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Impairments in top down attentional processes in right parietal patients: Paradoxical functional facilitation in visual search

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ABSTRACT

It is well known that the right posterior parietal cortex (PPC) is involved in attentional processes, including binding features. It remains unclear whether PPC is implicated in top-down and/or bottom-up components of attention. We aim to clarify this by comparing performance of seven PPC patients and healthy controls (HC) in a visual search task involving a conflict between top-down and bottom-up processes. This task requires essentially a bottom-up feature search. However, top-down attention triggers feature binding for object recognition, designed to be irrelevant but interfering to the task. This results in top-down interference, prolonging the search reaction time. This interference was indeed found in our HCs but not in our PPC patients. In contrast to HC, the PPC patients showed no evidence of prolonged reactions times, even though they were slower than the HCs in search tasks without the conflict. This finding is an example of paradoxical functional facilitation (PFF) by brain damage. The PFF effect enhanced our patients' performance by reducing the top down interference. Our finding supports the idea that right PPC plays a crucial role in top-down attentional processes. In our search tasks, right PPC induces top-down interference either by directing spatial attention to achieve viewpoint invariance in shape recognition or by feature binding.

1. Introduction

Clinical studies reported ample evidence that patients with posterior parietal cortex (PPC) damage can suffer from a variety of deficits in spatial attention (e.g., Corbetta, Patel, & Shulman, 2008; Husain, 2001; Riddoch et al., 2010; Vallar, 2007). Typically patients have been described with neglect, extinction (Heilman, Watson, & Valenstein, 1985; Karnath, 1988), and impairment in spatial working memory (Husain, 2001; Pisella, Berberovic, & Mattingley, 2004).

A recent review suggested that the inferior and the superior right parietal cortex are often implicated in these impairments (see Vandenberghe, Molenberghs, & Gillebert, 2012 for review). However, lesion studies and imaging studies of healthy subjects documented discrepant findings regarding the anatomical substrate for selective attention. Lesion studies have highlighted the role of the right inferior parietal and posterior temporal cortex (such as the right angular gyrus and the right temporoparietal junction). Neuroimaging studies, reported activation of the middle segment of the intraparietal sulcus (IPS) in attentional processing (Corbetta & Shulman, 2002; Vandenberghe, Molenberghs, & Gillebert, 2012) .

This apparent discrepancy may arise for a number of different reasons. Lesions may functionally affects remote attentional networks outside the structurally lesioned area. For example, it may involve the IPS, which is known to be involved in endogenous attentional control (Corbetta, Patel, & Shulman, 2008).

Visual search tasks are often used to investigate spatial attentional mechanisms in both healthy controls and neurological patients. We briefly outline the related background about attention and visual search before reviewing relevant visual search studies in patients. In general, attention has both top-down and bottom-up components (e.g., Itti & Koch, 2001; Treisman & Gelade, 1980). Bottom-up attention is driven by visual inputs, operates exogenously or automatically regardless of observers' task goal (Corbetta & Shulman, 2002; Itti & Koch, 2001; Theeuwes, 2010;

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Treisman & Gelade, 1980). For example, a vertical bar among many horizontal bars can capture bottom-up attention due to its unique basic (lower level) feature value (orientation), which makes it salient. It has been suggested that primary visual cortex underlies bottom-up attentional selection (Li, 2002).

In contrast, top-down attention is voluntarily driven by the observers' task goal and often involves higher-level processes such as object shape recognition, which requires feature binding (Itti & Koch, 2001; Treisman & Gelade, 1980). For example, in looking for a letter 'T' among letter 'L's, one has a template of the 'T' shape in mind while the 'attentional spotlight' scans the visual image. In this task, top-down attention is essential since the target and non-targets do not differ in any basic, low level, feature like orientation or color of bar elements, and therefore observers cannot rely on any bottom-up saliency to distinguish the target. Top-down attention has been suggested to involve a network of frontal and parietal areas (Corbetta & Shulman, 2002).

In terms of sensory inputs, a visual search can be a feature or a non-feature search. In a feature search, e.g., to find a vertical bar among horizontal bars, the target has a unique basic feature, such as the orientation or color of a bar element, which is absent in the non-targets. This basic target feature makes a target salient by an amount that increases with the contrast between the unique target feature and the non-target features. Since highly salient locations attract attention even if observers do not know the target identity, bottom-up processes play an essential role in feature searches. In a non-feature search, each basic feature in the target is also present in non-targets, so the target cannot be salient by bottom-up processes relying on basic features. For example, searching for a 'T' among 'L's is a non-feature search, since both the target and non-target have the same two basic features: one is vertical orientation and the other is horizontal orientation (of bars). Without bottom-up salience to guide attention automatically to the target, non-feature searches require top-down task-dependent factors, such as the knowledge of the target shape (by a particular configuration of basic features), to find the target location. A conjunction search is a particular type of non-feature search, in which each of the target features is present in non-targets and the target is distinguished only by a unique conjunction of basic features. For example, searching for a red-vertical bar among red-horizontal and green-vertical bars is a conjunction search.

In terms of ease of the task, a search can be an efficient or an inefficient search. A feature search can be efficient or inefficient, when the unique basic feature in the target is very different, or only slightly different, from the features in the non-targets. For example, a vertical target bar is easy to find among horizontal non-targets, but is difficult to find among bars tilted only 5° clockwise from vertical, even though in both cases the target has a unique vertical orientation absent in the non-targets. Meanwhile, a non-feature search can be made easier than a difficult feature search when the target can be easily distinguished by its high level, non-basic, properties such as a distinct shape.

In general, both bottom-up and top-down attentional processes are involved in typical visual searches. Bottom-up process can take advantage of the bottom-up target saliency when the target has a unique basic feature, while the top-down process helps by identifying and distinguishing the target in high level properties such as shape, and by additional task strategies and decisions. Fig. 1 illustrates examples of feature and non- feature searches, including a conjunction search.

In neurological patients, spatial attention impairments can often manifest in visual search tasks as an inability to perform conjunction search (e.g., Dent, Lestou, & Humphreys, 2010; Müller-Plath, Ott, & Pollmann, 2010; Treisman & Gelade, 1980). Studies of patients documented that the PPC is involved in conjunction searches . Indeed, patients with unilateral PPC damage had impairments in contra-lesional conjunction search (see Riddoch et al., 2010 for review). These patients, whilst unable to find a unique conjunction of features, were able to identify a target defined by a unique single feature (e.g., Eglin, Robertson, & Rafal, 1989; Riddoch & Humphreys, 1987). This was so even when the conjunction search was easier than a single feature search (Humphreys, Hodsoll, & Riddoch, 2009).

Transcranial Magnetic Stimulation (TMS) studies show an involvement of the right PPC in conjunction search (Ashbridge, Walsh, & Cowey, 1997; Ellison, Rushworth, & Walsh, 2003; Ellison et al., 2004; Muggleton, Cowey, & Walsh, 2008; Nobre et al., 2003; Walsh, Ashbridge, & Cowey, 1998), especially when the task is novel or not practiced so extensively that it might have become automatized (Walsh, Ashbridge, & Cowey, 1998). Another study reported that repetitive transcranial magnetic stimulation (rTMS) over the right PPC, interfered selectively with a non-feature search for a T amongst Ls compared to a feature search for a X amongst Ls (Rosenthal et al., 2006).

Impairments in non-feature searches, in particular in conjunction searches, have been interpreted as reflecting impairment in feature binding. Three clinical examples support this interpretation.

Patients with Balint-Holmes' syndrome are unable to identify one object at a time in a cluttered scene or to bind features of an object together (Friedman-Hill, Robertson, & Treisman, 1995; Humphreys et al., 2000; Vallar, 2007).

Binding deficits have been reported as illusory conjunctions for stimuli presented in contralesional space in patients with unilateral parietal lesions (Cohen & Rafal, 1991).

In contrast, patients with semantic dementia, a neurodegenerative disease somewhat sparing the parietal cortex, showed facilitation in conjunction searches (Viskontas et al., 2011).

Visual search tasks usually adopted in behavioral, lesion, or neuroimaging studies do not allow to unambiguously identify the contribution of bottom-up and top-down attentional processes. This is because typically the measurements adopted are reaction times (RT) and accuracy, and both top-down and bottom-up processes are involved in either measure. A noticeable exception is represented by the study of Zhaoping and Guyader (2007). The authors developed a visual search task (task A, Fig. 2 see also Fig. 1 a) involving a conflict between the bottom-up and top-down attentional processes. In this task, the target is unique in bottom-up feature – hence the search is a feature search – but not in higher-level shape. Specifically, the target is a uniquely oriented bar, capturing bottom-up attention with its lower level orientation feature. Meanwhile, the target bar is also part of an object whose shape is identical to those of the non-target objects. Consequently, top-down attention vetoes the bottom-up selection. During the search, observers' gaze was initially attracted to the target by its bottom-up salience. Often the gaze subsequently abandoned the target to search elsewhere, demonstrating the interference by the top-down process, which recognizes the object shape. We define this as the top-down interference to the task. This interference is manifested by a longer reaction time to report the target, particularly by the long latency between the gaze arrival to target and subject's report of the target. Top-down interference is absent in a control task (task B in Fig. 2, see also Fig. 1 b) in which there is no conflict between bottom-up and top-down processes, because the target is not only salient by the unique orientation (this is a basic, bottom-up, low level, feature) of one of its bars but also distinct in its unique shape. Therefore the RTs are not prolonged in this control task. One can use the difference between the RTs in the two tasks to measure the strength of top-down interference in task A.

Note that both tasks A and B are feature searches, since in both cases, the target has a uniquely oriented bar which is absent in the non-targets. Hence, bottom-up saliency makes target attract

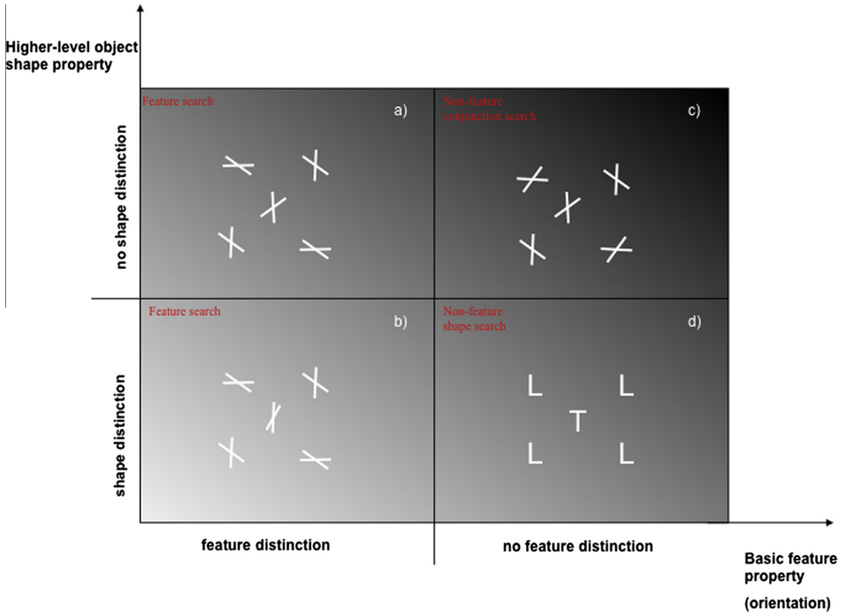

Fig. 1. Four examples of experimental stimuli in visual search studies. In each example, the target is the item in the center of the quadrant. Easy or difficult searches are indicated by darker or lighter background shading, respectively. (a) An example of feature search. The unique feature in the target is a 45° right oriented bar which is absent in the non-targets. Target and non-target do not differ in higher-level shape. (b) Another example of feature search. The unique feature in the target is a 20° right oriented bar which is absent in the non-targets.Target and non-target differ in their higher-level shape. (c) An example of conjunction search which is a special case of a non-feature search. Each of the target features (the vertical or the right oriented bar) is present in non-targets. The target is distinguished only by a unique conjunction of basic features. Hence, there is no distinction either in basic feature or in higher-level shape between target and non-target. (d) Another example of non-feature search. Both the target features (the vertical and the horizontal bar) are present in all non-targets. The target is distinguished only by a unique configuration of basic features into a shape. Hence, the target non-target distinction is only at the higher-level shape.

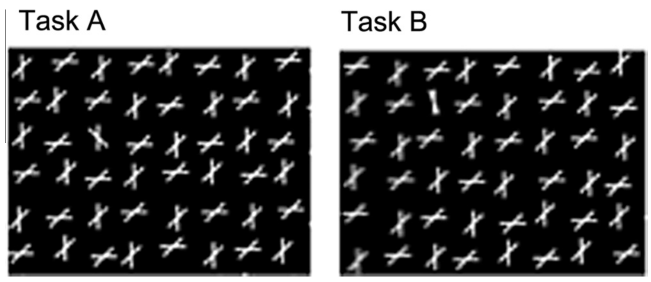

Fig. 2. Task A and task B experimental stimuli. Task A and B differed only in the angle, 45° and 20°, respectively, between the two bars in the target. Task-irrelevant, horizontal and vertical, bars made the orientation singleton much harder to find in condition A than in condition B. Note that task A and task B correspond to (a) and (b) in Fig. 1.

attention in both searches. In particular, the unique, smaller angle between the two bars in the target of task B is not a basic level feature, but a high level, object shape, property. Hence, this unique angle does not make the target in task B more salient in a bottom-up manner. Indeed, tasks A and B require the same RT for gaze to localize target during search (Zhaoping & Guyader, 2007). However, task A requires a much longer RT for observers to report the target. In principle, object shape recognition is unnecessary for either task A or B, if observers could ignore the shape information to let the bottom-up saliency of the target dictate their task decision. Nevertheless, in practice, top-down interference due to shape recognition typically occurs, especially in inexperienced observers.

A rTMS study in healthy controls (HC) adopted the visual search tasks described above (Zhaoping & Guyader, 2007). A significant reduction in the top-down interference (measured by the reduction in the RT to report the target) following rTMS over the right but not left parietal cortex was reported (Oliveri et al., 2010). Interestingly, rTMS over the right PPC had no effect on the performance in the control task, which involves no top-down interference (and can be done by bottom-up processes only). These results suggested an involvement of right parietal cortex in top-down attention only. This suggestion has been supported by a subsequent study showing that rTMS over parietal cortex unmasked bottom-up selection of stimuli with higher values of low-level features in HC (Ossandón et al., 2012).

On the basis of these rTMS results, one could expect that patients with right parietal lesions may have impairment in top-down attention only, if one assumes that rTMS causes an effect in the brain similar to that caused by the neurological lesion. However, disruption to neural activity caused by rTMS is both transient and acute, not allowing plastic reorganization of the brain. Whereas lesions can cause disturbance to function that may be more, or less, widespread than the disturbance to anatomy due to compensatory plasticity occurring over time (Pascual-Leone, Walsh, & Rothwell, 2000). Hence, it remains an open question whether patients with right parietal lesions will exhibit facilitation (compared to healthy controls) in tasks susceptible to top-down interference, but not in tasks relying mainly on bottom-up attention without top-down interference. This study aims to find the answer to this open question. We used the same visual search tasks previously adopted in the HC studies (Oliveri et al., 2010; Zhaoping & Guyader, 2007). We investigated the performance of seven patients with right parietal lesions and compared it with age and education matched HC.

2. Material and methods

2.1. Participants

2.1.1. Patients

Seven right-handed patients (4 male, 3 female) (mean age = 47 ± 17 years, mean level of education = 12 ± 4 years) with focal right posterior hemisphere damage were identified through the database of Ospedale Riuniti Villa Sofia-Cervello (Palermo) and Centro Studi e Ricerche in Neuroscienze Cognitive (Cesena). Inclusion criteria were: (1) age between 18 and 75 years; (2) level of education at least 8 years; (3) no history of previous psychiatric disorder or alcohol or drugs abuse; (4) no hemianopsia and (5) right parietal lesions identified on CT or MRI scan. Informed consent was obtained for each patient.

Patients' demographic and clinical characteristics are summarized in Table 1.

2.1.2. Healthy Controls

The HC group consisted of 14 right-handed healthy subjects matched for age (mean age = 49 ± 13 years) and education (mean level of education = 11 ± 3 years) to the patients. No HCs had any history of neurological or psychiatric impairments.

All subjects, HCs and patients, had normal or corrected to normal vision.

2.2. Neuropsychological assessment

A battery of neuropsychological tests standardized for Italian population (except for the Conventional Subtests from the Behavioral Inattention Test, BIT, Wilson, Cockburn, & Halligan, 1987) was administered to six of the patients (Carlesimo, Caltagirone, & Gainotti, 1996; Carlesimo et al., 2002; Giovagnoli et al., 1996; Vallar et al., 1994). For one patient (Pt 4), time limitation prevented the administration of the neuropsychological battery. Informal testing indicated that he did not have neglect.

The neuropsychological tests assessed the following cognitive domains: general intellectual functioning (Colored Raven's Progressive Matrices, Raven, 1956), word retrieval (Object Subtests from Esame Neuropsicologico per l'Afasia, ENPA, Capasso & Miceli, 2001), verbal and non verbal memory (Recognition Memory Test, RMT- Word and Building, Smirni et al., 2010), executive functions (Trial Making Test, AITB, 1944) and perception (BIT, Wilson, Cockburn, & Halligan, 1987; Bell cancellation, Gauthier, Dehaut, & Joanette, 1989).

The neuropsychological tests results are summarized in Table 2.

All patients had normal general intellectual functioning, nominal and executive functions. Verbal and non verbal memory were preserved in all patients except for patient 1, who had impairments in both verbal and non verbal memory. All patients obtained normal scores on perceptual tasks.

2.3. Experimental investigation

2.3.1. Visual search task

As in the previous studies (Oliveri et al., 2010; Zhaoping & Guyader, 2007), the task was to search for a uniquely oriented oblique bar in the stimulus image. The image contained many 'X'-like shapes, each was made by intersecting an oblique bar and a cardinal (horizontal or vertical) bar, see Fig. 2. Only the oblique bars were task relevant, all of them were uniformly oriented 45° from vertical, except for the target bar which was oriented in the opposite direction from vertical. In task A, the target bar was tilted 45° from vertical, but in task B, it was oriented only 20° from vertical or horizontal such that the X-shape containing the target bar was thinner than all other X-shapes in the image. Therefore, task A and B differed only in the X shape containing the target bar, but were otherwise identical in other characteristics of their stimuli. In both tasks, the target bar was salient by having a unique orientation feature in the image, attracting bottom-up attention. Meanwhile, the X-shape containing the target in task A was a rotated version of all the non-target X-shapes, i.e., all the X-shapes in the search array had identical shape. This caused confusion at the object shape recognition level whereas the task was at the orientation feature detection level. In contrast, in task B, the X-shape containing the target bar was uniquely thinner than all distractor X-shapes. Thus, the top-down interference in task A was absent in task B.

2.3.2. Stimuli

Each stimulus display, viewed on a 13 inch monitor at a distance of 40 cm, had 161 X-shapes in an 11 rows x 15 columns array, spanning in corresponding 16° and 21° in visual angle. The stimulus was modified from the original one used in Zhaoping and Guyader (2007) and Oliveri et al. (2010) by a reduction of 75% in the number of search items. Like in the previous studies, in each trial, the position of each 'X'-like shape was randomly jittered from its corresponding position in a regular 11 × 15 grid. Each stimulus bar was 0.14° × 1° in visual angle and 48 cd (candela)/m2 in brightness.

All the X-like shapes were white against a black background. The target could appear randomly at any of the grid positions, except in the central 3 columns of the search array or any of the boundary locations of the array.

In each trial, the fixation stimulus was a bright cross at the center of the black background (Zhaoping & Guyader, 2007).

2.3.3. Procedure

Stimuli were presented to participants on the screen of the computer. Each subject performed at least 15 trials for each task (task A and task B). The trials for the two tasks were randomly interleaved. Participants were informed that the uniquely oriented target bar could be randomly tilted to the left or right in each trial, and that the horizontal and vertical bars should be ignored. Participants were instructed to use their right hand to press a left or right button, with their index or middle fingers respectively, to indicate whether the target was in the left or right half of the display. They were told to press the button as soon as possible at the start of the session.

To minimize other top-down influences, we asked the participants not to search by looking around systematically. Before the experimental session, there was a training phase, involving 2 trials for task A and 2 trials for task B.

Table 1
Patients' demographic and clinical characteristics.

	Patients						
	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7
Gender	M	F	M	M	F	M	F
Age (years)	53	40	73	33	59	46	22
Education (years)	8	13	17	8	17	8	13
Etiology	Stroke	Stroke	Stroke	Stroke	Meningioma	Meningioma	Tumor
Lesion location	R Par/Temp	R Par/Bas G	R Par/Bas G	R Par/Occ	R Par/Occ	R Par	R Par/Occ
Time since lesion (days)	60	210	11	15	600	480	60
Motor deficit	L hemiparesis	L hemiparesis	L hemiparesis	Absent	R arm Tremor	Absent	Absent

Pt = patient; M = male; F = female; R = right; L = left; Par = parietal cortex; Temp = temporal cortex; Bas G = basal ganglia; Occ = occipital cortex.

Table 2
Neuropsychological tests scores.

		Patients					
Cognitive domain	Task performed	Pt 1	Pt 2	Pt 3	Pt 5	Pt 6	Pt 7
General intellectual functioning	CRPM§ ($N = 36$)	25.3	24.8	30	21.7	32	36
Word retrieval	Object Subtest§ ($N = 10$)	10	10	10	10	10	10
Verbal memory	RMT-Word§ ($N = 30$)	20.78*	25.07	27.6	n.t.	n.t.	27.9
Non verbal memory	RMT-Building§ ($N = 30$)	13.74*	26.06	25.78	n.t.	n.t.	26.9
Executive functions	Trail Making Test Part B†	263	104	73	100	32	n.t.
Perception	Conventional Subtest (BIT)$^{£}$ ($N = 146$)	135	146	146	144	146	146
	Line crossing$^{£}$ ($N = 36$)	36	36	36	36	36	36
	Letter cancellation$^{£}$ ($N = 40$)	34	40	40	40	40	40
	Figure and shape copying$^{£}$ ($N = 3$)	3	3	3	2	3	3
	Line bisection$^{£}$ ($N = 9$)	9	9	9	9	9	9
	Bell cancellation§ Δ omissions left–right	0	0	0	0	0	0

Pt = patient; n.t. = not tested; § = scores are age and education corrected; * = pathological score (below the lower limit of 95% tolerance interval measured in the normal population); † = Reaction Times in sec.; $^{£}$ = raw scores; Δ = number of omission in the left hemispace-number of omission in the right hemispace; CRPM, Colored Raven's Progressive Matrices; RMT, Recognition memory test memory; BIT, Behavioural Inattention Test.

Each trial started with a fixation stimulus lasting 600 ms, followed by blank black screen lasting 200 ms, and then followed by the search display. The search stimulus stayed on the screen till the participant's button press.

Button presses and Reaction times (RTs) were recorded using PsyScope for Mac OS X.

2.4. Data analysis

For each task (A or B), we calculated accuracy (Accuracy (A) or Accuracy (B)), which is the proportion of correct button presses, and the averaged RTs (RT(A) or RT(B)) of the correct button presses. Hence, trials with incorrect button presses were not included for the RTs analysis. In addition, we calculated an asymmetry index (AI) on the RT, defined as the RT difference between the two tasks as a fraction of their average RTs, i.e. [RT(A) – RT(B)]/[RT(A) + RT(B)]). According to a previous study (Zhaoping & Frith, 2011), a positive value of this asymmetry index reveals the top-down interference.

It is well known that lateralized attentional biases can occur following a right parietal damage. We therefore analyzed the above 3 parameters (accuracy, averaged RTs, asymmetry index) first irrespectively as to whether the target location was in the right or in the left half of the display, second separately as to whether the target location was in the right or in the left half of the display.

We compared the accuracy and the averaged RTs in task A and in task B within and between the two groups of participants (right parietal patients and HC). A further analysis compared the asymmetry index between the two groups of participants.

The data was analyzed using a two tailed *t*-test; the level of significance was set at $p < .05$.

3. Results

Overall analysis of responses irrespectively to the target location.

3.1. Accuracy

HC were significantly less ($t = -2.76$, $p = .01$) accurate in task A than in task B which has no top-down interference. The right parietal patients tended to be somewhat less accurate in task A than in task B, although their accuracy difference did not reach significance ($t = -2.38$, $p = .054$) (see Fig. 3a).

For each task, patients and controls were not significantly different in their accuracies ($t = -.89$, $p = .38$ for task A; $t = -.75$, $p = .46$ for task B).

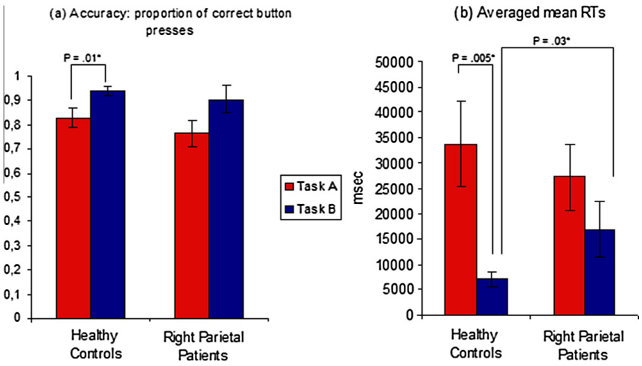

Fig. 3. Healthy controls and right parietal patients' performance in the visual search tasks regarfless of the target location. Error bars represent standard error of the mean. (a) Accuracy; (b) averaged RTs.

3.2. Averaged RTS

The HC' RTs were significantly longer in task A than in task B ($t = 3.30$, $p = .005$), demonstrating top-down interference in task A. In contrast, for the patients group, there were no significant difference between the RTs for the two tasks ($t = 1.43$, $p = .20$).

The HC group showed top-down interference in both RT and accuracy measures, whereas the patient group had interference in neither RT nor accuracy measures.

In task B, the patients' RTs were significantly longer than the controls' RTs ($t = 2.26$, $p = .03$), demonstrating that patients were generally slower in typical visual search tasks which do not involve a conflict between bottom-up and top-down attentional processes.

However, in task A, there was no significant difference between the RTs for the two subject groups ($t = -.50$, $p = .61$) (see Fig. 3b). We would like to suggest that this is due to two opposing factors: one is the slower search by the patients (than the controls) in the baseline task B, the other is stronger top-down interference in controls (than in the patients) in task A.

Since patients and controls were roughly comparable in accuracies, their RT difference in task B cannot be accounted for a speed-accuracy trade off.

One could argue that the lack of a significant RT difference between tasks for the patients is due to their smaller sample size ($N = 7$) compared to the HC group ($N = 14$). We conducted a further analysis by randomly drawing seven subjects from the HC group to match this sample size. This random drawing was repeated 1000 times, each time we compared RTs between the two tasks using the random smaller ($N = 7$) HC group and obtained a p value for this comparison. On averaging the 1000 random drawings, the average p value was .04, suggesting that there is a genuine difference between the patient group and the HC group.

3.3. Asymmetry index

To further compare the two subject groups on their top-down interference in task A, we calculated their asymmetry indices for the RTs. This asymmetry index is a useful measure for the interference in the face of different baselines between different subject groups. This is particularly since we expect, and indeed observed, a slower baseline RT (for task B) for the patient group. Additionally, once we obtain asymmetry indices for observers of each group, we can compare between groups without worries about different sample sizes for different groups. Specifically, we obtained $N = 7$ asymmetry indices of the RTs for $N = 7$ patients, and similarly for the $N = 14$ HCs. Comparing the $N = 7$ indices for the patients with the $N = 14$ indices of the HCs, we find that HCs have a significantly larger asymmetry index on average ($t = -2.66$, $p = .01$) (see Fig. 4).

These results are consistent with the conclusion from the RTs analysis that the patients have a much weaker top-down interference compared with the controls.

3.4. Analysis of responses with target located in the left half of the display

3.4.1. Accuracy

Both HC and the right parietal patients were significantly less accurate in task A than in task B ($t = -3.36$, $p = .005$; $t = -2.47$, $p = .04$, respectively). For each task, controls and patients were not significantly different in their accuracies ($t = -.89$, $p = .38$ for task A; $t = -.19$, $p = .85$ for task B) (see Fig. 5a).

3.4.2. Averaged RTS

As in the overall analysis, the HC' RTs were significantly longer in task A than in task B ($t = 3.79$, $p = .002$). In contrast, for the patients group, there were no significant difference between the RTs for the two tasks ($t = .99$, $p = .36$).

The patients' RTs were significantly longer than the controls' RTs in task B, ($t = 2.28$, $p = .03$) whereas there was no significant difference between the RTs for the two subject groups in task A ($t = -.08$, $p = .93$) (see Fig. 5b).

3.4.3. Asymmetry index

As in the overall analysis, comparing the $N = 7$ indices for the patients with the $N = 14$ indices of the HCs, we find that HCs have a significantly larger asymmetry index on average ($t = -2.26$, $p = .03$) (see Fig. 5c).

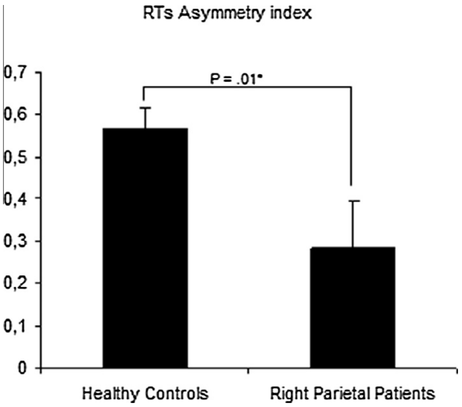

Fig. 4. Healthy controls and right parietal patients' RTs Asymmetry index in the visual search tasks regardless of the target location. Error bars represent standard error of the mean.

In summary, the analysis for when the target was located in the left half of the display replicated the results of the overall analysis except that patients were significantly less accurate in task A than in task B (as the HC). We would like to suggest that this reflects the pattern of omissions that right parietal patients show in the contralesional hemifield during a difficult visual search task.

3.5. Analysis of responses with target located in the right half of the display

3.5.1. Accuracy

Both HC and the right parietal patients tended to be somewhat less accurate in task A than in task B, although their accuracy difference did not reach significance ($t = -1.81$, $p = .09$; $t = -1.26$, $p = .25$; respectively). There were no significant differences in accuracy between patients and controls in either tasks ($t = -.67$, $p = .51$; $t = .78$, $p = .44$, respectively) (see Fig. 5d).

3.5.2. Averaged RTS

Both the HC' and the right parietal patients' RTs were significantly longer in task A than in task B ($t = 2.73$, $p = .01$; $t = 2.83$, $p = .02$, respectively) demonstrating top-down interference in task A. There were no significant differences between the RTs patients and the RTs controls in either tasks ($t = -.70$, $p = .48$; $t = 1.70$, $p = .10$, respectively) (see Fig. 5e).

3.5.3. Asymmetry index

The AI of Patients tended to be smaller than the HCs although this difference did not reach significance ($t = -2.02$, p =.056) (see Fig. 5f).

In summary, when the target was located in the right half of the display, the performance of the patients was not significantly different from that of their matched control sample.

There were no significant differences between patients and controls neither in accuracy nor RTs, nor in AI. The AI of patients tended to be smaller than that of the HCs although this difference did not reach significance.

4. Discussion

In this study, we investigated the performance of seven right parietal lesion patients without neglect and their age and educational matched HC, on two visual search tasks (task A and task B) previously used in HC (Zhaoping & Guyader, 2007) and rTMS studies (Oliveri et al., 2010). Both tasks are unique feature search tasks, with task A but not task B, susceptible to top-down interference. The results of the HCs are in line with the previous behavioral study (Zhaoping & Guyader, 2007). Specifically, the patients' matched HCs had significantly longer RT and were less accurate in task A than task B, demonstrating top-down interference in task A.

The results on the right PPC patients confirm our expectation that damage to the right parietal cortex impairs top-down attentional processes. Indeed, our right PPC patients did not have a significantly longer RT and were not less accurate, in task A than in task B. In other words, their performance was significantly different from that of their matched control sample. This significant difference is unlikely caused by a difference between the sample sizes of the two groups. Our analysis by matching sample sizes demonstrated that the HCs but not the patients had significantly longer RT in task A than task B. Additionally, our asymmetric index analysis showed that HC group had significantly larger top-down interference than the patients.

Since time from lesion occurrence was not homogeneous in our patients' sample, we cannot exclude that the reported findings are a combination of reduction of functional activity in the right PPC

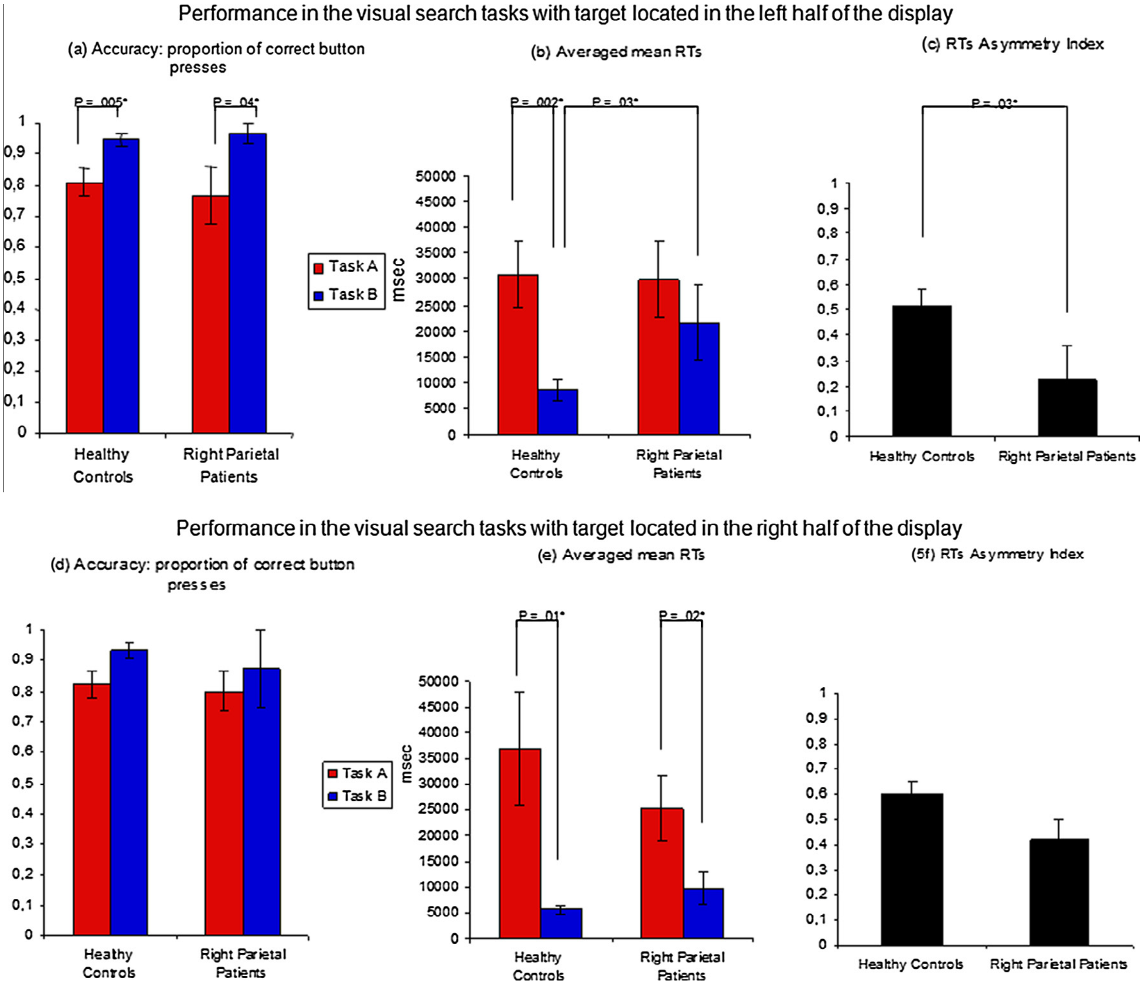

Fig. 5. Healthy controls and right parietal patients' performance in the visual search tasks in the left and right hemifield. Error bars represent standard error of the mean. (a) Accuracy with target located in the left half of the display; (b) averaged Rts with target located in the left half of the display; (c) RTs Asymmetry index with target located in the left half of the display; (d) accuracy with target located in the right half of the display; (e) averaged Rts with target located in the right half of the display; (f) RTs Asymmetry index with target located in the right half of the display.

(for subacute patients) and widespread changes in functional activity across the left and right PPC (for chronic patients).

Interestingly, we documented a difference in the performance between the left and the right visual fields.

The analysis of responses when the target was located in the left half of the display replicated the results of the overall analysis. Indeed, although their accuracy for task A was lower in the left hemifield, patients showed a smaller asymmetry index in this hemifield. When the target was located in the right half of the display, the performance of the patients was not significantly different from that of their matched control sample. There were no significant differences between patients and controls neither in accuracy nor RTs (nor in AI). Thus, it appears that the reduced interference observed in the patient group in the overall analysis is driven by performance in the left visual field suggesting a spatially specific reduction rather than a generalized reduction in top-down interference.

Our reported differences between the left and right visual fields are in line with neurological literature showing that patients with unilateral PPC damage had impairments in conjunction search predominantly in contra-lesional visual field (Riddoch et al., 2010; List et al., 2008). The absence of top-down interference in our PPC patients compared to the HCs are in line with the findings of Ossandón et al. (2012) and more closely with those of Oliveri et al. (2010). Our previous rTMS study in healthy controls reported that rTMS on right PPC caused a reduction in the top-down interference. However, our lesion study also revealed something not found in the rTMS study. Namely right PPC lesion patients are slower in the control task B which relied mainly on bottom-up attention. rTMS over the right PPC of healthy controls instead had no effect on this task. This difference in results may be accounted in terms of a generalized slowing in speed of information processing caused by the sub-cortical damage present in some of our PPC patients or by the right PPC lesion or both. Alternatively, it can also be argued that the slower reaction time in task B may simply be to the presence of brain damage, regardless lesion location. Future studies enrolling patients with focal lesion not involving the right PPC are needed to shed light on this.

An increasing number of studies have reported paradoxical functional facilitation (PFF) effects in brain damaged patients (e.g. Etcoff et al., 2000; Graf & Masson, 1993; Kapur, 1980, 1996; Ladavas, Petronio, & Umiltà, 1990; Morgan et al., 2012; Moscovitch, Winocur, & Behrmann, 1997; Oliveri et al., 1999; Vuilleumier et al., 1996). PFF effects typically describe enhanced performance following brain damage. Thus, for example, a PFF effect has been documented in patients with semantic dementia performing a conjunction search task. These patients were faster than HC in a conjunction search task when a large number of distractors were present. The authors suggested that this PFF effect may be underpinned by enhanced functioning in the dorsal frontoparietal attention network which is thought to be largely spared in semantic dementia (Viskontas et al., 2011). The PFF effect in our patients complements the findings reported in the semantic dementia patients. The right parietal lesion of our patients has impaired the top down attentional function which is necessary for the non-feature search but it is detrimental for optimal performance in our feature search task A.

The lack of top-down interference in our patients may be caused by deficits in one or both of the following processes: one is feature binding to form object shapes, the other is rotational invariance in shape recognition. We recall that top-down interference in our task A arises because observers confuse the X-shape containing the target with the X-shape for the non-targets. For the X-shape to form, two separate bars have to be combined in a particular configuration, i.e., intersect each other at their midpoints – this is feature binding. For the X-shape containing the target bar to be confused with the other X-shapes, even though the former has a unique orientation and so is a rotated version of the others, the X-shapes should be turned into an abstract shape property which does not contain the information about its orientation – this is rotational invariance in shape recognition. Rotational invariance in shape recognition helps us to recognize an object regardless of its viewpoint, in particular, regardless of the orientation of the image of this object.

It has been shown that top-down attention is necessary for rotational invariance in shape recognition (Stankiewicz, Hummel, & Cooper, 1998). Studies on patients with right parietal lesions, reported impairments in recognition of objects viewed from an unconventional angle (Davidoff & Warrington, 1999; Warrington & James, 1988; Warrington & Taylor, 1973). In addition, selective impairments of mirror image discrimination have been reported in patients with bilateral parietal lesions (Davidoff & Warrington, 2001; Turnbull & McCarthy, 1996). If our patients are impaired in identifying X-shapes at different orientations, they should lack the rotational invariance necessary for top-down interference, consistent with our data.

Alternatively, the lack of interference in our patients might be caused by their deficit in feature binding, which has been suggested to involve the right parietal cortex (Corbetta & Shulman, 2002; Treisman & Gelade, 1980). Our patients may be unable to bind two oriented bars into the X shape and consequently unable to achieve shape recognition when feature binding is required, regardless of whether they can achieve viewpoint invariance in their recognition. This is in line with the previous studies reporting that right parietal patients had impairment in non-feature, conjunction, searches (Eglin, Robertson, & Rafal, 1989; Riddoch & Humphreys, 1987; Riddoch et al., 2010).

Both of these interpretations – rotational invariance in shape recognition and feature binding – require intact top-down attentional processes. Our finding does not enable us to pinpoint exactly which, or whether both, of these two components underlie the lack of top-down interference in our patients. Future studies are needed to address this issue further.

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These funding institutions did not have any role in the collecting, analysis and interpretation of data.

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