



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.

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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 affect 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

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