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Effects of attentional and cognitive variables on unilateral spatial neglect

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ABSTRACT

Patients with visuospatial neglect when asked to cancel targets partially or totally omit to cancel contralesional stimuli. It has been shown that increasing the attentional demands of the cancellation task aggravates neglect contralesionally. However, some preliminary evidence also suggests that neglect might be worsened by engaging the patient in a demanding, non-spatial, cognitive activity (i.e. a mathematical task). We studied cancellation performance of 16 patients with right-hemisphere lesions, 8 with neglect, 8 without neglect, and 8 age-matched healthy control participants by means of five cancellation tasks which varied for the degree of attentional and/or high level cognitive demands (preattentive and attentive search of a visual target, searching for numbers containing the digit 3, even numbers, and multiples of 3).

Results showed that attentive search of visual targets, relative to the preattentive search condition, aggravated neglect patients' performance. Moreover, searching for multiples not only worsened spatial neglect contralesionally, but also slowed down performance of patients with right-hemisphere lesions without neglect.

Our findings further demonstrate the presence of specific deficits of attention in neglect. In addition, the worse performance of patients without neglect in the 'multiples of 3' task is consistent with the evidence that right-hemisphere lesions per se impair the ability to maintain attention (i.e. sustained attention). This suggests that the exacerbation of neglect during execution of a demanding, non-spatial, cognitive task might be explained by a deficit of sustained attention in addition to a selective deficit of spatial attention.

1. Introduction

Patients with visuospatial neglect following unilateral brain lesions to the right hemisphere fail to orient towards, attend to or act upon stimuli located in contralesional space (Heilman et al., 1993). Typically, when neglect patients are asked to search for and cancel targets printed on a sheet of paper (cancellation tasks, e. g. Albert, 1973; Diller et al., 1974; Mesulam, 1985; Wilson et al., 1987), they do not explore contralateral space effectively and omit to detect stimuli located in that side of space, even if they are free to move their head and eyes. This disturbance has been interpreted as a consequence of the disruption of selective spatial attentional processes (Kinsbourne, 1987; Heilman, et al., 1993). Moreover, since extensive right-hemisphere lesions also impair the ability to maintain sustained attention (Wilkins et al., 1987; Pardo et al., 1991; Robertson et al., 1997, 1998), some authors have suggested a possible interaction between the damage to the spatial attentional system implicated in neglect and a co-occurring deficit of the sustained attention system (Heilman et al., 1978; Robertson et al., 1998; Posner, 1993; Robertson et al., 1995, 1997). While the spatial selectivity component of human attention enhances perception of stimuli located in specific regions of space, the alertness component of attention allows the execution of effortful vigilance tasks (i.e. focusing attention to subtle sensory stimuli, filtering irrelevant information and maintaining alertness for the duration of the task) independently of stimulus location (Pardo et al., 1991).

Patients with neglect may manifest different degrees of spatial impairment, suggesting that the disorder is not an all-or-none phenomenon. In addition, it may dissociate across frames of reference (e. g. egocentric and allocentric coordinates, Rusconi et al., 2005), sectors of space (e. g. personal, peripersonal and

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extrapersonal space, Bisiach et al., 1986; Berti and Frassinetti, 2000; Neppi-Mòdona et al., 2007), and, within the same spatial domain, it may vary according to task demands. Nonetheless, the specific determinants of neglect within the same spatial domain are not yet fully understood. For instance, in cancellation tasks, other variables besides spatial location (Chatterjee et al., 1999) may affect neglect severity.

Attentional theories of neglect (Kinsbourne, 1987; Heilman, et al., 1993) predict that increasing the attentional demands of the cancellation task, would aggravate patients' performance. Indeed, it has been shown that target saliency (Weintraub and Mesulam, 1988; Kaplan et al., 1991; Aglioti et al., 1997; Husain and Kennard, 1997; Chatterjee et al., 1999), stimuli number and density (Mark et al., 1988; Eglin et al., 1989; Chatterjee et al., 1992; Kartsounis and Findley, 1994; Mennemeier et al., 1998; Chatterjee et al., 1999; Neppi-Mòdona et al., 2002; Ricci et al., 2004; Pia et al., 2013), targets and distractors ratio (Kaplan et al., 1991), distractors similarity (Riddoch and Humphreys, 1987), and stimuli perceptual configuration defined by gestalt grouping principles (Pia et al., 2004) may modulate neglect. These modulations are mainly related to bottom-up stimulus processing stages. A number of studies have also shown that top-down attentional requests can influence neglect patients' performance. For instance, top-down task-demands (Sarri et al., 2009) and dual task attentional paradigms (Robertson and Frasca, 1992) affect neglect severity, even if stimulus perceptual features are kept constant. Finally, different kind of backgrounds that trigger either preattentive/parallel (immediate, effortless) or attentive/serial (slow, effortful) search (Treisman and Gelade, 1980; Bergen and Julesz, 1983), can influence target search performance (Aglioti et al., 1997).

Interestingly, other variables, not explicitly linked to the attentional domain, seem to affect neglect (Ishiai et al., 1990; Chatterjee et al., 1992; Tegnér and Levander, 1991; Marshall and Halligan, 1996; Mark and Heilman, 1997). In particular, preliminary findings from a single case study suggested that the cognitive demands required to identify specific targets modulate neglect severity. Mennemeier et al. (2004) described a patient with a right-hemisphere lesion and left neglect whose cancellation bias worsened when target selection required to perform a mathematical task. Specifically, in the critical condition the patient was asked to search for the multiples of a specific number. This cognitive task is likely to require a greater amount of attentional resources to be accomplished. Because sustained attention might be impaired in right hemisphere patients (Wilkins et al., 1987; Pardo et al., 1991; Robertson et al., 1997; 1998), it is possible that worsening of neglect in the patient Mennemeier et al. (2004) was due to a concomitant deficit of both selective spatial attention and sustained attention. Since sustained attention can be considered a basic attentional function that determines the efficacy of higher attentional processes (e. g. selective spatial attention) and, in general, of cognitive abilities (Sarter et al., 2001), an influence of sustained attention on spatial attention during a demanding task might be expected. However, to our knowledge, this is the only existing evidence suggesting that a, non-spatial, demanding cognitive process, activated in order to accomplish the task, worsens neglect during stimuli cancellation. No other study has validated or further explored this issue at a group level in patients with and without neglect and in healthy controls. The only evidence that task-related attentional load can worsen neglect and/or extinction on cancellation (Robertson and Frasca, 1992) or detection tasks (Robertson and Frasca, 1992; Bonato et al., 2010, 2013, 2015) comes from dual task paradigms. However, carrying-out simultaneously a cognitive and a cancellation or detection task requires to divide attention between concurrent activities rather than increasing the 'cognitive' load of the current visuo-spatial task.

Here we investigated the influence of different categories of perceptual and cognitive load on cancellation performance in patients with right-hemisphere lesion with and without neglect, and in age-matched healthy participants. In two experimental conditions we manipulated bottom-up stimuli perceptual features (experiment 1), and in three conditions we manipulated top-down task demands (experiment 2).

In experiment 1, the three groups performed two cancellation tasks that required either 'preattentive' or 'attentive' texture segmentation (Aglioti et al., 1997) in order to segregate targets from distractors (Julesz, 1981, 1987; Bergen and Julesz, 1983; Sagi and Julesz, 1985). On the basis of previous findings (Aglioti et al., 1997) and according to attentional theories of neglect (Heilman et al., 1987; Kinsbourne, 1987), we expected to observe an attentional-dependent modulation of cancellation performance in neglect patients and not in the other groups (i.e. a worse performance on the attentive than on the preattentive texture condition).

In experiment 2, participants were asked to identify target stimuli (i.e. numbers) according to different task demands. As in the study of Mennemeier et al. (2004), in the control condition participants searched for stimuli containing a specific number, whereas in the critical high-load cognitive condition participants were asked to search for multiples of the same number. In addition, in a low-load cognitive condition, subjects were asked to search for even numbers. We assumed that this latter task implied, on the one hand, a higher cognitive load than searching for a specific number, but on the other hand, a lower cognitive load than searching for multiples. We hypothesized that if unilateral visual neglect is exclusively accounted for by a deficit of visuospatial attention, then we should not observe any effect on the visuospatial bias by the cognitive load, given that targets and distractors perceptual features (numbers) were kept constant. On the other hand, if unilateral visual neglect is also due to a non-spatial deficit in maintaining sustained attention (Robertson et al., 1995, 1997, 1998), then increasing the cognitive load should further aggravate the spatial orientation bias. Indeed, sustained attention is an important component of 'top-down' processes that mediate knowledge-driven target detection and selection.

Searching for the number 3 was expected to lead to a performance similar to the 'attentive' task of experiment 1, since both tasks involved serial attentive search of well-defined visual features. Searching for even numbers was supposed to be cognitively less demanding than searching for multiples, and therefore a possibility was that this condition produced a better performance than searching for multiples. In addition, searching for even numbers was hypothesized to be cognitively more demanding than searching for the number 3 (because it requires access to a stored semantic representation of number knowledge, Dehaene et al., 1993) and therefore was expected to produce worse performance than searching for 3 s In order to be functionally related to a deficit of the selective spatial attention system, any decrement in performance should be limited to the group of neglect patients. On the other hand, a concomitant decrement in performance in patients without neglect would suggest a modulatory influence of the sustained attention system over the spatial attentional system.

The method proposed here is complementary to dual-task computer-based detection paradigms that are able to unveil disorders of contralesional space awareness in patients with right hemisphere lesions not showing neglect at paper-and-pencil cancellation tasks (Bonato et al., 2010, 2013, 2015). Indeed, it allows studying patients with spatial neglect at standard tests, even if they are affected by visual field defects.