Efficacy and feasibility of home-based training for individuals with homonymous visual field defects

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Abstract

Background: Homonymous visual field defects (HVFDs) are one of the most common consequences of stroke. Compensatory training encourages affected individuals to develop more efficient eye-movements to improve function. However, training is typically supervised, which can be time-consuming and costly.

Objective: To develop and evaluate the efficacy and feasibility of an unsupervised reading and exploration computer training for individuals with HVFDs.

Methods: Seventy individuals with chronic HVFDs were randomly assigned to one of two groups: intervention or control. The former received 35 hours of reading and exploration training, and the latter 35 hours of control training. Visual and attentional abilities were assessed before and after training using perimetry, visual search, reading, activities of daily living, the Test of Everyday Attention, and a Sustained Attention to Response task.

Results: 18 individuals failed to complete the training; analyses were conducted on the remaining 28 intervention and 24 control group participants. Individuals in the intervention group demonstrated significant improvements in the primary outcomes of exploration [12.87%, 95% CI: 8.44–17.30%] and reading [18.45%, 95% CI: 9.93–26.97%], which were significantly greater than those observed following the control intervention [exploration = 4.80%, 95% CI: 0.09–9.51%; reading = 1.95%, 95% CI: -4.78–8.68%]. Participants in the intervention group also reported secondary subjective improvements, although these were not matched by objective gains in tasks simulating activities of daily living.

Conclusions: Home-based compensatory training is an inexpensive accessible rehabilitation option for individuals with HVFDs, which can result in objective benefits in searching and reading, as well as improving quality of life.

Key words: Hemianopia; Quadrantanopia; Reading; Rehabilitation; Transfer of Training

Introduction

Homonymous visual field defects (HVFDs) are one of the most frequent consequences of brain injury[1-3]. Hemianopia (blindness in half the visual field) is the most common, followed by quadrantanopia (blindness in one quarter of the visual field)[4]. Individuals with HVFDs exhibit slow and inefficient exploration[5,6], are visually disoriented and experience problems such as finding objects, avoiding obstacles and reading. Their impairment has a significant negative impact on quality of life[7-9], and spontaneous recovery is limited[10,11].

Although a variety of experimental rehabilitation techniques have been developed (including restorative, compensatory and substitution methods; see Lane, Smith & Schenk[12] for a review) these are rarely used in standard practice, possibly because evidence for the efficacy of any technique is inconclusive[13]. Compensatory training, which encourages individuals to develop more effective eye-movements to cope with their visual loss, is consistently identified as the most promising[12-15]. Although few studies have evaluated such therapy relative to a control intervention, several studies have reported significant benefits following compensatory training such as improved exploration, more efficient saccadic behaviour and subjective improvements in activities of daily living (ADL)[16-23]. Specific compensatory reading training has also been developed and positive effects reported[24-26].

Compensatory training can be time-consuming, labour intensive, and often requires specialist facilities such as large-scale training boards[19] or perimeters[18] thereby limiting its availability. Even the majority of computer-based training is either completed in clinic[16,17] or at home with therapist supervision[20, 22, 23], although one recent study has demonstrated that a web-based reading training can increase reading speed in patients with right-sided HVFDs[27]. Whether it is the patient

travelling to access treatment, or the therapist travelling to supervise training, this increases the cost and time associated with rehabilitation, as well as potentially limiting access to those patients within commutable distance.

The main aim of the present controlled study was to investigate the efficacy of a new unsupervised compensatory training for individuals with HVFDs. Patients trained independently at home, limiting their exposure to the researcher, thereby controlling the influence that the therapist-patient relationship may have on rehabilitation success. Previous studies have demonstrated training specificity with regards to exploration and reading[22, 28]. Since these are two of the most frequently observed impairments in patients with HVFDs[4] it was decided that the training should incorporate elements tailored towards each skill. To our knowledge this is the first programme combining both components within one rehabilitation package, meaning that individuals would only have to access and learn to use one tool. The primary outcomes of the study were therefore the effect of the interventions on visual exploration and reading.

Some additional secondary outcome measures were included. Since rehabilitation is aimed at improving patient activity and participation[29], transferability of the benefits to ADL was also investigated. Measures of attention were included as it is has been proposed that attention plays a role in HVFD rehabilitation[4,22]. Finally, the feasibility of training delivery was estimated based on the level of acceptance, drop-out rate and demand for technical assistance.

Methods

Participants

Study approval was granted by Durham University and Northern and Yorkshire Multi−Centre Research Ethics Committees. Participants provided written informed consent in accordance with the Declaration of Helsinki[30]. Seventy patients with chronic HVFDs resulting from any post-chiasmatic lesion were recruited from local hospitals or as self-referrals, with visual loss confirmed using monocular automatic perimetry (Twinfield 2, Oculus Optikgerate GmbH, Germany). None had previous access to any formal HVFD rehabilitation (restoration, substitution or compensation). Participants had to be at least 18 years old. Additional exclusion criteria included medical instability, inability to provide informed consent, visual loss as a consequence of pre-chiasmatic damage or a progressive condition, photosensitive epilepsy, oculomotor disorders, and severe cognitive impairment. Participants were not enrolled until at least three months post-onset to minimise confounding by spontaneous recovery[31] (range: 3 - 276 months).

Participants were randomly assigned to two groups: intervention and control (see Table 1 for details). Some patients had additional impairments including hemiparesis (n = 6), mild memory and cognitive impairments (n = 8), and aphasia (n = 2). Where necessary visual acuity was corrected as per any existing prescription, and was not retested. Three patients (two in the intervention group, one in the control group) had comorbid neglect as confirmed with the bells test[32]. Neglect is defined as a failure to respond or orient to stimuli in contralesional space[33] and can result in similar problems as HVFDs, including impaired exploration and reading[34].

Table 1. Baseline characteristics of patients in the two groups.

	All Participants			Participants who Completed		
	Intervention N = 35	Control N = 35	Comparison of groups	Intervention N = 28	Control N = 24	Comparison of groups
Mean age, years (SD)	58.00 (14.13)	62.74 (15.05)	$t(68)= 1.36$, $p = .18$	61.43 (10.28)	63.96 (10.89)	$t(50)= -.86$, $p = .39$
Gender, n (%)			$\chi^2(1) =.54$, $p = .46$			$\chi^2(1) =.05$, $p = .82$
Male	23 (65.7)	20 (57.1)		19 (64.3)	17 (70.8)	
Female	12 (34.3)	15 (42.9)		9 (35.7)	7 (29.2)	
HVFD side, n (%)			$\chi^2(1) =.06$, $p = .81$			$\chi^2(1) =.31$, $p = .58$
Left	20 (57.1)	19 (54.3)		15 (57.1)	11 (45.8)	
Right	15 (42.9)	16 (45.7)		13 (42.9)	13 (54.2)	
Defect type, n (%)			$\chi^2(1) = .36$, $p = .55$			$\chi^2(1) = 1.03$, $p = .31$
Hemianopia	27 (77.1)	29 (82.9)		20 (71.4)	20 (83.3)	
Quadrantanopia	8 (22.9)	6 (17.1)		8 (28.6)	4 (16.7)	
Mean pre-training perimetry fixation accuracy (%)[$]	84.4 (15.6)	84.0 (17.8)	$t(58) = -0.10$, $p = .92$	84.5 (15.7)	86.8 (14.6)	$t(41) = 0.48$, $p = .64$
Mean pre-training perimetry number of 'misses'[$]	46.0 (12.6)	50.3 (13.9)	$t(58) = 1.25$, $p = .22$	44.4 (13.5)	49.5 (14.5)	$t(41) = 1.20$, $p = .24$
Mean sparing, degrees (SD)[#]	2.00 (1.41)	2.46 (1.86)	$t(38) = 0.81$, $p = .42$	1.92 (1.44)	2.45 (1.85)	$t(31) = 0.87$, $p = .39$
Aetiology, n (%)			$\chi^2(3) = 3.26$, $p = .35$			$\chi^2(3) = 2.06$, $p = .56$
Ischaemic Stroke	25 (71.4)	30 (85.7)		19 (67.9)	20 (83.3)	
Haemorrhage	4 (11.4)	3 (8.6)		4 (14.3)	2 (8.3)	
Traumatic Brain Injury	4 (11.4)	2 (5.7)		4 (14.3)	2 (8.3)	
Tumour	2 (5.7)	0 (0)		1 (3.6)	0 (0)	

[$] Perimetry was performed monocularly and a mean calculated across eyes for each individual. Some of this data is missing due to technical failure, participant non-compliance or unavailability of the perimeter at the pre-training assessment session. Therefore, this data is based on 60 of the total participants (29 in the intervention, and 31 in the control group), and 43 of those who completed (22 from the intervention and 21 from the control group).

[#]The sparing data is based on the patients for whom a binocular kinetic perimetry had been completed (original sample, n = 40: 26 intervention and 14 control; completed sample n = 33: 20 intervention group and 13 control), which allowed an accurate measure of the field border. The amount of sparing was measured as the distance between the centre of the visual field and the point at which the target was first detected along the horizontal axis towards the blind hemifield.

Design

The trial was registered on the UK Clinical Research Network Portfolio (UKCRN, ID 7144). A randomised, controlled, parallel-group design was used, comparing the effects of reading and exploration (R-E) training with a control attention-based training. Participants were randomised equally to two groups (R-E or control) using parallel trial allocation software[35], and were advised to complete the allocated training (details below) for one hour per day during a time window of approximately five weeks. Participants were informed about the training types but did not know to which group they were assigned. Individuals in the control condition were offered the R-E training upon completion. Participants completed the same assessment tasks before and after training.

Materials and Procedures: Assessment

The assessment tasks were completed in a pseudo-random order, and counterbalanced across the sample. Participants completed tasks using their dominant hand, except those with hemiparesis who used their ipsilesional hand.

Perimetry. Monocular visual fields were assessed using an Oculus Twinfield 2 perimeter and the Esterman pre-set programme, repeated for each eye. Fixation was monitored using a video-camera and central probe stimuli. 100 target positions were assessed for each eye, with fixation accuracy (%) and number of undetected stimuli ("misses") recorded. Forty patients also completed suprathreshold binocular kinetic perimetry, in which a white target (0.25° in diameter) moved inwards until detected at a speed of 2° per second along 24 trajectories in a random order. Kinetic perimetry

was introduced when it became clear that the spatial resolution of the Esterman finding was insufficient to provide precise characterisation of the visual field border.

Visual search: Find the number.

This primary outcome task (not part of training) was programmed using E-Prime 1.1 (Psychology Software Tools, Inc., Pittsburgh, PA). Participants had to scan an array (subtending approximately 47° by 29° of visual angle) of yellow items displayed on a black background for a specific target (numbers 1-4) amongst distractors (*i.e*. £, #, ?), indicating their response as quickly as possible by pressing the corresponding keyboard number. Items subtended 1°, with position randomised. The target appeared equally frequently in each screen quadrant. Trials began with a central white fixation cross (1°) for 1000 ms, followed by the search array until response. There was a 1500ms inter-trial interval; a blank black screen. Participants completed eight practice trials and 40 test trials per session. Mean response time (RT) was calculated using correct response trials.

Reading. Reading aloud ability was assessed as another primary outcome using the same 200 word passages from a previous study[22], with reading time (seconds) and number of errors recorded. The corrected reading speed in words per minute (wpm) was calculated using the following formula: *(words read – number of errors) / time x 60*.

Tasks simulating ADL.

1) *Driving Hazard Perception.* A hazard perception task (The Studios, Rugley, 2009; www.focusmm.co.uk) was presented on a 47 cm x 29 cm screen, with participants seated at a distance of 57 cm. Participants were instructed to scan the clips and press a button upon noticing potential hazards. The computer

programme scored responses; the earlier the hazard was noticed the more points awarded (0-5). Three practice clips were completed. The test contained 14 one-minute clips, with 10 second breaks between clips. Across 14 clips there were 16 hazards. Participants received a total score out of 80, and a mean score per hazard was then calculated.

2) *Obstacle avoidance.* Participants had to walk through a corridor (15.4 m long) containing six obstacles. Eight paper targets (used to guide participants) were placed on the walls at a height of 165 cm. Participants had to complete the track avoiding obstacles and removing targets. Completion time (CT) was recorded.
3) *Visuomotor search.* Participants stood arm's length away from a 100 cm x 100 cm shelving unit, containing five rows (20 cm in height) each with five compartments (width range: 10-30 cm). The central compartment contained a computer mouse. Each remaining compartment contained different household items (*i.e.* sunglasses, coffee jar) labelled with a number (1 cm tall) from one to 24. Items were arranged in one of three arrays (containing non-consecutive numbers) for each of the five trials. Participants had to point, in order, to ten objects (1-10, 11-20, 8-17, 5-14, 15-24). Each sequence was used once and the order randomised. Participants wore liquid-crystal shutter glasses[36]. The experimenter used the computer mouse to clear the glasses and start the trial. When the participant pointed to the last object a second mouse-click indicated the end of the trial, turning the glasses opaque. This procedure restricted the viewing time, preventing participants memorising the array. The time between first and second mouse-clicks was the completion time (CT).

Attention tasks.

1) *Sustained Attention to Response (SART)*[37-39]*.* Numbers one to nine were sequentially presented centrally on a computer screen. Each appeared for 250 ms with a central fixation cross (900 ms) between items. Numbers were white on a black background; size varied randomly between approximately 2° and 5° of visual angle. Participants pressed the space-bar as soon as each number appeared except number 3 (no-go trials). 243 trials were performed, including 18 practice trials. The mean percentage error score on no-go trials was calculated.
2) *Test of Everday Attention (TEA)*[40-41]. Three subtests were used: the visual elevator task, and the auditory elevator task both with and without distraction. Full details of these tasks can be found in Robertson, Ward, Ridgeway and Nimmo-Smith (1996)[40].

Subjective questionnaires. The Visual Functioning Questionnaire (VFQ-25)[42] and Visual Impairments Questionnaire (VIQ)[17,22] both involved participants rating their difficulty in carrying out specific activities (*i.e.* crossing the street, reading). The Subjective Reasons Questionnaire (SRQ; supplementary material A) was used to evaluate whether patients thought the training helped them, and if so, which aspect they found most beneficial. The extent to which they agreed with statements relating to why they think their condition improved, what aspect of training was most helpful, and which part of the assessment was most helpful was rated out of 5 (with higher scores indicating more benefit). The SRQ was administrated at the end of the study to all patients who completed the R-E training, including those who completed it after the control intervention (N = 46).

Materials and Procedures: Training

At the start of the intervention period the experimenter demonstrated the training, during which the computer was set-up centrally at a distance of approximately 57 cm. Participants were encouraged to train in a similar manner, although adherence cannot be guaranteed. For full details of the training see supplementary material B.

Experimental Intervention: The experimental training consisted of reading and exploration components; patients completed components sequentially with order randomised. In the visual exploration tasks patients had to find a target defined by a specific feature (colour, shape, size) amongst an array containing distractors (*i.e.* a red letter amongst blue ones). In the reading task patients had to detect a non-word target (*i.e.* sowels) amongst a varying number of words (*i.e.* accent), presented in a single central horizontal line. In both task types participants responded to target presence using an appropriate computer-mouse press. Computer feedback on speed and accuracy of responses, and overall progress to date (i.e. difficulty level achieved and number of training sessions completed) was provided at the end of each block of trials.

For both training components difficulty level was dynamically adjusted based on both accuracy and speed of previous performance. If patients were $\geq$90% accurate then difficulty would increase to the next level, whereas with accuracy <75% difficulty would drop to an easier level. In exploration tasks difficulty was increased by enlarging the spatial zone within which a target could appear and by making targets and distractors more similar. For the reading task the word length and number of distractor words increased (up to a maximum of seven). For both

tasks, presentation time was directly related to previous response times, *i.e.* the faster the participant, the shorter the successive presentation time.

Patients could perform a maximum of 14 blocks per day. Each block contained 120 trials. They completed 294 exploration and 196 reading blocks.

Control: This training consisted of a number of tasks requiring visual attention but no systematic exploration or large horizontal eye-movements. The randomly presented tasks included a Go/No-Go task, centrally presented sequential search, Sternberg task and a “rabbit hunting” task. Difficulty was adjusted dynamically depending on performance by reducing presentation time or increasing attentional load. Patients were instructed to complete 10 blocks per day in approximately one hour, with a total of 350 blocks.

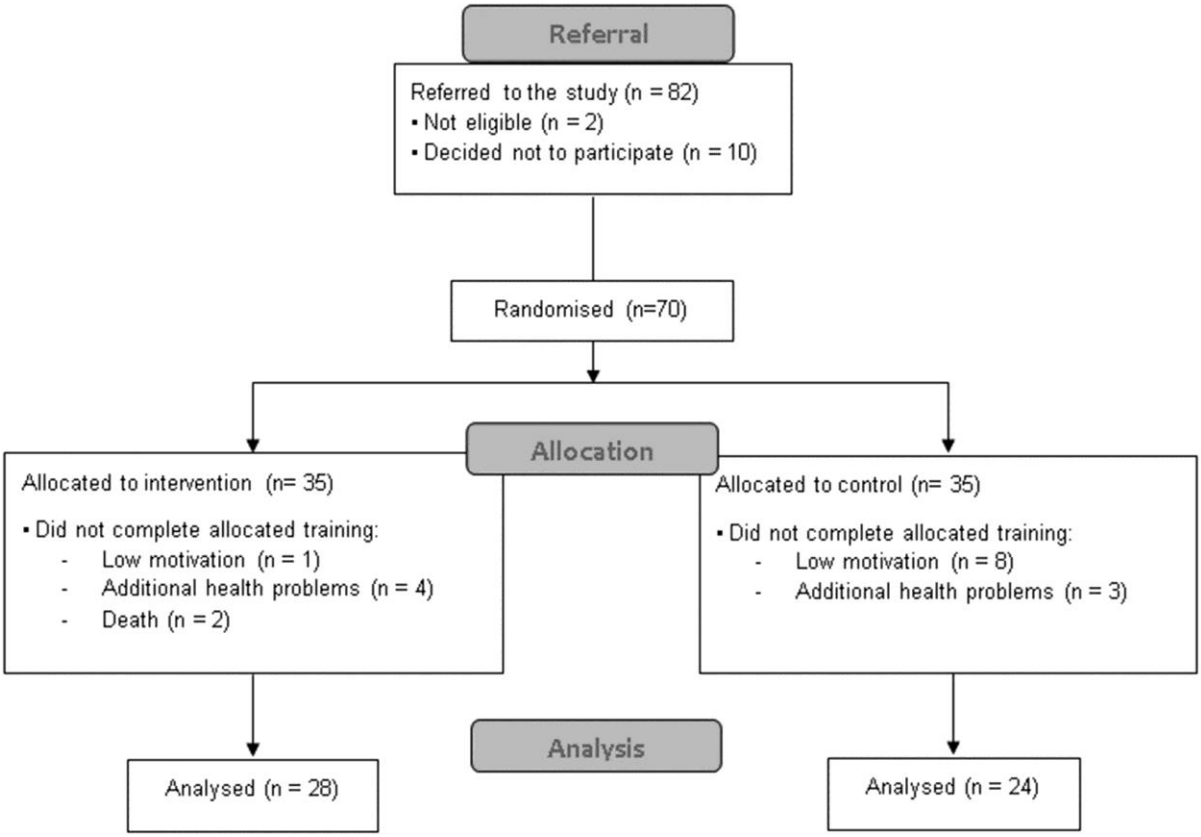
Statistical Analyses

Mixed-model ANOVAs were used, with the within-subject variable *Session* (pre- v. post-training) and between-subject variable *Group* (intervention v. control). Where relevant, paired-samples t-tests were used to further investigate relationships. Questionnaire data were analysed non-parametrically (Mann-Whitney-U for between-subjects, and Wilcoxon signed-ranks for within-subjects comparisons). Bonferroni corrections were applied throughout as appropriate.

Results

Eighteen participants dropped-out during the intervention period because of health problems (7), death (2) or low motivation (9). The final sample included in analyses consisted of 52 participants; 28 intervention and 24 control (see Figure 1).

Figure 1. CONSORT participant flow diagram



Visual search: Find the number

Mean accuracy for both groups was above 96% in all conditions. ANOVA performed on RT revealed a main effect of Session, [$F(1,50) = 25.56$; $P < .01$] but not Group [$F(1,50) = 1.95$; $P = .17$]. There was a significant Group by Session interaction [$F(1,50) = 4.71$; $P < .05$]; the intervention group improved significantly more than the controls (Figure 2A). The mean change in RT for the intervention group was 12.87% [95% CI, 8.44 – 17.30%], and only 4.80% for the control group [95% CI, 0.09 – 9.51%].

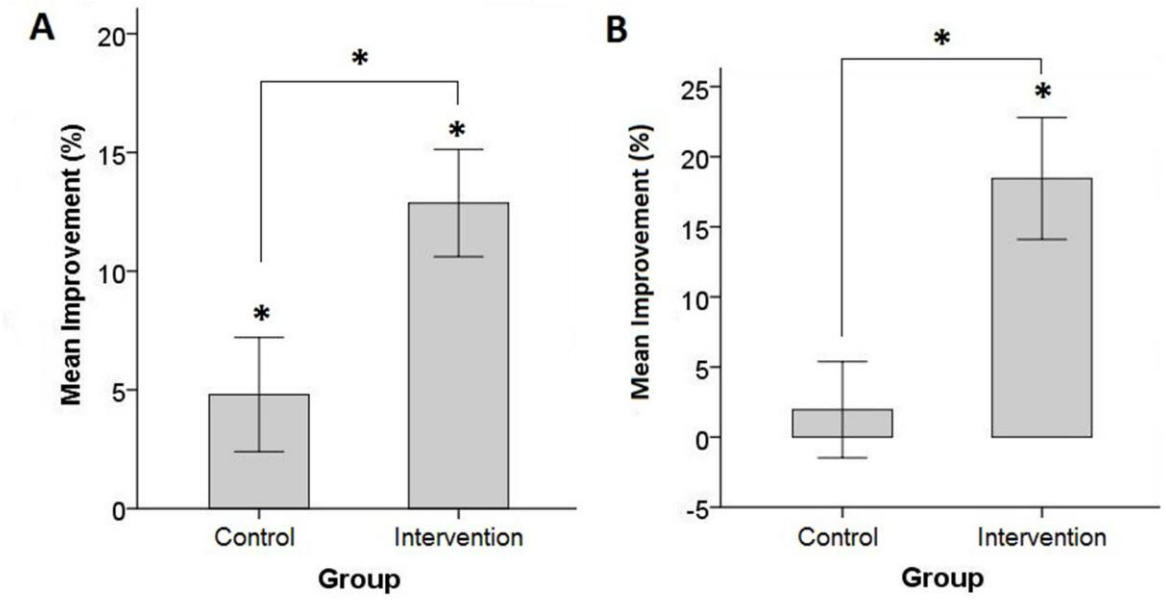
Reading

A significant difference was observed in the pre-training reading speed of individuals with left and right HVFDs ($t(50) = 13.43$, $P = .001$); those with a right-sided HVFD were significantly slower. An ANOVA was performed including a factor for side of defect (Hemifield). This revealed a significant effect of Session [$F(1,50) = 6.88$; $P = .01$]; participants read significantly faster after training (Figure 2B). The significant interaction between Group and Session [$F(1,50) = 9.01$; $P < .01$] showed that improvement observed for the intervention group [18.45%, 95% CI, 9.93 – 26.97%] was larger than that of the controls [1.95%, 95% CI, -4.78 – 8.68%]. No significant Group effect was observed [$F(1,50) = 1.01$; $P = .32$]. Furthermore, there were no significant interactions involving the factor Hemifield ($P \geq .33$), demonstrating that reading speed increased following experimental intervention regardless of defect side (Table 2).

Table 2
Mean corrected reading speed in words per minute (with standard deviation) both before and after training for the two groups, separated into those with a left or right visual field defect. Statistically significant changes between pre- and post-training assessments are indicated (*).

	Mean Corrected Reading Speed (*wpm*)	
	Pre-Training	**Post-Training**
Intervention Group (*n*)	114.43 (42.19)	132.46 (50.16)*
Left (15)	136.20 (23.85)	157.73 (34.82)*
Right (13)	89.31 (45.44)	103.31 (50.28)*
Control Group (*n*)	110.33 (56.38)	109.13 (52.63)
Left (11)	132.82 (48.94)	128.73 (41.85)
Right (13)	91.31 (56.92)	92.54 (56.56)

Figure 2. Bar-graphs showing the mean (+/- standard error) percentage improvement in performance at the post-training session relative to the pre-training session, for the intervention and control groups, for the find number visual search task (A) and the reading task (B). Significant differences are shown (*).



Tasks simulating ADL

Visuomotor search. Three intervention group patients were unable to perform this task so were excluded from the analysis. ANOVA performed on CT revealed a significant effect of Session [F(1,47) = 5.19; *P* <.05; Table 3], with patients faster after training. There was no significant effect of Group [F(1,47) = .11; P =.74] or Group and Session interaction [F(1,47) = .09; *P* =.76].

Obstacle avoidance. Four patients were unable to complete this task (three in the intervention and one in the control group) so were excluded from the analysis. The ANOVA showed no significant main effects or interactions ($P \geq .09$; Table 3), indicating no change in CT after either training.

Driving and hazard perception. Analysis of the mean score revealed no significant main effects or interactions ($P \geq .25$; Table 3), indicating no improvement in hazard perception.

Attention tasks

SART. The ANOVA performed on the mean error rate revealed no significant main effects or interactions ($P \geq .09$; Table 3), indicating unchanged sustained attention.

TEA. Two patients (one in each group) were unable to perform the visual elevator task, so were excluded from the analysis, whilst one intervention group patient did not complete the auditory version.

TEA: Visual elevator. The ANOVA revealed a main effect of Session on accuracy [$F(1,48) = 16.69$; $P < .01$; Table 3], but no effect of Group [$F(1,48) = 1.61$; $P = .21$], and no interaction between Group and Session [$F(1,) = 2.13$; $P = .15$]. Analysis of the time per switch component revealed a significant Session effect [$F(1,48) = 7.11$; $P = .01$]. There was no effect of Group [$F(1,48) = 2.32$; $P = .13$], and no interaction [$F(1,48) = 1.62$; $P = .21$].

TEA: Auditory elevator without distraction. The ANOVA performed on mean accuracy scores revealed no significant effects or interactions ($p \geq .31$; Table 3), indicating that performance remained unchanged.

TEA: Auditory elevator with distraction. There were no significant main effects or interactions revealed by the ANOVA ($P \geq .27$; Table 3).

Table 3
Mean results (with standard deviation) for each of the tasks simulating activities to daily living (ADL) and the attention tasks, for the intervention and control groups and each assessment session separately.

	Intervention Group			Control Group		
	n	Pre-training	Post-training	n	Pre-training	Post-training
ADL						
Obstacles^	25	40 (25)	35 (19)	23	44 (14)	45 (19)
Visuomotor Search^	25	114 (51)	101 (53)	24	117 (49)	107 (40)
Driving simulator°	28	2.9 (0.76)	2.9 (0.84)	24	2.7 (0.50)	2.9 (0.71)
Attention						
TEA						
Visual Elevator	27			23		
Accuracy (%)		7.9 (2.32)	8.8 (1.61)		6.8 (2.47)	8.7 (2.11)
Time per switch*		5.5 (2.07)	4.5 (1.28)		5.9 (2.53)	5.6 (2.94)
Auditory	27			24		
Elevator		6.7 (.81)	6.8 (.64)		6.6 (.83)	6.5 (.78)
No distraction±		8.0 (2.69)	7.5 (2.83)		7.7 (2.82)	7.9 (3.35)
With distraction±						
SART#	28	17.4 (17.80)	9.9 (14.62)	24	17.8 (15.65)	19.2 (20.43)

^Seconds (SD); °Mean accuracy score (SD); *Calculation described in the method section (SD); ±Mean accuracy score (SD); #Percentage error (SD)

Questionnaires

For both the VIQ and the VFQ-25 the majority of items showed a significant improvement (lower mean rating) after the R-E intervention [U ≥149.5; *P* <.05; Table 4]. As for the control training, only one item on the VFQ-25 (“doing small jobs”) showed a post-training improvement.

Table 4
Mean rating (SD) for each item of the Visual Impairments Questionnaire (VIQ) and the Visual Functioning Questionnaire (VFQ-25), for each assessment session for the two groups. Lower scores are associated with less impairment, except the last five items of the VFQ-25 where a higher score indicates lower impairment. Significant differences are shown (*).

	Intervention Group (n = 28)		Control group (n = 24)	
	Pre-Training	Post-Training	Pre-Training	Post-Training
VIQ				
Seeing objects	2.18 (1.09)	1.57 (0.88)*	2.67 (1.17)	2.58 (1.18)
Bumping into obstacles	1.64 (1.39)	0.89 (1.10)*	1.92 (1.53)	1.71 (1.40)
Loosing way	1.57 (1.50)	1.18 (1.39)*	1.30 (1.49)	1.04 (1.30)
Finding items (table)	1.25 (1.14	0.89 (1.10)*	1.17 (0.96)	1.17 (0.96)
Finding items (room)	1.71 (1.05)	1.14 (1.14)*	1.83 (1.24)	1.75 (1.19)
Finding items (shop)	2.11 (1.34)	1.28 (1.30)*	2.37 (1.17)	2.21 (1.14)
Using public transport	1.36 (1.52)	1.21 (1.55)	1.66 (1.58)	1.50 (1.53)
Find way at home	0.50 (1.07)	0.32 (0.90)	0.37 (0.9)	0.37 (0.92)
Crossing the street	1.71 (1.44)	1.28 (1.56)*	1.87 (1.39)	1.83 (1.52)
Reading	1.93 (1.49)	1.21 (1.34)*	2.17 (1.58)	2.17 (1.63)
VFQ-25[#]				
General vision	3.03 (0.79)	2.61 (0.74)*	3.08 (0.65)	3.12 (0.80)
Worry	3.03 (1.14)	2.46 (1.14)*	2.54 (1.28)	2.37 (1.34)
Reading	2.46 (1.32)	1.96 (1.23)*	2.58 (1.41)	2.50 (1.41)
Do small jobs	3.00 (1.25)	2.64 (1.28)*	2.87 (1.45)	2.46 (1.35)*
Street signs	1.68 (0.94)	1.46 (0.84)	1.79 (1.18)	1.83 (1.27)
Searching	2.68 (0.77)	2.00 (0.72)*	2.58 (0.97)	2.50 (1.02)
Miss objects	2.86 (0.80)	2.32 (0.94)*	2.92 (1.10)	2.92 (1.14)
Visiting friends	2.03 (1.26)	1.71 (1.01)	1.67 (1.05)	1.67 (0.82)
Self-care	1.68 (1.02)	1.61 (0.92)	1.46 (0.78)	1.37 (0.77)
Recognising people	1.64 (1.03)	1.50 (1.00)	1.58 (0.83)	1.54 (0.72)
Watching TV	1.71 (0.97)	1.57 (0.96)	1.50 (0.93)	1.54 (0.93)
Mood change	2.50 (1.52)	2.93 (1.54)*	2.75 (1.70)	3.17 (1.58)
Going out alone	3.18 (1.59)	3.57 (1.62)*	3.00 (1.74)	3.29 (1.57)
Accomplishment	2.86 (1.01)	3.14 (0.89)	2.71 (1.27)	2.87 (1.33)
Time length working	2.93 (1.24)	3.32 (1.31)*	3.00 (1.64)	3.12 (1.54)
Staying at home	3.68 (1.61)	4.00 (1.41)	4.29 (1.16)	4.33 (1.05)
Control	2.40 (1.26)	2.89 (1.34)*	2.71 (1.49)	2.79 (1.44)
Help from others	3.14 (1.43)	3.35 (1.43)	3.29 (1.46)	3.37 (1.47)

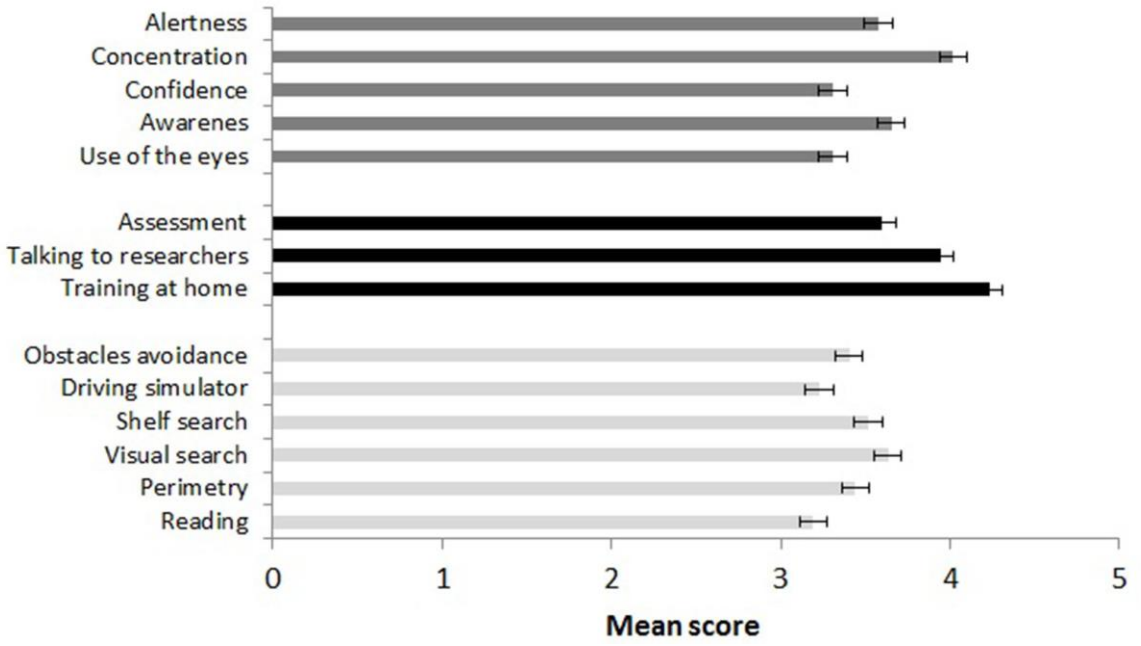
Training results

Training data was examined to determine average performance. Data was unavailable from one control group participant (technical failure). For the control training, the maximum training level of 12 was obtained by 83% (n = 19) of patients (mean = 11.5, SD = 1.5). Mean accuracy at training completion was 90.5% (SD = 9.0). For the experimental training, the maximum level for the exploration component was 8, achieved by 50% (n = 14) of patients. The mean level obtained was 6.0 (SD = 2.4) and mean end accuracy was 87.2% (SD = 7.9%). For the reading component the maximum level was 26, obtained by 18% of patients (n = 5). The mean level achieved was 16.4 (SD = 8.0), and accuracy was 85.0 % (SD = 6.0).

Training acceptance and feasibility

Figure 3 illustrates the mean SRQ scores for the different questions. In particular patients agreed that their improvements related to concentration, awareness of their condition, and alertness. Participants were also particularly pleased about being able to train at home. The assessment tasks which they felt helped them the most were visual and visuomotor search.

Figure 3. Bar-graph showing the mean satisfaction score (with standard error bars) for the different questions of the SRQ subdivided into three categories: “why patients thought their condition improved” (dark grey bars), “aspect of the training that was most helpful to them” (black bars) and “part of the assessment they thought was most useful” (light grey bars). Higher scores indicate greater agreement.



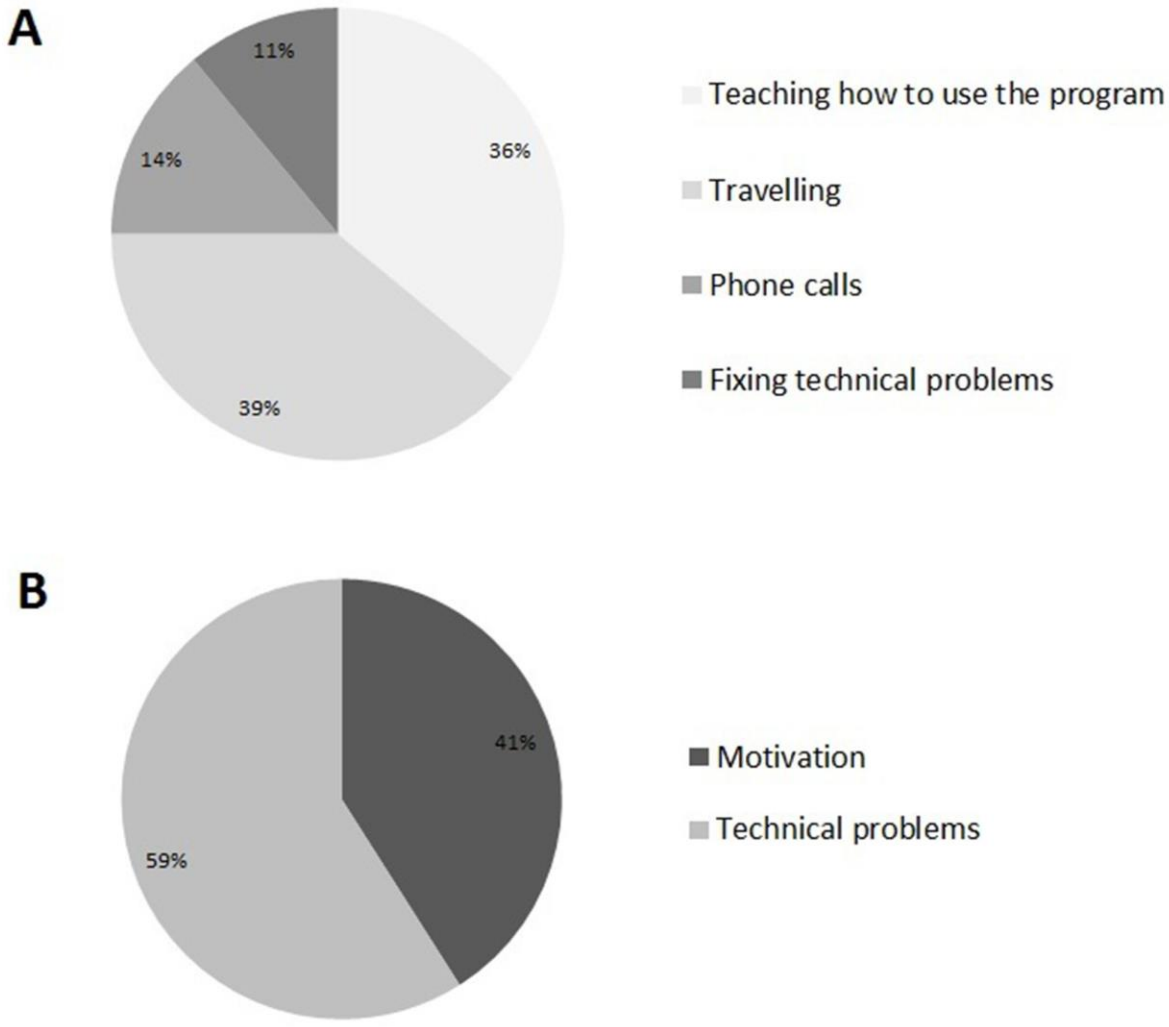
Two factors were considered to estimate the feasibility of the R-E training: compliance and support time.

Compliance: There were 18 withdrawals, nine due to low motivation. 89% of the low-motivation withdrawals were in the control group. Recommended training duration was five weeks. However, only three patients met this requirement; the mean completion time for the experimental training was 9.3 weeks (SD = 6.0).

Support time: The time spent supporting each participant during training was recorded. The following aspects were considered: teaching patients how to use the program, travelling to their home (first visit and additional visits when needed), solving technical problems, and phone calls (differentiated between providing

technical assistance or maintaining motivation; Figure 4). The mean overall support time per completed training was 137 minutes (SD = 91).

Figure 4. Pie-charts showing the percentage of time cost allocated to teaching the patients to use the program, travelling to their homes, phone calls and fixing technical problems (A); the percentage of phone calls made to provide technical support and to maintain motivation (B).



Discussion

Overview of findings

R-E training significantly improved exploration and reading performance relative to the control training. Patients also reported subjective improvements in

several ADL domains that were specific to the R-E intervention. However, these subjective improvements were not accompanied by improvements in objective ADL tasks (obstacle avoidance, visuomotor search and hazard perception). We speculate that this null result occurred because performance was measured on a small number of trials due to task length. It is therefore possible that analyses lacked the statistical power to detect small improvements. Moreover, the tasks were complex, requiring skills beyond the eye-movement strategies specifically trained.

Both R-E and control training led to significant improvements in the Visual Elevator task, but not to other measures of attention. This confirms that R-E training improves visual attention. However, the effect is no bigger than observed for other attention-training regimes and therefore cannot explain the superior effects of this training on search and reading. This implies that R-E training has a non-specific effect (on attention) in addition to specific effects on exploration and reading. In summary, it appears that R-E training is clinically effective and specific.

To assess the feasibility of the training we examined adherence, satisfaction and support time. Eighteen out of 70 (26%) patients failed to complete the training, half of these stopped because of health problems or death. Motivation problems accounted for only nine drop-outs, and most importantly only one of those patients was in the experimental group. However, only three out of 28 patients completed the R-E training within the prescribed five weeks, with average completion taking 9.3 weeks (*i.e.* almost twice as long as expected). Therefore, training can achieve satisfactory adherence but there are issues with ensuring patients keep to the treatment schedule. Satisfaction with R-E training was quite high and patients particularly liked the fact that they could train themselves at home. Regarding support time, the therapist had to spend an average of 137 minutes on each patient.

This compares favourably with a typical time investment of 600 minutes (15 training sessions of at least 40 minutes each) for similar supervised training[22]. Encouragingly, the majority of problems could be solved via phone without requiring a home-visit.

Comparing our study to previous findings

Our study confirmed previous findings on the effectiveness of supervised compensatory training[16-26], and is the first to demonstrate that reading and exploration skills can be improved following unsupervised training. This finding is of obvious practical relevance, but also of theoretical interest. While previous studies[22,28] demonstrated little transfer between reading and exploration (*i.e.* exploration training does not improve reading and vice-versa) it remained unclear which difference between the two training types was responsible for this. In our case the reading and exploration training components are very similar. Both are tasks that could be described as visual search (patients have to indicate the presence of a given target). The main difference seems to be that the reading task requires a specific search direction (horizontal, left-to-right) whereas exploration does not. It seems likely that it is the more specific oculomotor strategy which leads to the significant improvements in reading.

Secondly, we included a control training group. This comparison of the specific with a non-specific (*i.e.* attentional) training sets our study apart from most other clinical studies on the subject, with two exceptions. We have previously compared the efficacy of supervised exploration training with supervised attentional training[22], and Spitzyna and colleagues[25] reported specific benefits of supervised optokinetic training for improving reading performance of patients with HVFDs

compared to a control training. However, neither of the studies looked at the effect of combining exploration and reading training as reported here.

Interestingly, in a previous trial of exploration training[22] we found no significant improvement of reading, whereas the current study did. This shows that adding a specific reading training is sufficient and necessary to improve the reading of patients with HVFDs. However, in other respects the supervised training previously studied seemed more effective. Specifically, improvement in an untrained visual search task was substantially larger in the previous (21.6%) than the current study (12.9%). Numerous factors might explain this. Firstly, the task was not entirely the same in both studies and perhaps the earlier version was more sensitive to improvements. Secondly, although total training time was longer in the current study since it combined two training components (1500 versus 600 minutes), it was also spread across a longer time interval (mean 9.3 weeks versus 4.0 weeks) which may have reduced training intensity and thus efficacy. Thirdly, it is possible that reading and exploration components might interfere, such that the oculomotor patterns learned during the reading training disrupt the consolidation of the eye-movement skills acquired during exploration training. Finally, automated feedback provided by the unsupervised training may be less effective than human feedback. Lack of personal supervision might reduce motivation, feedback value and thus overall efficacy.

Conclusions

The central finding is that unsupervised home-based R-E training significantly improves the primary outcomes of visual search and reading, outperforming generic attentional training. Furthermore, this training is popular with patients, achieves

satisfactory adherence, and of additional importance, the time which a therapist needs to invest is five-times less than for comparable supervised training. The lesser investment from the therapist means that implementation costs are reduced, and access can be increased because rehabilitation can be provided to more individuals simultaneously. However, this training has some drawbacks. Specifically, subjective everyday improvements were not accompanied by objective ADL-related task improvements. Furthermore, the unsupervised R-E training may be less effective than the supervised equivalent. Given the great potential of offering neurorehabilitative training in an unsupervised form, research on factors that might allow similar efficacy with unsupervised as with supervised training should be a high priority.

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