Neuropsychologia 47 (2009) 869–878

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Visual search patterns in neglect: Comparison of peripersonal and extrapersonal space

Beverly C. Butler[a,*], Mike Lawrence[b], Gail A. Eskes[a,b,c], Raymond Klein[b]

[a] Department of Psychiatry, Dalhousie University, Nova Scotia, Canada
[b] Department of Psychology, Dalhousie University, Nova Scotia, Canada
[c] Department of Medicine (Neurology), Dalhousie University, Nova Scotia, Canada

ARTICLE INFO

Article history:
Received 7 January 2008
Received in revised form 1 December 2008
Accepted 18 December 2008
Available online 30 December 2008

Keywords:
Visuospatial neglect
Peripersonal
Extrapersonal
Reference space
Visual search
Neuropsychology
Stroke

ABSTRACT

Previous studies of visual search patterns in visuospatial neglect have analyzed shifts of attention during search tasks using eye tracking technology and verbal reports. The purpose of the present study was to replicate and extend upon reported parameters of visual scanning patterns of neglect patients in peripersonal space (within arms reach) and to examine whether similar patterns of visual search are also apparent in extrapersonal space (beyond arms reach). Using a simple verbal visual search and target detection paradigm right-hemisphere stroke participants, with and without neglect, and healthy older volunteers named targets on scanning sheets placed in peripersonal and extrapersonal space. The healthy controls and right-hemisphere stroke group without neglect showed similar ‘reading’ type strategies, while the neglect group displayed an unsystematic search pattern, during search in both peripersonal and extrapersonal space. Group comparisons of search parameters support the presence of multiple cognitive deficits affecting the complex visual search patterns of neglect patients, including a rightward attentional bias, a reduced spatial scale of attention (local processing bias), and a deficit of working memory affecting both near and far space search. Ventral visual stream damage and neglect, however, were related to slower target report rate and more misidentification errors in extrapersonal space. The ease of administration of this verbal target detection task in both peripersonal and extrapersonal space, and the relationship of the measures produced to theorized attentional and executive deficits in neglect, provide impetus for further research on the severity and independence of individual scanning deficits in neglect.

1. Introduction

Patients with visuospatial neglect after right-hemisphere stroke will fail to orient, report or respond to stimuli toward the contralesional (left) side of space (Halligan & Marshall, 1994), unless explicitly directed to do so (Riddoch & Humphreys, 1983). Some accounts of neglect suggest that this visuospatial attention deficit is related to a rightward attentional bias and gradient of attention that manifests on visual search and cancellation tasks as decreasing target detection from right to left in the visual space (Butler, Eskes, & Vandorpe, 2004; Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005; Halligan, Burn, Marshall, & Wade, 1992; Kinsbourne, 1987; Kinsbourne, 1993; Marshall & Halligan, 1989; Small, Cowey, & Ellis, 1994). In oculographic analysis of the visual search performance of neglect patients, a rightward initial fixation and fewer and shorter duration fixations on the left than the right has supported a rightward bias and a gradient in eye movement patterns that reflect a fundamental attentional deficit in neglect (Behrmann, Watt, Black, & Barton, 1997). Behrmann et al. (1997) reported, however, that while there was a decreasing probability of fixations from right to left across the search area, the proportion of leftward saccades did not differ significantly between the neglect group and the healthy control group in either the far left or the far right horizontal quartile of the search area, suggesting that the neglect patients' search is as constrained by the boundaries of the search field as the healthy control group.

In addition to a rightward bias and a right-to-left decreasing gradient of attention, the search pattern of neglect patients has been shown to be irregular and unsystematic with fewer row searches, shorter search sequences, many shifts between column, row, and diagonal search, and a higher percentage of repeated readings compared to healthy controls (Samuelsson, Hjelmquist, Jensen, & Blomstrand, 2002). The percentage of repeated target detections on visual search tasks by left neglect patients is typically greater on the right side of the search area and on tasks where object identity cannot be used as a visual cue (i.e., all targets are the same letter) or there is a greater spatial memory load (i.e., larger display set size, no visual mark on detected targets: Husain et al., 2001; Parton et al., 2006; Wojciulik, Husain, Clarke, & Driver, 2001).

---

* Corresponding author at: Department of Psychiatry, Room 3073, Abbie J. Lane Building, 5909 Veteran's Memorial Lane Halifax, Nova Scotia, Canada B3H 2E2.
Tel.: +1 902 473 6472; fax: +1 902 473 4596.
E-mail address: DrBevButler@gmail.com (B.C. Butler).

0028-3932/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2008.12.020

The relationship between repeated target detections and neglect may be due to a deficit in spatial working memory that results in difficulty retaining visual locations across saccades during search (Danckert & Ferber, 2006; Husain et al., 2001; Malhotra et al., 2005; Parton et al., 2006; Wojciulik et al., 2001) and consequently misjudging previously searched locations as new ones (Mannan et al., 2005). However, damage to the parietal lobe, which often results in neglect, may also lead to a deficit in the inhibitory tagging of environmental locations necessary for inhibition of return (IOR), a low level attentional mechanism that discourages re-inspection of targets at previously visited locations (see discussion of Sapir, Hayes, Henik, Danziger, & Rafal, 2004 in Klein, 2004). Thus, an IOR and/or spatial working memory failure in neglect patients may result in recursive searching from an ipsilesional start position, a failure to proceed leftward and, consequently, neglect of leftward stimuli (Malhotra, Mannan, Driver, & Husain, 2004).

Irregular visual search patterns, gradients of attention, and repeated rightward target detection in neglect have been shown predominantly on scanning or cancellation tasks performed in peripersonal space (i.e., within arms reach, Behrmann et al., 1997; Chatterjee, Thompson, & Ricci, 1999; Halligan et al., 1992; Marshall & Halligan, 1989; Samuelsson et al., 2002; Small et al., 1994). Neglect symptoms have been dissociated in peripersonal (near) and extrapersonal (far) space, however, including performance on line bisection, cancellation tasks, word reading, target counting, and square completion (Cowey, Small, & Ellis, 1994; Halligan & Marshall, 1991; Shelton, Bowers, & Heilman, 1990; Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998) as well as lateral gradients (i.e., left-to-right increasing slopes) of target detection performance (Butler et al., 2004). Butler et al. reported a double dissociation in differences in the slopes of target detection gradients between extrapersonal and peripersonal space on a visual search and detection task, suggesting severity of neglect differed between the coordinate spaces (Butler et al., 2004). Analysis of lesion locations of the individual stroke participants in that study was consistent with a relationship between dorsal stream damage and neglect in near space, while ventral stream damage was related to neglect in far space (Previc, 1990; Weiss et al., 2000).

The dorsal and ventral visual streams which project from the striate cortex to the posterior parietal lobe and inferotemporal cortex, respectively, have dedicated perceptual and attentional functions, despite considerable cross-talk between the two visual streams (Goodale & Milner, 1992). The dorsal stream, specialized for spatial perception (i.e., 'where'), apparently has a full representation of the visual field, including the far periphery, and may be responsible for higher attentional resolution and enhanced focused attention (e.g., discriminating targets from distractors; attentional tracking) in tasks performed in near space (in the lower visual field). In contrast, the ventral stream is reportedly specialized for perception and representation of objects and scenes (i.e., 'what') and is heavily biased toward central vision (particularly the fovea). The ventral stream provides an apparent visual search advantage in far space (in the upper visual field) through spatial analysis, motion processing, depth processing, and more efficient saccadic eye movements and attentional shifting (Goodale & Milner, 1992; Mishkin, Ungerleider, & Macko, 1983, and Danckert & Goodale, 2003; Previc, 1998 for reviews).

In addition to the near and far space attentional biases related to the dorsal and ventral visual streams, orienting of attention is controlled by dorsal and ventral networks connecting the frontal and parietal lobes. The bilateral dorsal attention networks, linking the intraparietal sulcus and frontal eye field within each hemisphere, control the allocation of spatial attention and the selection of stimuli and responses (endogenous orienting), while the right-hemisphere ventral attention network, involving the temporoparietal junction and ventral frontal cortex, is concerned with target detection and reorienting to salient stimuli (exogenous orienting) (Corbetta & Shulman, 2002). While these two frontoparietal attention networks are largely independent and functionally dissociable, they have been shown in a recent fMRI study of functional connectivity to overlap in the right middle and inferior frontal lobe (He et al., 2007). Thus, a potential link exists between the networks that would allow them to work together during visual orienting tasks (Corbetta & Shulman, 2002). According to this model, spatial neglect results from a combination of structural damage and functional disruption of these ventral and dorsal frontoparietal attention networks (Corbetta et al., 2005). Furthermore, disrupted feedback interactions from attention-controlling dorsal regions of the frontoparietal network to visual cortex in neglect (Corbetta & Shulman, 2002) are theorized at this time to result in a dissociation between visual search performance in near and far space due to the differential effect of attention deficits in the upper and lower visual fields.

The purpose of the present study was to compare the visual scanning patterns of neglect patients, right-hemisphere control participants and healthy control participants in peripersonal and extrapersonal space on a target detection task. The target detection task involved search for and verbal reporting of multiple unique targets (i.e., numbers and letters) among distractors (i.e., symbols) with *no* marking of the visual search area to indicate reported targets. Thus, this easily administered task had equivalent characteristics for peripersonal and extrapersonal space presentation that approximated real-world search parameters (i.e., unrestricted visual exploration for static targets amongst distractors that remain unmarked when detected). Furthermore, although movements of attention can be made independent of eye movements (Klein, Kingstone, & Pontefract, 1992), target report requires attentional focus at the locus of each reported target; therefore, we can infer movements of attention between successively reported targets without the cost or inconvenience of monitoring eye movements.

It was hypothesized, due to the influence of reading patterns on visuospatial attention in healthy Indo-European readers (Chokron & Imbert, 1993; Geldmacher & Alhaj, 1999), that visual search patterns for verbal stimuli in healthy participants would follow a left-to-right, top-to-bottom reading pattern in both peripersonal and extrapersonal space. In addition, the stroke control group (without neglect) was hypothesized to show a visual scanning pattern that more closely resembled the healthy control group than the neglect group, although chronic non-lateralized attention deficits may influence the strength of the search pattern (Samuelsson et al., 2002). In contrast to the hypothesized reading-related search pattern in healthy participants and stroke controls without neglect, neglect patients were expected to show irregular and unsystematic visual search patterns. The unique contribution of this study was to examine whether these patterns differed in peripersonal and extrapersonal space depending on the location of lesions and the related attentional deficits.

2. Method

2.1. Participants

This study was approved by the QEII Health Sciences Centre Research Ethics Committee and all participants gave their informed consent prior to participation in the study. See Table 1 for demographic characteristics and Baseline Neuropsychological Test results of all groups.

2.1.1. Left neglect group (NEG)

Of eleven stroke patients with unilateral lesions in the right-hemisphere (confirmed by neuroradiological reports) and neglect, nine (8 male) were included in the neglect group. Neglect was defined as failure (performance at or below standardized cutoff values) on at least three of six Behavioral Inattention Test (BIT) conventional subtests (Butler et al., 2004; Stone, Halligan, Greenwood, & Marshall, 1991; Stone, Wilson et al., 1991). All nine of the participants in the neglect group failed at least two non-drawing BIT subtests. Two neglect participants were

Table 1
Demographic and neuropsychological test data for neglect (NEG, $n = 9$), right-hemisphere damaged control (RHC, $n = 11$), and healthy control (NC, $n = 10$) groups. Means ± S.D.

	NEG	RHC	NC
Age (years)	66.0 ± 11.3	57.1 ± 16.7	57.9 ± 13.7
Education (years)	10.0 ± 2.1[*]	11.9 ± 3.5[*]	15.8 ± 2.4
Days post-stroke	101.1 ± 59.4	63.9 ± 40.2	NA
NAART (FSIQ)	98.6 ± 10.1[*]	101.8 ± 8.7[*]	109.3 ± 5.6
Cognistat (total/84)	64.8 ± 7.9[§]	72.2 ± 5.5[*]	76.6 ± 3.1
BIT (total/146)	98.8 ± 37.3[§]	139.8 ± 6.0[*]	144.6 ± 1.4
DSf (score)	8.3 ± 0.7	7.8 ± 1.5	8.2 ± 1.9
DSb (score)	4.6 ± 2.1[*]	5.1 ± 1.6[*]	7.5 ± 2.3
VOSP NL (total/10)	5.6 ± 2.2[§]	8.8 ± 1.3	9.4 ± 0.8
VOSP PD (total/20)	12.9 ± 2.3[§]	17.6 ± 2.4[*]	19.9 ± 0.3

NAART – North American Adult Reading Test; Cognistat – Neurobehavioral Cognitive Status Examination; BIT – Behavioral Inattention Test; DSf – Digit Span forward; DSb – Digit Span backward; VOSP NL – Visual Object and Space Perception Battery, Number Location; VOSP PD – Visual Object and Space Perception Battery, Position Discrimination.

[*] Significantly different from NC group ($p < 0.05$).

[§] Significantly different from both RHC and NC groups ($p < 0.05$).

excluded from analyses because they did not complete the target detection task in extrapersonal space. All included patients were alert and oriented with no diffuse cognitive deficits. All patients had a left homonymous hemianopia.

2.1.2. Right-hemisphere damaged non-neglect controls (RHC)

Stroke participants with unilateral right-hemisphere lesions (confirmed by neuroradiological reports), whose performance on the BIT conventional subtests did not meet criteria for neglect, were included in this group. Of 13 RHC participants recruited, two were excluded from analyses because they did not complete the target detection task in extrapersonal space. Of the remaining 11 stroke control participants (7 male), five passed all BIT subtests, two failed a single BIT subtest, and four stroke control participants failed two BIT subtests. It was decided to include those participants with one or two BIT subtest failures in the control group since their failures were related more to visuospatial deficits on drawing and copying tasks or to general attentional deficits (e.g., both left and right sided errors). All patients were oriented with no diffuse cognitive deficits. Four patients had a left homonymous hemianopia.

2.1.3. Healthy controls (NC)

Ten healthy volunteers (5 males) with no known neurological problem (screened by self-report) took part in the study.

2.2. Apparatus

2.2.1. Scanning sheets

Visual search behavior was studied using 10 scanning sheets with 48 individual letter and number targets and 49 distractors (symbols: ?, &, #, %) pseudo-randomly distributed in a 32 × 32 x–y coordinate grid with the bottom left corner unit represented as (1, 1). In peripersonal space each grid section was 8 mm in width and 6 mm in height and individual targets were approximately 3 mm in height and width. Letters and numbers were distributed such that 6 different targets appeared in each column of an imaginary 8 column by 2 row grid and no target was repeated on a single sheet.

In peripersonal space the target detection sheets were positioned on a table with the center of the sheet 30 cm from the participant at their midline. In general, the target area subtended approximately 28.8° and individual targets were approximately 0.32° of visual angle in the horizontal plane, although this varied slightly depending upon the height of the individual participant. In extrapersonal space the target detection sheets were projected onto a white board 250 cm from the subject with the centre of the scanning sheet at eye level and in line with the participant's sagittal midplane. Extrapersonal space targets were approximately 12 mm (0.28°) in height and width and the target area subtended approximately 20.3° of visual angle in the horizontal plane.

2.3. Procedure

2.3.1. Baseline Neuropsychological Tests

At the time of the study, unless previously completed as part of their clinical admission, all subjects completed a set of Baseline Neuropsychological Tests immediately prior to the experimental target detection tasks. These tasks were administered to confirm the presence/absence of neglect or other visuospatial deficits associated with right-hemisphere damage (Lezak, 1995) and to screen for general cognitive deficits. Measures included: a total score on the Neurobehavioral Cognitive Status Examination (Cognistat) (Mysiw, Beegan, & Gatens, 1989; Osmon, Smet, Winegarden, & Gandhavadi, 1992), calculated as the sum of all subtest scores to a maximum score of 84; total score on the Behavioral Inattention Test conventional subtests (Wilson, Cockburn, & Halligan, 1987), full scale IQ from the North American Adult Reading Test (NAART) (Blair & Spreen, 1989); Digit Span scores (forward and backward) (Wechsler, 1987), and total scores on the Visual Object and Space Perception Battery (VOSP) 'Position Discrimination' (PD) and 'Number Location' (NL) subtests (Warrington & James, 1991).

2.3.2. Visual Scanning Tests

In each trial the stimulus sheet was centered at the participant's trunk midplane. Participants were instructed to sit with their hands in their lap and to visually scan and read out loud all of the numbers and letters on the paper (peripersonal) or wall (extrapersonal) in front of them, within a two-minute time limit. Head and eye movements were unrestricted. The participants were also instructed to indicate when they had detected all of the targets, within the two-minute time limit. Five trials (i.e., different stimulus sheets) in peripersonal and extrapersonal space conditions were administered with the order of space presentation counterbalanced between subjects.

The verbal reports of the subjects were recorded verbatim for each trial and included any letter and number targets, repeated detections, distractor reports, and errors of commission/misidentification. In addition, sessions were audio tape-recorded, and the tape recordings were independently reviewed by a person who was blind to the conditions to verify scoring. If discrepancies between scorers occurred, the correct response (if identified) was accepted.

2.3.3. CT analyses of lesion localization

Lesion location was reconstructed from clinical CT scans using the method of (Damasio & Damasio, 1989) by an experienced neuroradiologist blind to the results of the study. Each lesion was charted on standardized CT templates and on a checklist of brain areas to assist in detailed localization. Dorsal visual stream damage was inferred from lesions involving the superior parietal lobule and/or the superior frontal lobe, while ventral stream damage was inferred from lesions involving the inferior parietal lobe, superior temporal gyrus, and/or the inferior frontal lobe (Corbetta et al., 2005).

3. Results

3.1. Demographic and Baseline Neuropsychological Test results

The three groups did not differ in age ($F(2, 27) = 1.13$, $p = 0.336$) and the two stroke groups did not differ in mean time post-stroke ($F(1, 18) = 2.78$, $p = 0.113$). There was, however, a significant difference in mean level of education among the groups ($F(2, 27) = 10.80$, $p < 0.001$). Post-hoc independent t-tests showed that the NC group had more years of education than either of the stroke groups (RHC: $t_{19} = 2.94$, $p = 0.008$; NEG: $t_{17} = 5.50$, $p < 0.001$), while the stroke groups (NEG, RHC) did not differ ($t_{18} = 1.44$, $p = 0.167$). See Table 1.

On Baseline Neuropsychological Testing, significant differences among the three groups were found in mean NAART score ($F(2, 27) = 4.19$, $p = 0.026$), mean Cognistat Total score ($F(2, 27) = 10.09$, $p = 0.001$), mean BIT Total score ($F(2, 27) = 14.00$, $p < 0.001$), mean VOSP_NL score ($F(2, 27) = 18.08$, $p < 0.001$), mean VOSP_PD score ($F(2, 27) = 33.04$, $p < 0.001$), and mean Digit Span-backward score ($F(2, 27) = 5.83$, $p < 0.01$). No difference was apparent in mean Digit Span-forward score ($F(2, 27) = 0.33$, $p = 0.719$) among the three groups. See Table 1.

3.2. Lesion localization

Table 2 indicates areas of damage in the dorsal and ventral visual streams, basal ganglia and thalamus for all stroke participants. One RHC participant (#1020) did not have a CT scan available for detailed analysis and was not included in the lesion localization analyses, although the neurological report stated 'right parietal lobe infarct'. The majority of NEG participants (88.9% or 8 of 9) had lesions of the ventral network, including inferior parietal, superior temporal and/or inferior frontal damage. Furthermore, six of the eight NEG participants with ventral stream damage had lesions involving the inferior parietal lobe. In contrast, only one of seven RHC participants with ventral stream damage had a lesion involving the inferior parietal lobe. Of the six NEG participants with dorsal stream damage (66.7%), five had lesions involving the superior

Table 2
Clinical and lesion localization data for right brain-damaged subjects (NEG and RHC).

Subject	BIT (total/146)	VFD (LHH)	Ventral network			Dorsal network		Subcortical	
			IFL	IPL	STL	SFL	SPL	BG	Thal
NEG	98.8*								
1014	36	+	+	+	+		+	+	
1019	46	+					+		
1013	75	+	+	+	+			+	
1018	103	+	+	+	+	+	+	+	+
1024	119	+	+		+				
1016	120	+	+	+	+		+	+	
1022	125	+	+		+			+	
1034	130	+	+	+	+		+		
1017	135	+	+	+	+	+		+	
RHC	139.8*								
1015	128	?			+			+	
1012	132		+	+	+				
1020[a]	134			?			?		
1025	139	+						+	+
1021	141	+							+
1043	142		+		+	+		+	
1000	142		+		+	+		+	
1036	144	+			+				
1032	145	+			+			+	
1035	145				+			+	
1042	146								+

VFD – visual field defect; L HH – left homonymous hemianopsia; IFL – inferior frontal lobe; IPL – inferior parietal lobe; STL – superior temporal lobe; SFL – superior frontal lobe; SPL – superior parietal lobe; BG – basal ganglia; Thal – thalamus.

[a] CT scan unavailable; neurological report stated right parietal lobe infarct.

* Group mean.

parietal lobe. The lesions of the two RHC participants with dorsal stream damage (22.2%), however, did not encroach on the superior parietal lobe. Five NEG (55.6%) and two RHC (18.2%) participants had mixed ventral and dorsal stream damage, with or without subcortical involvement. Three NEG (33.3%) and five RHC (45.5%) participants had ventral stream damage only, with or without subcortical involvement. One neglect participant (11.1%; #1019) had dorsal stream damage only. Three RHC participants had lesions affecting subcortical structures only.

3.3. *Visual search results*

The verbal reports of participants during the visual search task were translated into target coordinates based on the 32 × 32 grid. Dependent measures were derived from these coordinate sequences and are described in detail before each analysis below. To relate our visual search analyses to the literature, repetitions, start location, proportion of directional shifts to targets, length of search sequences, target detection, and the leftward shift gradient across columns were calculated in a fashion similar to Samuelsson et al. (2002) and Behrmann et al. (1997). Each measure was calculated on a per-subject/per-space/per-sheet basis, and an average for each participant and space was calculated across sheets for use in ANOVAs as described below. Post-hoc *t*-tests were performed using the Welch modification for degrees of freedom, since homogeneity of variance is an untenable assumption with such small samples (Welch, 1947).

3.3.1. *Target detection*

The proportion of unique targets detected on the left and right halves of the search area was analyzed by a 3 (groups) × 2 (spaces) × 2 (sides) analysis of variance. ANOVA revealed a main effect of space ($F(1, 27) = 15.18$, $p < .001$) such that overall more targets were detected in peripersonal space than extrapersonal space. There were also significant main effects of side ($F(1, 27) = 17.81$, $p < .001$) and group ($F(2, 27) = 30.27$, $p < .001$, $FLSD = 0.12$), such that more targets were detected on the right than the left of the search area and the NEG group ($M = 0.54$, S.D. = 0.21) detected significantly fewer targets than both control groups, while the RHC group ($M = 0.88$, S.D. = 0.08) detected significantly fewer targets than the NC group ($M = 0.97$, S.D. = 0.02) (NEG vs. RHC: $t(10.03) = -4.57$, $p < 0.01$; NEG vs. NC: $t(8.12) = -6.06$, $p < 0.01$; RHC vs. NC: $t(11.13) = -3.37$, $p < 0.01$). The main effects of side and group, however, were moderated by a significant group-by-side interaction ($F(2, 27) = 13.56$, $p < 0.001$). Post-hoc paired *t*-tests comparing target detection on the left and right within each group revealed that the neglect group detected significantly more targets on the right than the left ($t(8) = 4.91$, $p < 0.01$), while the two control groups did not differ across sides (RHC: $t(10) = 1.42$, $p = 0.19$; NC: $t(9) = -1.75$, $p = 0.11$). There were no significant interactions with space. See Table 3.

3.3.2. *Target detection gradient*

For analyses of lateral gradients the target detection grid was separated into eight columns with six targets per column. A linear function was fit to the data representing the proportion of targets found per column. A 3 (groups) × 2 (spaces) mixed ANOVA on the linear slopes of target detection yielded only a main effect of group ($F(2, 27) = 18.98$, $p < .001$) such that the neglect group ($M = 5.44$, S.D. = 2.73) had a greater slope than both control groups (NC: $M = -0.38$, S.D. = 0.68; RHC: $M = 1.02$, S.D. = 2.43) (NEG vs. RHC: $t(16.27) = 3.78$, $p < 0.01$; NEG vs. NC: $t(8.89) = 6.22$, $p < 0.01$; RHC vs. NC: $t(11.69) = 1.83$, $p = 0.09$). See Table 3 and Fig. 1.

3.3.3. *Repetitions*

Repetitions were defined as the report of targets that had previously been reported on that particular trial. To determine the probability of reporting a target on either the left or right half of each sheet more than once, the total number of repetitions per side was divided by the total number of unique target detections on that side, yielding proportions unconfounded by differences in lateralization of target detection. A 3 (groups) × 2 (spaces) × 2 (sides) ANOVA yielded a significant main effect of group ($F(2, 26) = 7.91$, $p < 0.01$) such that healthy controls ($M = 0.01$, S.D. = 0.02) made a significantly

Table 3
Target detection assessment: means (S.D.) for each group, space and side.

Variable	NEG ($n = 9$)[a]		RHC ($n = 11$)[b]		NC ($n = 10$)[c]	
	PP	EP	PP	EP	PP	EP
Targets detected (prop. of all targets)	0.60 (0.23)	0.49 (0.21)	0.91 (0.08)	0.86 (0.10)	0.98 (0.01)	0.96 (0.03)
Left side	0.49 (0.27)	0.40 (0.25)	0.90 (0.09)	0.82 (0.19)	0.99 (0.01)	0.97 (0.03)
Right side	0.70 (0.21)	0.58 (0.19)	0.92 (0.07)	0.89 (0.05)	0.97 (0.02)	0.96 (0.04)
Detection gradient slope	5.56 (3.38)	5.31 (2.98)	0.40 (1.65)	1.64 (4.23)	−0.51 (.64)	−0.25 (.87)
Repetitions (prop. of all reports)	0.26 (0.25)	0.26 (0.17)	0.10 (0.10)	0.13 (0.22)	0.01 (0.02)	0.02 (0.02)
Left side	0.27 (0.27)	0.22 (0.15)	0.08 (0.10)	0.10 (0.15)	0.01 (0.01)	0.02 (0.02)
Right side	0.25 (0.25)	0.31 (0.23)	0.11 (0.11)	0.16 (0.30)	0.02 (0.03)	0.02 (0.02)
# Unique reports between repeats	13.85 (3.72)	13.13 (4.55)	10.49 (5.78)	12.53 (6.14)	12.20 (3.46)	8.52 (1.44)
Left side	13.01 (5.92)	12.11 (4.51)	10.20 (9.11)	12.82 (5.44)	13.00 (5.66)	8.08 (1.53)
Right side	14.68 (5.43)	14.14 (6.37)	10.78 (3.56)	12.23 (7.96)	11.39 (1.27)	8.96 (1.36)
Time per report (seconds)	2.7 (1.1)	3.3 (1.1)	1.6 (0.3)	1.8 (0.3)	1.2 (0.2)	1.2 (0.2)
Misidentifications (prop. of reports)	0.03 (0.05)	0.13 (0.11)	0.02 (0.02)	0.03 (0.01)	0.03 (0.01)	0.03 (0.02)

[a] $n = 8$ for repetitions and # Unique reports between repeats: one neglect participant was excluded because his target detection was restricted to the rightmost columns.

[b] $n = 7$ for # Unique reports between repeats.

[c] $n = 2$ for # Unique reports between repeats; NEG = neglect group; RHC = right-hemisphere lesioned non-neglect control group; NC = healthy control group; PP = peripersonal space; EP = extrapersonal space.

lower proportion of repetitions than the two stroke groups, which did not differ (NEG: $M = 0.26$, S.D. = 0.18; RHC: $M = 0.11$, S.D. = 0.15) (NC vs. NEG: $t(7.08) = -3.85$, $p < 0.01$; NC vs. RHC: $t(10.23) = -2.24$, $p = 0.05$; NEG vs. RHC: $t(13.2) = 1.9$, $p = 0.08$). There was also a significant main effect of side ($F(1, 26) = 4.78$, $p < .05$) such that a greater proportion of repetitions were made on the right than on the left. There were no main effects or interactions with space. See Table 3.

3.3.4. *Number of unique target reports between repetitions*

The number of reports between repetitions was submitted to a 3 (groups) × 2 (space) × 2 (side) ANOVA yielding no significant effects. See Table 3.

3.3.5. *Average time per report*

The time per report (in seconds) was calculated for each sheet by dividing the total time for reports by the number of reports for each sheet and then an average time per report was calculated for each participant in each space. These values were then submitted to a 3 (groups) × 2 (space) ANOVA that revealed significant main effects of group ($F(2, 27) = 20.63$, $p < .001$) and space ($F(1, 27) = 13.82$, $p < .001$), which were moderated by a significant group by space interaction ($F(2, 27) = 7.20$, $p < .01$). Post-hoc paired t-test analyses of the interaction showed that both stroke groups had slower report rates in extrapersonal than peripersonal space (NEG: $t(8) = -3.13$, $p = .01$; RHC: $t(10) = -2.30$, $p < .05$), while the report rate of the healthy control group did not differ between the spaces ($t(9) = 0.03$, $p = .98$). Furthermore, the difference in rate of detection between extrapersonal and peripersonal space was significantly greater for the NEG group (diff = 0.64 sec/report greater in extrapersonal space) than the NC group (diff = −0.001 sec/report), while the RHC group rate difference (diff = 0.18 sec/report) was intermediate and did not differ significantly from the other groups (NEG vs. NC: $t(8.8) = -3.06$, $p = 0.01$, RHC vs. NEG: $t(10.27) = 2.12$, $p > 0.05$, RHC vs. NC: $t(16.05) = -1.99$, $p > 0.05$). See Table 3.

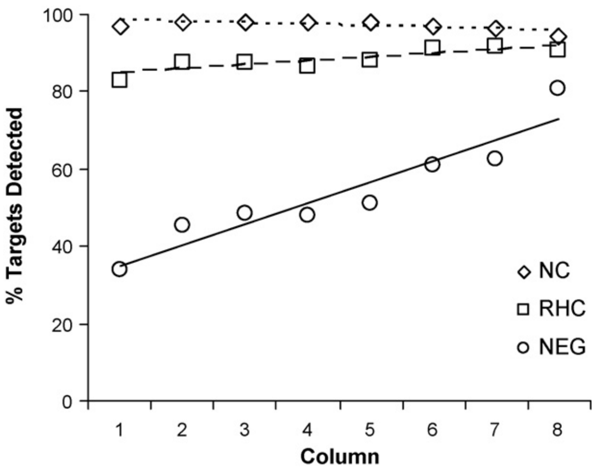

Fig. 1. Mean percent of unique targets detected by each group within each column of the stimulus array. Lines represent mean linear slope for each group. Data are collapsed across peripersonal and extrapersonal space. NEG – neglect group; RHC – right-hemisphere control group; NC – healthy control group.

3.3.6. *Verbal report errors: misidentifications*

Verbal reports of letters or numbers that were not on the search sheet on a given trial were categorized as misidentifications. Data on the rate at which such errors occurred (as a proportion of total number of reports) were submitted to a 3 (groups) × 2 (spaces) ANOVA that revealed main effects of group ($F(2, 27) = 8.66$, $p < .001$) and space ($F(1, 27) = 5.77$, $p < .03$) as well as a significant group by space interaction ($F(2, 27) = 5.10$, $p < .05$). Post-hoc paired t-test comparisons showed that the neglect group had a significantly higher proportion of misidentification errors in extrapersonal space than both of the control groups (NEG vs. RHC: $t(8.07) = 2.92$, $p < 0.05$; NEG vs. NC: $t(8.08) = 2.93$, $p < 0.05$; RHC vs. NC: $t(18.8) = -0.28$, $p = 0.79$), while the proportion of misidentification errors in peripersonal space did not differ significantly among the groups (NEG vs. RHC: $t(8.06) = 1.19$, $p = 0.27$; NEG vs. NC: $t(8.02) = 1.3$, $p = 0.23$, RHC vs. NC: $t(16.33) = 1.43$, $p = 0.17$). See Table 3.

3.3.7. *Start location*

The x-axis location of the first reported target (within the 32 × 32 x–y grid) was submitted to a 3 (groups) × 2 (spaces) mixed ANOVA, yielding only a significant main effect of group ($F(2, 27) = 7.15$, $p < 0.01$) such that the neglect participants ($M = 20.6$, S.D. = 8.3) started their search significantly rightwards of the starting points of both control groups (NC: $M = 10.1$, S.D. = 3.1; RHC: $M = 10.8$, S.D. = 7.7) (NEG vs. RHC: $t(16.65) = 2.24$, $p = 0.05$; NEG vs. NC: $t(9.96) = 3.59$, $p < 0.01$; RHC vs. NC: $t(13.34) = 0.28$, $p = 0.79$). See Table 4.

3.3.8. *Direction of shifts to targets (proportion diagonal, vertical, and horizontal)*

When the number of grid units between successively reported targets was greater in the x dimension than the y dimension, the

Table 4

Visual search pattern assessment: means (S.D.) for each group and space.

Variable	NEG ($n=9$)		RHC ($n=11$)		NC ($n=10$)	
	PP	EP	PP	EP	PP	EP
Start location (x-axis)	18.85 (9.30)	22.27 (7.95)	10.06 (6.81)	11.46 (9.47)	11.12 (2.90)	9.00 (5.03)
Diagonal shifts (prop. of total)	0.10 (.03)	0.11 (.04)	0.08 (.04)	0.09 (.05)	0.06 (.04)	0.07 (.03)
Vertical shifts (prop. of total)	0.57 (.24)	0.57 (.18)	0.39 (.33)	0.39 (.32)	0.17 (.24)	0.25 (.32)
Horizontal shifts (prop. of total)	0.32 (.24)	0.32 (.18)	0.53 (.35)	0.52 (.34)	0.77 (.24)	0.68 (.33)
Leftward shifts (prop. without vertical)	0.53 (.10)	0.51 (.07)	0.39 (.15)	0.38 (.12)	0.39 (.09)	0.35 (.08)
Left shift gradient[a] (slope)	0.04 (.02)	0.05 (.03)	0.07 (.04)	0.07 (.04)	0.10 (.03)	0.09 (.04)
Horizontal shift size (x-axis units)	3.41 (1.56)	4.40 (1.89)	6.06 (4.15)	5.75 (3.65)	8.17 (2.80)	7.57 (3.68)
Left shift	3.52 (1.78)	4.69 (1.93)	7.61 (6.34)	7.06 (5.09)	10.08 (4.30)	9.51 (5.33)
Right shift	3.30 (1.42)	4.12 (1.91)	4.51 (2.36)	4.43 (2.32)	6.26 (1.65)	5.63 (2.42)
Vertical shift size (y-axis units)	5.11 (1.78)	6.48 (2.26)	4.04 (2.49)	3.93 (2.53)	2.85 (2.70)	3.19 (2.60)
Length of sequence	2.58 (.52)	2.62 (.64)	5.48 (4.19)	5.52 (4.54)	7.14 (3.54)	6.36 (3.11)

NEG = neglect group; RHC = right-hemisphere lesioned non-neglect control group; NC = healthy control group; PP = peripersonal space; EP = extrapersonal space.

[a] One neglect participant was excluded from this analysis because his target detection was restricted to the rightmost column only in extra-personal space.

movement to the successive target was labeled a "horizontal shift"; when the reverse was true, the movement was labeled a "vertical shift". Otherwise, the movement was labeled as 'diagonal'. A 3 (groups) × 2 (spaces) mixed ANOVA performed on the proportion of diagonal shifts revealed no significant effects of group or space.

A similar group by space ANOVA performed on the proportion of vertical shifts yielded a main effect of group ($F(2, 27) = 4.03$, $p < 0.05$) such that neglect participants ($M = 0.57$, S.D. = 0.20) made a significantly greater proportion of vertical shifts than healthy controls ($M = 0.21$, S.D. = 0.27), while the stroke controls ($M = 0.39$, S.D. = 0.33) made an intermediate proportion of vertical shifts that did not differ significantly from the other groups (NEG vs. NC: $t(16.32) = -3.59$, $p < 0.01$; RHC vs. NEG: $t(16.53) = 1.63$, $p = 0.12$; RHC vs. NC: $t(18.78) = -1.45$, $p = 0.16$). See Table 4 and Fig. 2.

A group × space ANOVA on the proportion of horizontal shifts revealed only a main effect of group ($F(2,27) = 4.59$, $p < 0.05$), such that neglect participants ($M = 0.32$, S.D. = 0.20) made proportionally fewer horizontal shifts of attention than healthy controls ($M = 0.72$, S.D. = 0.28). The proportion of horizontal shifts made by the stroke control group ($M = 0.53$, S.D. = 0.34) was intermediate between the neglect and healthy controls and did not differ significantly from either group (NEG vs. NC: $t(16.51) = 3.29$, $p < 0.01$; RHC vs. NEG: $t(16.98) = -1.54$, $p = 0.14$; RHC vs. NC: $t(18.81) = 1.35$, $p = 0.19$). See Table 4 and Fig. 2.

3.3.9. *Leftward shifts to targets*

After removing shifts with a horizontal component of zero, the proportion of leftward shifts was calculated. A 3 (groups) × 2 (spaces) ANOVA yielded a main effect of group ($F(2, 27) = 6.41$, $p < 0.01$) such that the neglect participants ($M = 0.52$, S.D. = 0.09) made a greater proportion of leftward shifts than both control groups (NC: $M = 0.37$, S.D. = 0.08; RHC: $M = 0.38$, S.D. = 0.13) (NEG vs. NC: $t(16.29) = 4.21$, $p < 0.01$; NEG vs. RHC: $t(17.16) = 2.84$, $p = 0.01$; RHC vs. NC: $t(16.31) = 0.39$, $p = 0.70$). See Table 4.

Because the proportion of leftward shifts was significantly correlated with start location (Pearson $r = 0.61$, $p < 0.01$) and start location differed significantly between the groups (not affected by space), the proportion of leftward shifts for each group was re-analyzed using analysis of covariance with start location as the covariate. With the start position as a covariate the groups no longer differed significantly on proportion of leftward shifts ($F(2, 26) = 1.61$, $p = 0.22$; NEG: $M = 0.47$, S.D. = 0.11; NC: $M = 0.39$, S.D. = 0.11; RHC: $M = 0.40$, S.D. = 0.10).

Further analyses of the proportion of leftward shifts within the groups (collapsed across space) revealed that the neglect group had an equivalent proportion of leftward and rightward shifts of attention (proportion left = 0.5; $t(8) = 0.71$, $p = 0.50$), while each of the control groups had significantly more rightward than leftward shifts of attention (proportion left < 0.5; NC: $t(9) = -5.63$, $p < 0.01$; RHC: $t(10) = -2.98$, $p = 0.01$). See Table 4.

3.3.10. *Leftward shift gradient across columns*

For each participant, the proportion of horizontal shifts in the leftward direction from each of the eight columns was determined and then submitted to a linear regression across columns. A 3 (group) × 2 (space) ANOVA on the mean slope of these functions revealed only a main effect of group ($F(2, 26) = 3.37$, $p = 0.05$) such that the neglect participants ($M = 0.05$, S.D. = 0.02) had a shallower slope than the healthy controls ($M = 0.09$, S.D. = 0.03), while the stroke control group slope ($M = 0.07$, S.D. = 0.04) was intermediate and not different from the other groups (NEG vs. NC:

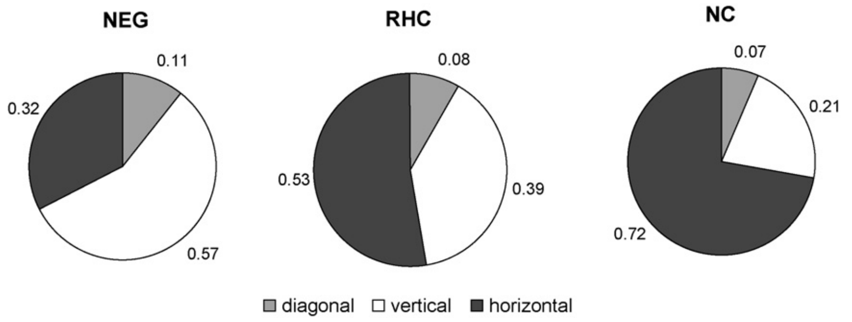

Fig. 2. Mean proportion of total shifts for each group made in the diagonal, vertical and horizontal dimensions during visual search. Data are collapsed across peripersonal and extrapersonal space. NEG – neglect group; RHC – right-hemisphere control group; NC – healthy control group.

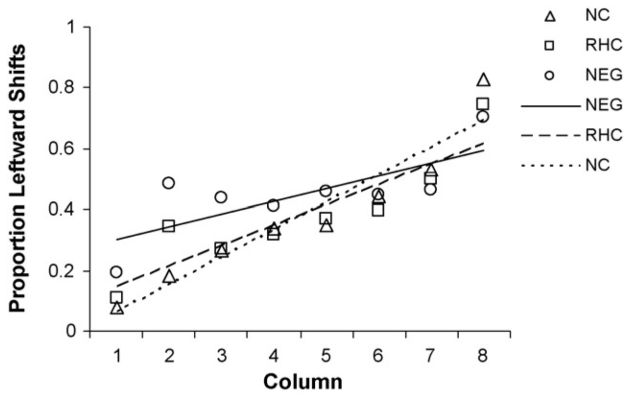

Fig. 3. Mean proportion of leftward shifts made by each group as a function of the column from which the shift was initiated. Lines represent mean linear slopes for each group. Data are collapsed across peripersonal and extrapersonal space. NEG – neglect group; RHC – right-hemisphere control group; NC – healthy control group.

$t(15.78) = -3.21$, $p < 0.01$; RHC vs. NEG: $t(16.01) = 1.29$, $p = 0.22$; RHC vs. NC: $t(18.59) = -1.39$, $p = 0.18$). See Table 4 and Fig. 3.

3.3.11. *Size of horizontal shifts to targets*

The number of x-axis units between consecutively reported targets was measured and submitted to mixed 3 (Group) × 2 (Space) × 2 (Direction: leftward vs. rightward) ANOVA, yielding a significant main effect of Direction ($F(1, 27) = 19.51$, $p < 0.001$) such that shifts in the leftward direction were larger. There was also a main effect of group ($F(2, 27) = 3.9$, $p < 0.05$) such that the neglect participants made significantly smaller horizontal shifts ($M = 3.9$, S.D. = 1.6) than healthy controls ($M = 7.9$, S.D. = 3.2), with the stroke controls ($M = 5.9$, S.D. = 3.8) statistically indistinguishable from either group (NEG vs. NC: $t(13.54) = -3.48$, $p < 0.01$; RHC vs. NEG: $t(13.92) = 1.57$, $p = 0.14$; RHC vs. NC: $t(18.87) = -1.28$, $p = 0.21$). In addition, a marginally significant interaction between group and direction ($F(2, 27) = 3.22$, $p = 0.056$) followed by post-hoc paired t-tests revealed that the difference in horizontal size between leftward and rightward shifts for the neglect group (diff = 0.4 x-axis units) was significantly smaller than the left-right difference for both control groups, which did not differ (NC: diff = 3.8 x-axis units; RHC: diff = 2.9 x-axis units) (NEG vs. NC: $t(9.75) = 3.06$, $p = 0.01$; RHC vs. NEG: $t(10.83) = -2.18$, $p = 0.05$; RHC vs. NC: $t(18.96) = 0.63$, $p = 0.54$). There were no main effects or interactions involving space. See Table 4 and Fig. 4.

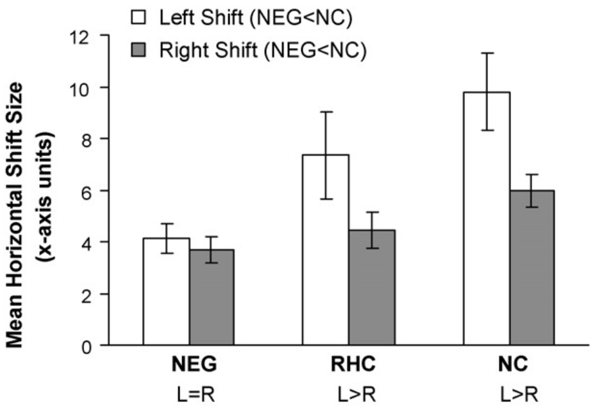

Fig. 4. Size of horizontal attentional shifts (mean number of x-axis units) between subsequent target reports for each group showing the marginally significant Group-by-Direction interaction. Error bars represent the standard error of the mean. NEG – neglect group; RHC – right-hemisphere control group; NC – healthy control group.

3.3.12. *Size of vertical shifts to targets*

The number of y-axis units between consecutively reported targets was measured and submitted to mixed 3 (Group) × 2 (Space) ANOVA, yielding a significant main effect of group ($F(2, 27) = 3.47$, $p < 0.05$) such that the neglect participants made larger vertical shifts ($M = 5.8$, S.D. = 1.7) than healthy controls ($M = 3.0$, S.D. = 2.6), with the stroke controls ($M = 4.0$, S.D. = 2.5) statistically indistinguishable from either group (NEG vs. NC: $t(15.71) = 2.79$, $p = 0.01$; RHC vs. NEG: $t(17.54) = -1.92$, $p = 0.07$; RHC vs. NC: $t(18.67) = 0.87$, $p = 0.39$). See Table 4.

3.3.13. *Average length of search sequences*

Given shifts classifiable as either horizontal or vertical, the average length of sustained search sequences was calculated by dividing the total number of categorizable shifts by the number of times the participant switched between horizontal and vertical search plus one. A 3 (group) × 2 (space) mixed ANOVA revealed only a main effect of group ($F(2, 27) = 4.27$, $p < 0.05$) such that neglect participants ($M = 2.6$ reports, S.D. = 0.5) had significantly shorter search sequences than both control groups (NC: $M = 6.8$ reports, S.D. = 3.0; RHC: $M = 5.5$ reports, S.D. = 4.3) (NEG vs. NC: $t(9.62) = -4.34$, $p < 0.01$, NEG vs. RHC: $t(10.35) = -2.20$, $p = 0.05$; RHC vs. NC: $t(17.75) = -0.77$, $p = 0.45$). See Table 4.

4. Discussion

Visual search tasks are often used in the experimental and clinical analyses of visuospatial neglect because of their sensitivity to the rightward bias and gradient of attention in neglect patients (Butler et al., 2004; Ferber & Karnath, 2001; Halligan et al., 1992; Small et al., 1994). The performance of neglect patients on typically-used clinical target cancellation tasks (e.g., Albert's Test, Mesulam Target Cancellation), however, is susceptible to variation by limb use (Heilman, Watson, & Valenstein, 1993), the spatial reference frame of the search (within vs. beyond arms reach: (Butler et al., 2004; Cowey et al., 1994; Halligan & Marshall, 1991; Shelton et al., 1990; Vuilleumier et al., 1998), and reduced load on spatial working memory when targets are marked (Wojciulik et al., 2001). Therefore, to assess visual search patterns in neglect that were not affected by reductions in spatial working memory load or lateralized manual response our study employed an easy-to-administer visual search and target detection task in which targets remain unchanged and a verbal response was required.

We were able, using consecutive verbal reports of unique targets amidst distractors, to show that the search pattern of the neglect group (in both peripersonal and extrapersonal space) differed significantly from the systematic 'reading' strategy employed by the healthy control group and to a lesser extent the stroke controls (Chokron & Imbert, 1993; Geldmacher & Alhaj, 1999; Marinkovic, 2004). Our results have replicated the results from previous studies of peripersonal space search, with and without oculographic analysis, and extended these findings to extrapersonal space, of an unsystematic search pattern and lack of a direction-specific bias in movements of attention in neglect (Behrmann et al., 1997; Husain et al., 2001; Karnath, Niemeier, & Dichgans, 1998; Mannan et al., 2005; Niemeier & Karnath, 2000; Samuelsson et al., 2002). Overall, compared to the healthy control group, in both peripersonal and extrapersonal space, the neglect group began reporting targets further to the right of the search field, made proportionally more and larger vertical shifts with fewer horizontal shifts, smaller leftward shifts and shorter search sequences in any one plane before changing direction (i.e., from vertical to horizontal search). Furthermore, within the neglect group the proportion and size of leftward and rightward shifts to consecutive targets was similar. The neglect group also made a greater proportion of repeated target detections and showed the expected decrease in proportion of target detections as they progressed from right-to-left across the page in both peripersonal and extrapersonal space.

The unsystematic search pattern and target detection performance of the neglect group on this simple verbal task appears to be related to a number of deficient attentional processes. In particular (1) a rightward spatial orienting bias that initially focuses attention rightward and is reflected in gradients of decreasing target detection from right-to-left across the search area (Kinsbourne, 1987; Kinsbourne, 1993): 2) a local processing bias or restricted lateral spatial scale of attention that reduces the distance between consecutively detected targets and the length of unidirectional search sequences (Bartolomeo et al., 2003; Doricchi & Incoccia, 1998; Lux, Thimm, Marshall, & Fink, 2006; Robertson, Lamb, & Knight, 1988; Russell, Malhotra, & Husain, 2004); and (3) a spatial working memory deficit that increases the likelihood of repeating previous target reports (Danckert & Ferber, 2006; Husain et al., 2001; Malhotra et al., 2005). Of interest from this study is that these neglect deficits, while originally investigated in peripersonal space, also appear relevant to visual searching in extrapersonal space.

Although there was an apparent local processing bias or restricted lateral scale of attention in neglect on the current search task, other visual search paradigms have shown more holistic processing of peripersonal visual search arrays. For instance, improved peripersonal space search performance after context priming by neglect patients has recently been associated with an ability to group together and quickly reject similar distractors during conjunctive search for a single target (Saevarsson, Joelsdottir, Hjaltason, & Kristjansson, 2008). Thus, the presence of a local processing bias or restricted lateral scale of attention in both peripersonal and extrapersonal space on our task is likely related to the heterogeneity of distractors and multiplicity of targets in the visual search field which may contribute, in part, to an increase in spatial working memory load and/or a spatial working memory deficit.

A spatial working memory deficit is also implicated in the greater proportion of repeated target detections by neglect participants than controls on this task. Although an increase in repeated target detections could be due to a deficit in either spatial working memory or inhibition of return (Castel, Pratt, & Craik, 2003; Klein, Castel, & Pratt, 2006), an IOR deficit would be indicated by less time or fewer reports between repetitions compared to controls. The lack of group differences in the number of unique reports between repetitions in our data indicates that repeated target detections were not likely due to a change in IOR compared to age matched stroke and normal controls. The time-course of the repetitions also does not support changes in IOR mechanisms. Although IOR appears to be robust for at least three seconds, the point at which IOR has decayed completely remains unclear and somewhat context dependent (Samuel & Kat, 2003), and the time course and duration of IOR has not yet been measured in search tasks. Furthermore, while IOR is delayed in the presence of a verbal memory load (Klein et al., 2006), the time course of the repetitions in the neglect group (i.e., about 40 s between repeats; a mean of 3 s per report and 13.5 reports between repetitions) does not support a reduction in IOR.

In order to more fully compare the leftward search performance in neglect on our task with an oculographic analysis of visual search in neglect (Behrmann et al., 1997), we obtained the Behrmann et al. raw data and performed a reanalysis that used a complementary procedure to our own (i.e., removing non-horizontal saccades before performing an ANOVA and ANCOVA on the proportion of leftward saccades from each horizontal quartile). The results of these re-analyses were similar to our own; whereby, after removing non-horizontal saccades, Behrmann's neglect group had a larger proportion of leftward saccades than the healthy control group (neglect group vs. control: 0.522 vs. 0.466, $t(15.7) = 2.8$, $p = 0.01$); a result that was rendered non-significant after controlling for differences in start position among the groups ($F(1, 15) = 1.5$, $p = 0.24$). This result highlights the importance of controlling for start position when analyzing visual search performance as the rightward start position of neglect patients may affect their subsequent search strategy and confound the effects of lateralized search variables between groups.

Re-analysis of the Behrmann et al. (1997) data for the probability of making a leftward saccade from a given horizontal coordinate supported Behrmann's suggestion that the eye movements of neglect patients are as constrained by the boundaries of the search field as those of the healthy control group. A between-groups comparison of the proportion of leftward saccades as a linear function across quartiles from Behrmann's data yielded similar slopes for the neglect and healthy control groups ($t(15.08) = 0.66$, p-value = 0.52). In contrast, the shallower slope of leftward shifts to targets from each search column by our neglect group compared to healthy controls provided converging evidence of an unsystematic search pattern that does not imitate the strategic 'reading' pattern of healthy individuals. The smaller change in proportion of leftward shifts across the width of the search field, particularly within the central columns (2–7), by the neglect group also supported the lack of a direction-specific bias in the movement of attention (Husain et al., 2001; Karnath et al., 1998; Niemeier & Karnath, 2000).

Lesion localization data supported the presence of spatial neglect after right-hemisphere damage to ventral and/or dorsal stream regions, particularly inferior and superior parietal and inferior frontal areas (Corbetta et al., 2005). Our group data also indicate that the pathological processes in neglect patients that affect visual scanning and target detection respond in similar ways during visual search in both peripersonal/near and extrapersonal/far space. Ventral stream damage may be expected to produce a greater degree of neglect deficits in far space related to dysfunctional saccadic eye movements/attentional shifting, while dorsal stream damage may be expected to adversely affect neglect in near space as a result of focused attention/attentional resolution deficits (Danckert & Goodale, 2003; Goodale & Milner, 1992; Mishkin et al., 1983; Previc, 1990; Previc, 1998). In our group, however, the mix of dorsal and ventral stream damage, and the considerable interaction between the dorsal and ventral networks (Goodale & Milner, 1992; He et al., 2007), ultimately make it difficult to relate search deficits displayed by the neglect group in both near and far space (i.e., rightward start position, gradient of target detection, target repetitions, smaller leftward shifts and shorter search sequences) to dorsal or ventral stream damage independently.

A disproportionately slower rate of target detection and a higher proportion of misidentification errors in extrapersonal space for the neglect group than the control groups, however, suggest dysfunctional object perception, less efficient attentional shifting, and a lack of visual search advantage in far space that is consistent with the predominance of ventral visual stream damage in the neglect group (Goodale & Milner, 1992; Mishkin et al., 1983), and (Danckert & Goodale, 2003) for review). Unfortunately, the lack of equivalence of visual angles in peripersonal and extrapersonal space is a methodological limitation of the current study that may have affected the salience of targets amidst distractors and consequently decreased target detection in extrapersonal space in all groups. In future studies presentation of larger stimuli on a vertically-aligned surface (e.g., a computer screen) in peripersonal space as well as extrapersonal space will allow for better overall acuity and equalization of visual angles, which may improve the overall accuracy of target discrimination. Furthermore, low statistical power is a limitation in this study. Thus, larger samples of more carefully grouped neglect participants, based upon lesions involving only the dorsal or ventral visual and attention streams, may be required to show dissociations of visual search patterns in peripersonal and extrapersonal space.

5. Conclusion

The simple task of tracking consecutive verbal reports of unique numbers and letters pseudo-randomly placed among distracters within a search grid provides a wealth of information that can be used to characterize neglect with regard to deficits in spatial awareness/bias, orienting and executive control (i.e., spatial working memory) in multiple reference frames. Furthermore, the ease of administration of this verbal target detection task in both peripersonal and extrapersonal space and the variety of measures produced, without the need for expensive and cumbersome technologies, may, after further research, prove to be a useful clinical tool to measure the presence and severity of a variety of attentional deficits related to neglect.

Acknowledgements

We extend thanks to the patients and control subjects recruited for this study, to Jennifer Pringle for help with recruitment, to Dr. Ed Harrison and Alison MacDonald for patient referrals and assistance with the conduct of the study, to Jesse Rusak for initial programming and inspiration for the analyses, and to Dr. Marlene Behrmann and colleagues for supplying their raw data for re-analysis.

Funding: This research was supported by the Heart & Stroke Foundation of Nova Scotia, the QEII Health Sciences Centre Research Fund, the Nova Scotia Department of Health Designated Mental Health Research Fund (to GE); BB was supported by a Natural Sciences and Engineering Research Council of Canada Pre-doctoral Fellowship) and an Isaak Walton Killam Memorial scholarship.

References

Bartolomeo, P., Urbanski, M., Chokron, S., Chainay, H., Moroni, C., Sieroff, E., et al. (2003). Neglected attention in apparent spatial compression. *Neuropsychologia*, *42*, 49–61.

Behrmann, M., Watt, S., Black, S. E., & Barton, J. J. S. (1997). Impaired visual search in patients with unilateral neglect: An oculographic analysis. *Neuropsychologia*, *35*(11), 1445–1458.

Blair, J. R., & Spreen, I. (1989). Predicting premorbid IQ: A revision of the National Adult Reading Test. *The Clinical Neuropsychologist*, *3*(2), 129–136.

Butler, B. C., Eskes, G. A., & Vandorpe, R. A. (2004). Gradients of detection in neglect: Comparison of peripersonal and extrapersonal space. *Neuropsychologia*, *42*(3), 346–358.

Castel, A. D., Pratt, J., & Craik, F. I. M. (2003). The role of spatial working memory in inhibition of return: Evidence from divided attention tasks. *Perception & Psychophysics*, *65*(6), 970–981.

Chatterjee, A., Thompson, K. A., & Ricci, R. (1999). Quantitative analysis of cancellation tasks in neglect. *Cortex*, *35*, 253–262.

Chokron, S., & Imbert, M. (1993). Influence of reading habits on line bisection. *Cognitive Brain Research*, *1*(4), 219–222.

Corbetta, M., Kincade, M. J., Lewis, C., Snyder, A. Z., & Sapir, A. (2005). Neural basis and recovery of spatial attention deficits in spatial neglect. *Nature Neuroscience*, *8*(11), 1603–1610.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews: Neuroscience*, *3*, 201–215.

Cowey, A., Small, M., & Ellis, S. (1994). Left visuo-spatial neglect can be worse in far than in near space. *Neuropsychologia*, *32*(9), 1059–1066.

Damasio, H., & Damasio, A. R. (1989). *Lesion analysis in neuropsychology*. New York: Oxford University Press.

Danckert, J., & Ferber, S. (2006). Revisiting unilateral neglect. *Neuropsychologia*, *44*, 987–1006.

Danckert, J. G., & Goodale, M. A. (2003). Ups and downs in the visual control of action. In S. H. Johnson-Frey (Ed.), *Taking action: Cognitive neuroscience perspectives on intentional acts* (pp. 29–64). Cambridge, Mass: The MIT Press.

Doricchi, F., & Incoccia, C. (1998). Seeing only the right half of the forest but cutting down all the trees? *Nature*, *394*, 75–78.

Ferber, S., & Karnath, H. O. (2001). How to assess spatial neglect—line bisection or cancellation tasks. *Journal of Clinical and Experimental Neuropsychology*, *23*(5), 599–607.

Geldmacher, D. S., & Alhaj, M. (1999). Spatial aspects of letter cancellation performance in arabic readers. *International Journal of Neuroscience*, *97*, 29–39.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neuroscience*, *15*(1), 20–25.

Halligan, P. W., Burn, J. P., Marshall, J. C., & Wade, D. T. (1992). Visuo-spatial neglect: Qualitative differences and laterality of cerebral lesion. *Journal of Neurology, Neurosurgery, and Psychiatry*, *55*, 1060–1068.

Halligan, P. W., & Marshall, J. C. (1991). Left neglect for near but not far space in man. *Nature*, *350*, 498–500.

Halligan, P. W., & Marshall, J. C. (1994). Toward a principled explanation of unilateral neglect. *Cognitive Neuropsychology*, *11*(2), 167–206.

He, B. J., Snyder, A. Z., Vincent, J. L., Epstein, A., Shulman, G. L., & Corbetta, M. (2007). Breakdown of functional connectivity in frontoparietal networks underlies behavioral deficits in spatial neglect. *Neuron*, *53*, 905–918.

Heilman, K. M., Watson, R. T., & Valenstein, E. (1993). Neglect and related disorders. In K. M. Heilman & E. Valenstein (Eds.), *Clinical neuropsychology* (pp. 279–335). New York: Oxford University Press.

Husain, M., Mannan, S., Hodgson, T., Wojciulik, E., Driver, J., & Kennard, C. (2001). Impaired spatial working memory across saccades contibutes to abnormal search in parietal neglect. *Brain*, *124*, 941–952.

Karnath, H. O., Niemeier, M., & Dichgans, J. (1998). Space exploration in neglect. *Brain*, *121*(12), 2357–2367.

Kinsbourne, M. (1987). Mechanisms of unilateral neglect. In M. Jeannerod (Ed.), *Neurophysiological and neuropsychological aspects of spatial neglect* (pp. 69–83). North-Holland: Elsevier Science Publishers B.V.

Kinsbourne, M. (1993). Orientational bias model of unilateral neglect: Evidence from attentional gradients within hemispheres. In I. H. Robertson & J. C. Marshall (Eds.), *Unilateral neglect: Clinical and experimental studies* (pp. 63–86). Hove, U.K: Lawrence Erlbaum Associates.

Klein, R., Kingstone, A., & Pontefract, A. (1992). Orienting of visual attention. In K. Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading* (pp. 46–65). New York: Springer-Verlag.

Klein, R. M. (2004). Orienting and inhibition of return. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 545–560). Cambridge, MA: MIT Press.

Klein, R. M., Castel, A. D., & Pratt, J. (2006). The effects of memory load on the time course of inhibition of return. *Psychonomic Bulletin and Review*, *13*(2), 294–299.

Lezak, M. D. (1995). *Neuropsychological assessment* (3rd ed.). New York: Oxford University Press, Inc.

Lux, S., Thimm, M., Marshall, J. C., & Fink, G. R. (2006). Directed and divided attention during hierarchical processing in patients with visuo-spatial neglect and matched healthy volunteers. *Neuropsychologia*, *44*, 436–444.

Malhotra, P., Jager, H. R., Parton, A., Greenwood, R., Playford, E. D., Brown, M. M., et al. (2005). Spatial working memory capacity in unilateral neglect. *Brain*, *128*, 424–435.

Malhotra, P., Mannan, S., Driver, J., & Husain, M. (2004). Impaired spatial working memory: One component of the visual neglect syndrome? *Cortex*, *40*, 667–676.

Mannan, S. K., Mort, D. J., Hodgson, T. L., Driver, J., Kennard, C., & Husain, M. (2005). Revisiting previously searched locations in visual neglect: Role of right parietal and frontal lesions in misjudging old locations as new. *Journal of Cognitive Neuroscience*, *17*(2), 340–354.

Marinkovic, K. (2004). Spatiotemporal dynamics of word processing in the human cortex. *Neuroscientist*, *10*(2), 142–152.

Marshall, J. C., & Halligan, P. W. (1989). Does the midsagittal plane play any privileged role in “left” neglect? *Cognitive Neuropsychology*, *6*(4), 403–422.

Mishkin, M., Ungerleider, L. G., & Macko, K. A. (1983). Object vision and spatial vision: Two cortical pathways. *Trends in Neuroscience*, 414–417.

Mysiw, W. J., Beegan, J. G., & Gatens, P. F. (1989). Prospective cognitive assessment of stroke patients before inpatient rehabilitation. The relationship of the Neurobehavioral Cognitive Status Examination to functional improvement. *American Journal of Physical Medicine and Rehabilitation*, *68*(4), 168–171.

Niemeier, M., & Karnath, H. O. (2000). Exploratory saccades show no direction-specific deficit in neglect. *Neurology*, *54*(2), 515–518.

Osmon, D. C., Smet, I. C., Winegarden, B., & Gandhavadi, B. (1992). Neurobehavioral Cognitive Status Examination: Its use with unilateral stroke patients in a rehabilitation setting. *Archives of Physical Medicine and Rehabilitation*, *73*, 414–418.

Parton, A., Malhotra, P., Nachev, P., Ames, D., Ball, J., Chataway, J., et al. (2006). Space re-exploration in hemispatial neglect. *Neuroreport*, *17*(8), 833–836.

Previc, F. H. (1990). Functional specialization in the lower and upper visual fields in humans: Its ecological origins and neuropsychological implications. *Behavioral and Brain Sciences*, *13*, 519–575.

Previc, F. H. (1998). The neuropsychology of 3-D space. *Psychological Bulletin*, *124*(2), 123–164.

Riddoch, M. J., & Humphreys, G. W. (1983). The effect of cueing on unilateral neglect. *Neuropsychologia*, *21*(6), 589–599.

Robertson, L. C., Lamb, M. R., & Knight, R. T. (1988). Effects of lesions of temporal-parietal junction on perceptual and attentional processing in humans. *The Journal of Neuroscience*, *8*(10), 3757–3769.

Russell, C., Malhotra, P., & Husain, M. (2004). Attention modulates the visual field in healthy observers and parietal patients. *NeuroReport*, *15*, 2189–2193.

Saevarsson, S., Joelsdottir, S., Hjaltason, H., & Kristjansson, A. (2008). Repetition of distractor sets improves visual search performance in hemispatial neglect. *Neuropsychologia*, *46*, 1161–1169.

Samuel, A. G., & Kat, D. (2003). Inhibition of return: A graphical meta-analysis of its time course and an empirical test of its temporal and spatial properties. *Psychonomic Bulletin and Review*, *10*(4), 897–906.

Samuelsson, H., Hjelmquist, E. K. E., Jensen, C., & Blomstrand, C. (2002). Search pattern in a verbally reported Visual Scanning Test in patients showing spatial neglect. *Journal of the International Neuropsychological Society*, *8*, 382–394.

Sapir, A., Hayes, A., Henik, A., Danziger, S., & Rafal, R. (2004). Parietal lobe lesions disrupt saccadic remapping of inhibitory location tagging. *Journal of Cognitive Neuroscience*, *16*(4), 503–509.

Shelton, P. A., Bowers, D., & Heilman, K. M. (1990). Peripersonal and vertical neglect. *Brain*, *113*, 191–205.

Small, M., Cowey, A., & Ellis, S. (1994). How lateralised is visuospatial neglect? *Neuropsychologia*, *32*(4), 449–464.

Stone, S. P., Halligan, P. W., Greenwood, R. J., & Marshall, J. C. (1991). Performance of age-matched controls on a battery of visuo-spatial neglect tests. *Journal of Neurology, Neurosurgery, and Psychiatry*, *54*(4), 341–344.

Stone, S. P., Wilson, B., Halligan, P. W., Lange, L. S., Marshall, J. C., & Greenwood, R. J. (1991). Assessment of visuo-spatial neglect after acute stroke. *Journal of Neurology, Neurosurgery, and Psychiatry*, *54*(4), 345–350.

Vuilleumier, P., Valenza, N., Mayer, E., Reverdin, A., & Landis, T. (1998). Near and far visual space in unilateral neglect. *Annals of Neurology*, *43*, 406–410.

Warrington, E. K., & James, M. (1991). *Visual object and space perception battery manual*. Suffolk, England: Thames Valley Test Company.

Wechsler, D. (1987). *Wechsler memory scale—revised manual*. New York, NY: Psychological Corporation.

Weiss, P. H., Marshall, J. C., Wunderlich, G., Tellmann, L., Halligan, P. W., Freund, H.-J., et al. (2000). Neural consequences of acting in near versus far space: A physiological basis for clinical dissociations. *Brain*, *123*, 2531–2541.

Welch, B. L. (1947). The generalization of 'Student's' problem when several different population variances are involved. *Biometrika*, *34*(1), 28–35.

Wilson, B. A., Cockburn, J., & Halligan, P. W. (1987). *Behavioral Inattention Test*. Suffolk, England: Thames Valley Test Company.

Wojciulik, E., Husain, M., Clarke, K., & Driver, J. (2001). Spatial working memory deficit in unilateral neglect. *Neuropsychologia*, *39*, 390–396.