provide a reliable indicator of functional improvement. The greater effect of ET than AT on subjective assessment of reading ability might simply reflect patients' perception that reading is more similar to the tasks involved in ET.

The results reported here imply that for the most part the two interventions are equally as effective, and both provide a practical rehabilitation option since training can be completed at home using standard computer equipment. However, there are other factors to consider when determining preference. AT is simpler than ET to program and it is faster to complete. Also, due to the limited size of the display needed for AT (2°) it may be possible to perform this training using existing, non-medical technologies such as mobile phones or portable games consoles, which would make it cheaper. Therefore, if research can confirm the comparable functional efficacy of the techniques then AT may be the preferred option.

Clinical efficacy has not been unequivocally established for any HVFD rehabilitation procedure, and large randomised controlled trials are required in order to address this issue. Such research could help to confirm the relative efficacy of AT and ET, including using automated perimetry to examine the visual field. Future studies should include measures of attention to assess the effect of visual training procedures on attentional capacity. It should also be noted that for some aspects of functioning small but non-significant improvements were observed. Our results cannot exclude the possibility that those aspects might also benefit from training, but it is clear that the effects are relatively small and substantially larger samples may therefore be needed to demonstrate these effects.

In conclusion, the findings from this first study comparing visual exploration training with a control intervention might seem disappointing given that visual exploration training has been consistently viewed as a promising HVFD rehabilitation approach. The findings suggest that exploration training is not significantly better than attention training. However, this could also be seen as positive news. It suggests that a simple attention training presented on a small display, potentially even on portable games-console, can provide many of the benefits observed after exploration training. However, this study also highlights the limits of this approach: hemianopic dyslexia, one of the most disabling consequences of HVFDs, is not improved by either training. This suggests that an effective HVFD treatment requires both general and specific components, in accordance with other areas of cognitive rehabilitation (Sohlberg and Mateer, 2001). The treatment should include a general training of visual attention in addition to the teaching of skills and strategies that are specific to functionally relevant activities, such as reading (see also Kerkhoff *et al*., 1992b, 1994).

Funding

The study was funded by an Economic and Social Research Council and Medical Research Council studentship (number PTA-037-2004-00025, AL).

Acknowledgements

The authors would like to thank staff from James Cook University Hospital, City of Sunderland Hospitals, Newcastle-Upon Tyne Hospitals (especially Alison Jones) and Action for Blind People for their assistance with the recruitment of suitable participants for the study. Specific thanks go to Professor D. Mendelow who acted as the clinical supervisor for the study.

References

Bestmann S, Ruff CC, Blakemore C, Driver J, Thilo KV. Spatial attention changes excitability of human visual cortex to direct stimulation. Curr Biol 2007; 17: 134-139.

Bouwmeester L, Heutink J, Lucas C. The effect of visual training for patients with visual field defects due to brain damage: a systematic review. J Neurol Neurosurg Psychiatry 2007; 78: 555-564.

Carrasco M, Ling S, Read S. Attention alters appearance. Nat Neurosci 2004; 7: 308-313.

Celesia GG, Brigell MG, Vaphiades MS. Hemianopic anosognosia. Neurology 1997; 49: 88-97.

Ende M. The Grey Gentlemen. London: Burke Books, 1974.

Halligan PW, Cockburn J, Wilson BA. The behavioural assessment of visual neglect. Neuropsychol Rehabil 1991; 1: 5-32.

International Committee of Medical Journal Editors. Statements from the Vancouver Group. BMJ 1991; 302: 1194.

Kasten E, Müller-Oehring E, Sabel BA. Stability of visual field enlargements following computer-based restitution training – results of a follow-up. J Clin Exp Neuropsychol 2001; 23: 297-305.

Kasten E, Bunzenthal U, Müller-Oehring EM, Mueller I, Sabel B. Vision restoration therapy does not benefit from costimulation: A pilot study. J Clin Exp Neuropsychol 2007; 29: 569-584.

Kasten E, Wüst S, Behrens-Baumann W, Sabel B. Computer-based training for the treatment of partial blindness. Nat Med 1998; 4: 1083-1087.

Kerkhoff G. Neurovisual rehabilitation: recent developments and future directions. J Neurol Neurosurg Psychiatry 2000; 68: 691-706.

Kerkhoff G, Münßinger U, Meier EK. Neurovisual Rehabilitation in Cerebral Blindness. Arch Neurol 1994; 51: 474-481.

Kerkhoff G, Münßinger U, Eberle-Strauss G, Stögerer E. Rehabilitation of hemianopic alexia in patients with postgeniculate visual field disorders. Neuropsychol Rehabil 1992a; 2: 21-42.

Kerkhoff G, Münßinger U, Haaf E, Eberle-Strauss G, Stögerer E. Rehabilitation of homonymous scotomata in patients with postgeniculate damage of the visual system: saccadic compensation training. Restor Neurol Neurosci 1992b; 4: 245-254.

Lane AR, Smith DT, Schenk T. Clinical treatment options for patients with homonymous visual field defects. Clin Ophthalmol 2008; 2: 93-102.

Lu ZL, Dosher BA. External noise distinguishes attention mechanisms. Vision Res 1998; 38: 1183-1198.

Mueller I, Mast H, Sabel BA. Recovery of visual field defects: a large clinical observational study using vision restoration therapy. Restor Neurol Neurosci 2007; 25: 563-572.

Nelles G, Esser J, Eckstein A, Tiede A, Gerhard H, Diener H. Compensatory visual field training for patients with hemianopia after stroke. Neurosci Lett 2001; 306: 189-192.

Pambakian ALM, Kennard C. Can visual function be restored in patients with homonymous hemianopia? Br J Ophthalmol 1997; 81: 324-328.

Pambakian A, Currie J, Kennard C. Rehabilitation strategies for patients with homonymous visual field defects. J Neuroophthalmol 2005; 25: 136-142.

Pambakian ALM, Mannan SK, Hodgson TL, Kennard C. Saccadic visual search training: a treatment for patients with homonymous hemianopia. J Neurol Neurosurg Psychiatry 2004; 75: 1443-1448.

Pelak VS, Dubin M, Whitney E. Homonymous hemianopia: A critical analysis of optical devices, compensatory training, and NovaVision. Curr Treat Options Neurol 2007; 9: 41-47.

Pessoa L, Kastner S, Ungerleider LG. Neuroimaging studies of attention: From modulation of sensory processing to top-down control. J Neurosci 2003; 23: 3990-3998.

Pommerenke K, Markowitsch HJ. Rehabilitation training of homonymous visual field defects in patients with postgeniculate damage of the visual system. Restor Neurol Neurosci 1989; 1: 47-63.

Rayner K. Eye movements in reading and information processing: 20 years of research. Psychol Bull 1998; 124: 372-422.

Reinhard J, Schreiber A, Schiefer U, Kasten E, Sabel BA, Kenkel S, *et al.* Does visual restitution training change absolute homonymous visual field defects?: a fundus controlled study. Br J Ophthalmol 2005; 89: 30-35.

Reynolds JH, Chelazzi L. Attentional modulation of visual processing. Annu Rev Neurosci 2004; 27: 611-647.

Robertson IH, Tegnér R, Tham K, Lo A, Nimmo-Smith I. Sustained attention training for unilateral neglect: theoretical and rehabilitation implications. J Clin Exp Neuropsychol 1995; 17: 416-430.

Roth T, Sokolov A, Messias A, Roth P, Weller M, Trauzettel-Klosinski S. Comparing explorative saccade and flicker training in hemianopia: a randomized controlled study. Neurology 2009; 72: 324-331.

Sabel BA, Kenkel S, Kasten E. Vision restoration therapy (VRT) efficacy as assessed by comparative perimetric analysis and subjective questionnaires. Restor Neurol Neurosci 2004; 22: 399-420.

Schendel K, Robertson LC. Reaching out to see: Arm position can attenuate human visual loss. J Cog Neurosci 2004; 16: 935-943.

Schlageter K, Gray B, Hall K, Shaw R, Sammet R. Incidence and treatment of visual dysfunction in traumatic brain injury. Brain Inj 1993; 7: 439-448.

Schreiber A, Vonthein R, Reinhard J, Trauzettel-Klosinski S, Connert C, Schiefer U. Effect of visual restitution training on absolute homonymous scotomas. Neurology 2006; 67: 143-145.

Schuett S, Heywood CA, Kentridge RW, Zihl J. Rehabilitation of hemianopic dyslexia: Are words necessary for re-learning oculomotor control? Brain, 2008; 131: 3156-3168.

Simons DJ, Chabris CF. Gorillas in our midst: sustained inattentional blindness for dynamic events. Perception 1999; 28: 1059-1074.

Smith DT, Schenk T. Reflexive attention attenuates change blindness (but only briefly). Percept Psychophys 2008; 70: 489-495.

Smith DT, Lane AR, Schenk T. Arm position does not attenuate visual loss in patients with homonymous visual field deficits. Neuropsychologia 2008; 46: 2320-2325.

Sohlberg MM, Mateer CA. Cognitive Rehabilitation: an integrative neuropsychological approach. New York, NY: Guildford Press, 2001.

Spitzyna GA, Wise RJS, McDonald SA, Plant G, Kidd D, Crewes H, Leff AP. Optokinetic therapy improves text reading in patients with hemianopic alexia: A controlled trial. Neurology 2007; 68: 1922-1930.

Townend BS, Sturm JW, Petsoglou C, O'Leary B, Whyte S, Crimmins D. Perimetric homonymous visual field loss post stroke. J Clin Neurosci 2007; 14: 754-756.

Trauzettel-Klosinski S, Brendler K. Eye movements in reading with hemianopic field defects: the significance of clinical parameters. Graefes Arch Clin Exp Ophthalmol 1998; 236: 91-102.

Treisman A, Gelade G. A feature integration theory of attention. Cog Psychol 1980; 12: 97-136.

Trexler LE. Volitional control of homonymous hemianopsia: a single case study. Neuropsychologia 1998; 36: 573-580.

Zihl J. Visual scanning behaviour in patients with homonymous hemianopia. Neuropsychologia 1995a; 33: 287-303.

Zihl J. Eye movement patterns in hemianopic dyslexia. Brain 1995b; 118: 891-912.

Zihl J. Rehabilitation of visual disorders after brain injury. East Sussex, UK: Psychology Press Ltd, Publishers, 2000.

Zihl J, Kennard C. Disorders of higher visual function. In: Brandt T, Caplan LR, Dichgans J, et al., editors. Neurological disorders: course and treatment. California, CA: Academic Press, 1996: 201-212.

Tables

Table 1 Summary of the baseline patient characteristics for the two groups.

	Group A (***n*** **= 21)**	**Group B** (***n*** **= 21)**	**Comparison of samples**
Mean age in yrs (SD)	65.3 (12.1)	57.1 (15.8)	t (40) = 1.87, P = 0.069
Gender, *n* (%)			$\chi^2(1)$ = 0.12, P = 0.726
Male	16 (76.2%)	15 (71.4%)	
Female	5 (23.8%)	6 (28.6%)	
HVFD side, *n* (%)			$\chi^2(2)$ = 1.22, P = 0.542
Right	5 (23.8%)	6 (28.6%)	
Left	16 (76.2%)	14 (66.7%)	
Bilateral	0 (0%)	1 (4.8%)	
Macular splitting/sparing, *n* (%)	5 (23.8%) / 16 (76.2%)	9 (42.9%) / 12 (57.1%)	$\chi^2(1)$ = 1.17, P = 0.190
Splitting: right/left side, *n*	2 / 3	2 / 7	
Sparing: right/left/bilateral, *n*	3 / 13	4 / 7 / 1	
Aetiology, *n* (%)			$\chi^2(2)$ = 1.40, P = 0.497
Ischaemic stroke	14 (66.7%)	14 (66.7%)	
Haemorrhage	6 (28.6%)	4 (19.0%)	
Traumatic brain injury	1 (4.8%)	3 (14.3%)	
Mean HVFD duration, months (SD)	24.9 (60.5)	14.0 (19.0)	t (40) = 0.80, P = 0.431
Find-the-number task performance			
Reaction time in ms (SD)	2836.5 (712.5)	3059.5 (1023.0)	t (40) = 0.82, P = 0.417
Accuracy in % (SD)	96.6 (8.2)	97.5 (4.4)	t (40) = 0.42, P = 0.676

Table 2 Results from the Wilcoxon signed ranks tests conducted for each outcome task and each training session.

Task	**ET (group A)**		**AT (group B)**		**ET (group B)**	
	z	***p***	***z***	***p***	***z***	***p***
Perimetry						
Blind hemifield	-3.21	<0.001*	-2.69	0.007*	-2.05	0.040*
Seeing hemifield	-2.45	0.014*	-2.32	0.021*	-2.05	0.040*
Find the Number	-4.02	0.001*	-1.86	0.063	-3.08	0.002*
Projected Search	-2.94	0.003*	-2.97	0.003*	-0.75	0.455
Visuomotor Search	-3.27	0.001*	-3.35	0.001*	-4.02	<0.001*
Reading	-1.42	0.156	-1.93	0.054	-1.03	0.305
VIQ						
Reading	-2.51	0.012*	-0.09	0.931	-1.40	0.163
All other items	≥-1.85	≥0.064	≥-1.81	≥0.070	≥1.97	≥0.048

Note: Results from the patients' performance in the assessment tasks are illustrated in Figures 1-4.

Table 3 Mean corrected reading speed in words per minute (and standard deviation) for each of the assessment sessions and for both groups (A and B). Each group has been subdivided to demonstrate the results for patients defined by defect side and whether or not the macula was spared or split.

	Mean corrected reading speed (*wpm*)		
	Baseline	**Post-AT**	**Post-ET**
Group A (*n*)	115.66 (41.19)	-	121.94 (43.28)
Left + (13)	127.28 (33.55)		132.12 (38.32)
Left – (3)	119.65 (37.04)		106.71 (49.14)
Right + (3)	121.89 (14.96)		141.40 (16.46)
Right – (2)	30.62 (20.43)		54.58 (43.85)
Group B (*n*)	85.76 (28.70)	91.31 (31.58)	95.21 (38.77)
Left + (7)	98.41 (23.17)	107.47 (29.42)	122.06 (31.85)
Left – (7)	96.11 (17.79)	99.89 (21.35)	98.03 (25.61)
Right + (4)	68.79 (38.82)	71.39 (41.21)	82.48 (43.80)
Right – (2)	46.65 (23.10)	63.34 (1.96)	49.93 (7.19)
Bilateral + (1)	71.00	53.64	28.99

Table 4 Table showing the mean rating (and standard deviation) for each item of the Visual Impairments Questionnaire, for each assessment session for group A and group B. A lower score indicates less impairment.

VIQ Item	Group A		Group B		
		Post-ET	***Baseline***	***Post-AT***	***Post-ET***
Seeing objects	1.76 (1.42)	1.57 (1.18)	1.95 (1.42)	2.38 (1.13)	1.79 (1.29)
Bumping into objects	1.55 (1.40)	1.38 (1.20)	1.74 (1.36)	1.72 (1.31)	1.67 (1.28)
Losing way	0.38 (0.92)	0.29 (0.96)	1.35 (1.41)	0.94 (1.20)	0.71 (0.99)
Finding items (table)	1.17 (1.41)	1.02 (1.36)	2.10 (1.38)	1.81 (1.26)	1.50 (1.22)
Finding items (room)	1.50 (1.33)	1.07 (1.29)	1.71 (1.39)	1.76 (1.21)	1.69 (1.36)
Finding items (shop)	1.55 (1.61)	1.30 (1.45)	2.09 (1.29)	2.06 (1.34)	2.06 (1.34)
Using public transport	0.55 (1.29)	0.36 (1.21)	1.13 (1.25)	1.50 (1.60)	1.13 (1.55)
Finding way at home	0.10 (0.30)	0.17 (0.48)	0.05 (0.22)	0.00 (0.00)	0.05 (0.22)
Crossing the street	1.24 (1.40)	0.90 (1.17)	1.91 (1.60)	1.92 (1.43)	1.67 (1.27)
Reading	1.95 (1.53)	1.19 (1.48)	2.41 (1.54)	2.29 (1.32)	1.98 (1.29)

Figures

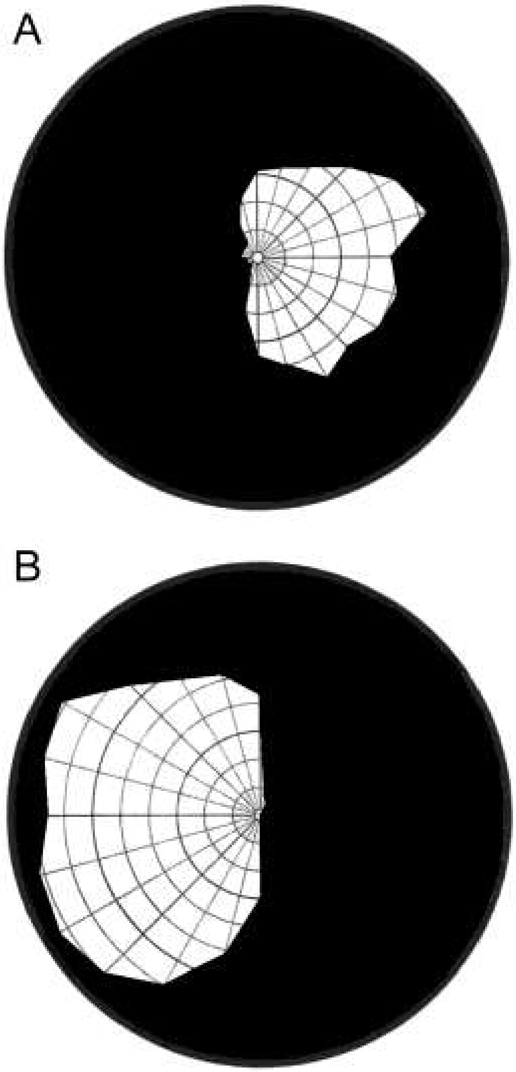

Figure 1. Examples of the baseline visual field of two patients. Plot A demonstrates a patient with a left-sided hemianopia with a minimum of 3° of macular sparing. Plot B is an example of a patient with a right-sided hemianopia with macular splitting.

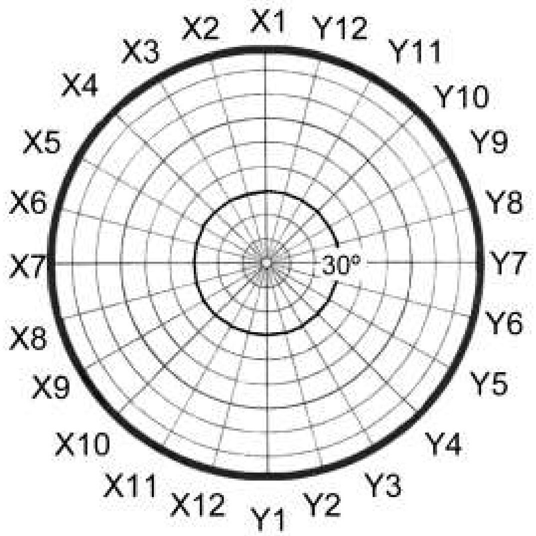

Figure 2. Diagram representing the 24 meridians assessed during the perimetry with 11 meridians for each side; the two vertical meridians (X1 and Y1) were used for both fields, resulting in a total of 13 eccentricity values for the blind/seeing border for each hemifield. Each concentric circle represents 10° of visual angle. The mean left visual field border was calculated using the formula (X1 + X2 + ... + X12 + Y1) / 13, whilst the mean right visual field border was calculated using (Y1 + Y2 + ... + Y12 + X1) / 13.

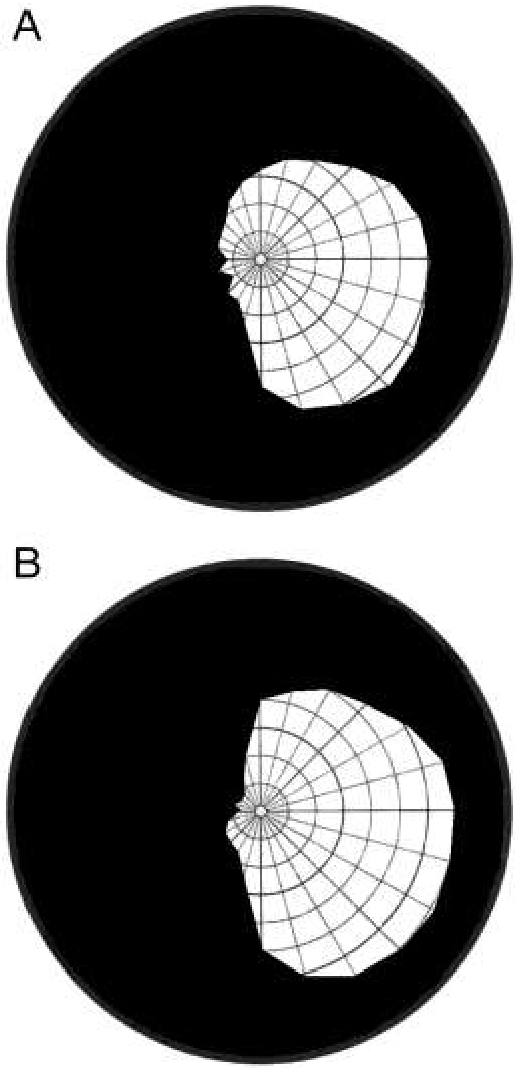

Figure 3. Diagrams representing the mean baseline visual field border (in degrees) for each meridian for groups A (panel A) and B (panel B) separately. The left side of each plot represents the blind hemifield and the right side represents the seeing hemifield (those patients with a right-sided defect had their visual field mirror-reversed).

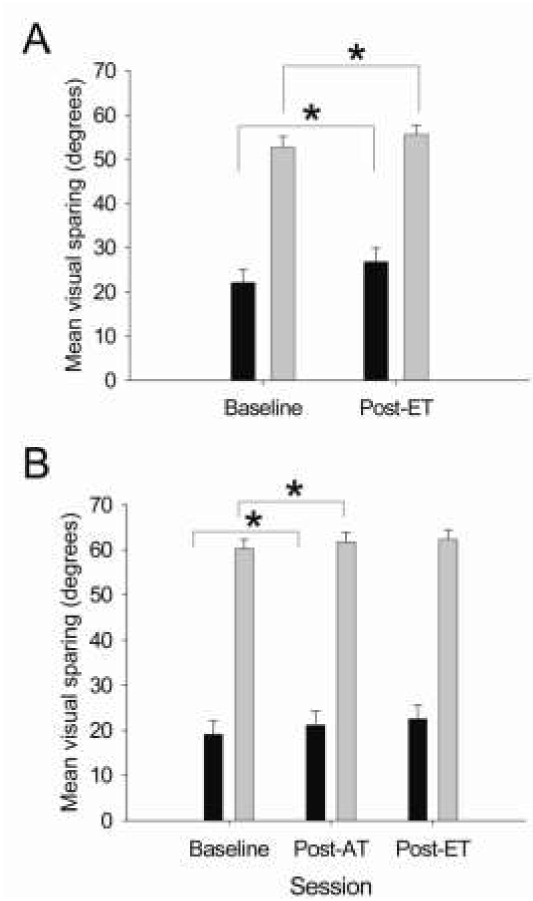

Figure 4. Bar-graphs showing the mean visual field sparing for the blind (dark bars) and seeing (pale bars) hemifields, for each assessment session (baseline and post-training) for group A (Fig. 4A) and group B (Fig. 4B). The error bars represent the standard error of the mean and * indicates a significant difference ($p < 0.05$).

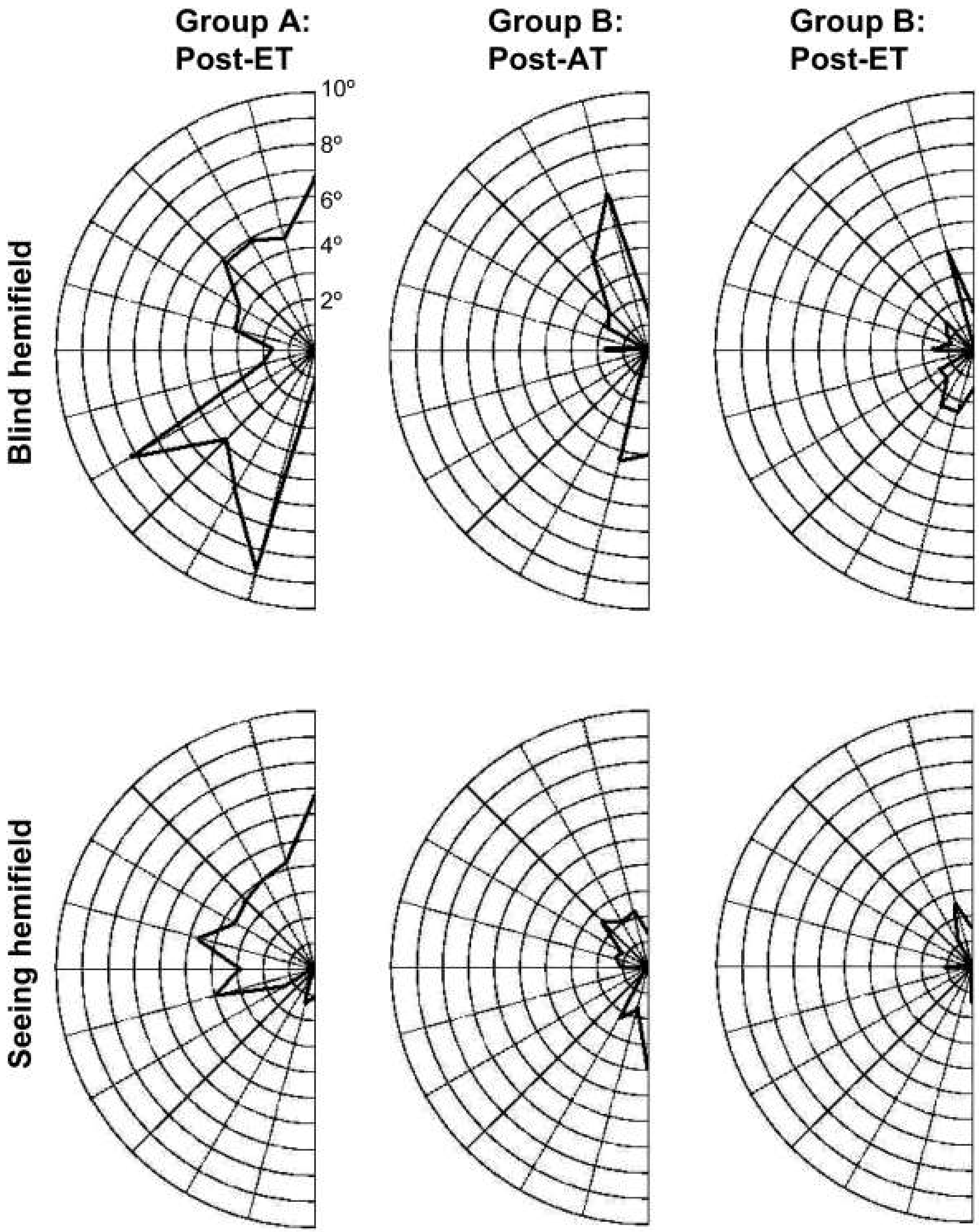

Figure 5. Diagrams representing the mean change in the visual field size (in degrees). Each concentric circle represents 1° of visual angle, and changes less than 1° have not been depicted. There are separate plots for the blind and seeing hemifields, and for each group and condition. Data from patients with left and right sided defects were collapsed and presented within one hemifield, namely the left hemifield.

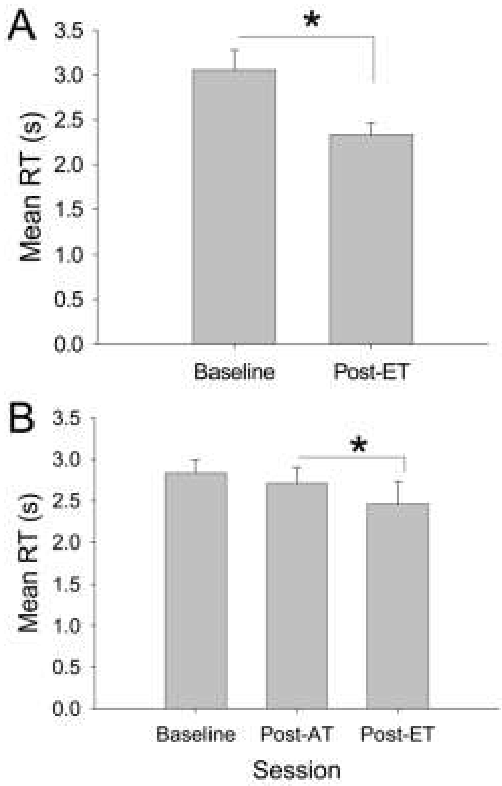

Figure 6. Bar-graphs showing the mean response time (ms) for the find-the-number task, for each assessment session for group A (Fig. 6A) and group B (Fig. 6B). The error bars represent the standard error of the mean and * indicates a significant difference ($p < 0.05$).

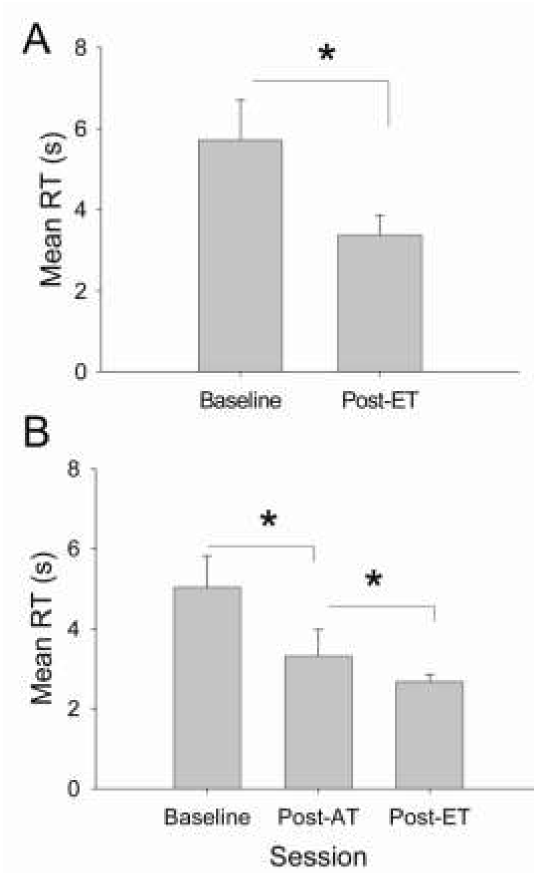

Figure 7. Bar-graphs showing the mean response time (ms) for the target-present condition of the projected search task. Each bar represents a different assessment session for group A (Fig. 7A) and group B (Fig. 7B). The error bars represent the standard error of the mean and * indicates a significant difference ($p < 0.05$).

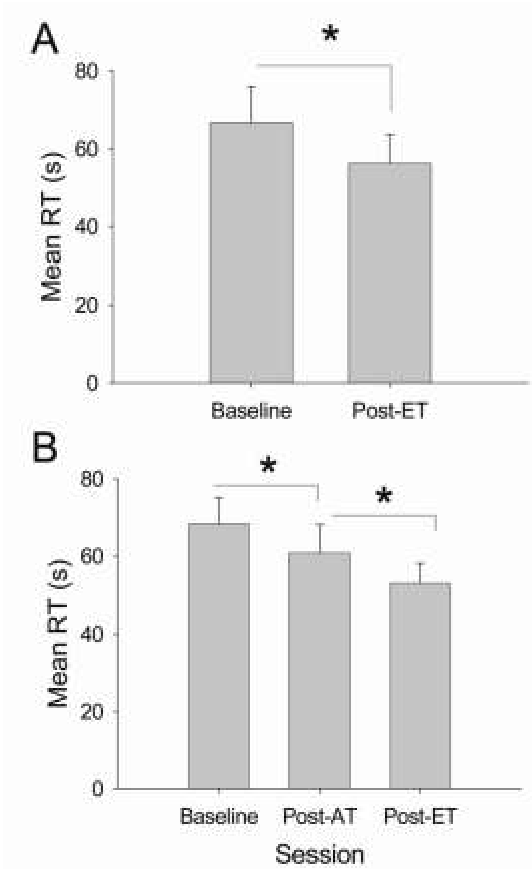

Figure 8. Bar-graphs showing the mean response time (s) for the visuomotor search task, for each assessment session for group A (Fig. 8A) and group B (Fig. 8B). The error bars represent the standard error of the mean and * indicates a significant difference ($p < 0.05$).