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Editorial

Spatial and non-spatial aspects of visual attention: Interactive cognitive mechanisms and neural underpinnings

Visual attention is broadly defined as the ability to rapidly detect and respond to stimuli within the surrounding environment, and to effectively select between relevant and irrelevant visual information. As a complex cognitive function, attention entails multiple components or dimensions, sub-served by widely distributed but highly specialised fronto-parietal neural networks, and including both spatial and non-spatial attentional mechanisms. Spatial attention (defined as the ability to direct attention to a particular location in space) has been extensively investigated in both healthy controls and neuropsychological patients. Particular emphasis has been placed on spatial biases in visual attention, manifested in the healthy population as so-called pseudoneglect (i.e., a leftward attentional bias when performing cognitive tasks; e.g., Bowers and Heilman, 1980; Jewell and McCourt, 2000; McCourt and Jewell, 1999; Sosa et al., 2010) or in neuropsychological patients as so-called unilateral neglect (i.e., the distinctive rightward attentional bias resulting from right-hemispheric brain damage; e.g., Driver and Mattingley, 1998; Halligan et al., 2003; Heilman and Valenstein, 1979; Vallar, 1998). The spatial allocation of visual attention can be defined within different reference frames (for a review see Farah et al., 1990; Humphreys et al., 2013), with spatial locations defined with respect to the viewer (viewer-centred), based on external references (environment-centred), or according to locations within individual objects (object-centred). However, a purely spatial account of visual attention fails to explain the complexity of the underlying cognitive mechanisms, and over the years a substantial amount of evidence has been compiled about the non-spatial aspects of visual attention, which have been shown to significantly influence the spatial aspects. For instance, changes in alertness, attentional load, or attentional processing resources are known to influence the spatial deployment of visual attention and its biases. The nature of the interplay between spatial and non-spatial processes in visual attention, the mechanisms guiding them, and their common versus dissociate neural underpinnings are a matter of ongoing debate and of intensive research. Accordingly, many newer models of the neural underpinnings of attentional control in the human brain stress the importance of the interactions between spatial and non-spatial facets of visual attention.

Therefore, with this special issue, we aimed to provide an updated overview of some of the main trends in visual research concerned with how different spatial and non-spatial attentional functions, and their neural underpinnings, interact and contribute to human attentional abilities. The studies compiled here provide evidence based on a variety of research approaches and techniques, including, but not limited to, cognitive assessment, eye-tracking, and brain imaging in healthy controls and neuropsychological patients. In the present editorial, we highlight some of the themes that emerge through the submitted works (2 reviews and 17 original papers), which we divided into four parts: 1) neural underpinnings of spatial and non-spatial visual attention aspects; 2) visual attention in different spatial and temporal reference frames; 3) visual perception, eye movements, and the analysis of non-spatial factors in the deployment of visual attention; and 4) non-spatial factors in the modulation of visuospatial attention: evidence from studies in right- and left- hemispheric stroke patients.

1. Neural underpinnings of spatial and non-spatial visual attention aspects

Visual attention operates via fronto-parietal networks, divided into dorsal and ventral attention systems, with distinct functional roles (Corbetta and Shulman, 2002; Mesulam, 1990). The dorsal network, including several core cortical regions, such as the intraparietal sulcus and the frontal eye field, controls the orientation of attention in space and top-down selection. The ventral network is involved in target detection and reorientation of attention towards salient, unexpected stimuli, and its core regions include the temporoparietal junction (TPJ), the anterior insula, and the ventral frontal cortex (Corbetta and Shulman, 2002). While it has been suggested that the dorsal network is organized bilaterally, it is thought – based on evidence from functional neuroimaging studies and neuropsychological patients – that the ventral attention network is strongly lateralized towards the right hemisphere (Corbetta and Shulman, 2002, 2011). The interplay between dorsal and ventral systems is critical for attentional control, requiring the integration of bottom-up sensory information with top-down signals, guided by current behavioural goals and task demands (Corbetta et al., 2008; Corbetta and Shulman, 2002). Several long association fronto-parietal pathways, including three separate branches of the superior longitudinal fasciculus (SLF I-III) and the inferior fronto-occipital fasciculus (IFOF), provide essential structural connectivity within attention networks, affording functional interactions within and between dorsal and ventral attentional systems, as well as spatial and non-spatial facets of visual attention (e.g., Bartolomeo et al., 2007; Chechlacz et al., 2015; Doricchi et al., 2008; Schmahmann et al., 2007; Thiebaut de Schotten et al., 2011). The importance of such interactions has been confirmed by

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several studies examining functional connectivity, based on a variety of different neuroimaging approaches (e.g., Fox et al., 2006; He et al., 2007; Leitao et al., 2015). In this special issue, Fellrath et al. (2016) provide compelling evidence for interactions between spatial and non-spatial attentional mechanisms in the dorsal attentional system. Specifically, using resting-state electroencephalography (EEG) analysis, the authors demonstrate that the functional connectivity within the dorsal network predicts impaired goal-directed processing in patients with spatial attention deficits (Fellrath et al., 2016).

It is widely accepted that limited processing resources are allocated on the basis of dynamically changing "attentional priority maps", providing topographical representations of the visual scene, in which each object/location has an assigned, specific "weight", based on perceptual saliency and behavioural relevance (e.g., Bays et al., 2010; Bisley and Goldberg, 2010; Bundesen, 1990; Ptak, 2012; Treisman, 1998). Among different cortical areas within the dorsal and ventral networks involved in attentional control, the posterior parietal cortex (encompassing the TPJ, and the inferior and superior parietal lobules) has been indicated as a key region in encoding spatial priority maps (e.g., Husain and Nachev, 2007; Ptak, 2012). The review by Shomstein and Gottlieb (2016), included in this special issue, presents and critically evaluates experimental findings from human neuroimaging and monkey neurophysiological studies, supporting the existence of several interactions between spatial and non-spatial attentional processing, supported by the posterior parietal cortex. Shomstein and Gottlieb (2016) elegantly put forward an integrative model of the function of the parietal cortex in attentional selection, arguing that accumulated evidence indicates that priority maps reflect both spatial and non-spatial priorities, which ultimately act on sensory information in a spatial way. A second review by Clarke and Crottaz-Herbette (2016), also included here, discusses the neural mechanisms subtending prism adaptation (PA) in both neglect patients and healthy controls, focusing on the interactions between spatial and non-spatial attentional functions, and with respect to the PA-induced modulation of the interplay between dorsal and ventral networks. As numerous prior reports demonstrate, rightward PA triggers changes in the visual field representations from the right to the left inferior parietal lobule, resulting in a Shift of Hemispheric Dominance within the Ventral Attentional System (SHD-VAS model). Consequently, based on the reviewed evidence, Clarke and Crottaz-Herbette (2016) conclude that, as a consequence of this change, in neglect patients the visual input might be redirected to the dorsal network. This, in turn, might re-install the balance between left- and the right-hemispheric network components. However, as the authors note, while the SHD-VAS model provides a plausible explanation for the effects of rightward PA on attentional biases in patients with left neglect, it is still unclear whether this model can be generalized to leftward PA.

2. Visual attention in different spatial and temporal reference frames

One of the critical issues for understanding cognitive processes underlying visual attention is attentional selection. The environment relentlessly delivers a large amount of visual information, which needs to be prioritized on the basis of the current behavioural goals. This prioritization process can predict the locus of attention, i.e., the visual stimuli with the assigned greatest behavioural priority are the best candidates for attentional selection, and determine the spatial allocation of attention (Koch and Ullman, 1985). The allocation of attention can be defined in different spatial reference frames (for a review see, e.g., Farah et al., 1990; Humphreys et al., 2013), with spatial locations defined with respect to the viewer (viewer-centred), based on external references (environment-centred), or according to spatial locations within individual objects (object-centred), representing the space in relation to the planned behavioural actions towards visual stimuli. Furthermore, the successful selection of relevant objects, i.e., the successful interpretation of complex visual scenes, requires mechanisms enabling the effective structuring and organization of the incoming visual inputs. One of the mechanisms allowing the integration of visual objects within visual scenes, as well as of individual elements of complex objects into coherent wholes, is grouping (Koffka, 1935; Wertheimer, 1923). While it is clear that object integration relies both on grouping processes and on selective attention, the precise nature of the relationship between attention and grouping is still the matter of ongoing research. In particular, it has been questioned to what extent attention is required for integrating information about features and object fragments into coherent wholes (see, e.g., Gilchrist et al., 1996; Treisman and Gelade, 1980). In order to address some of these issues, Gögler and colleagues examined the role of selective attention in object integration processes in patients with visual extinction, resulting in clear spatial attention biases, using a visual search paradigm with Kanizsa figures (Gögler et al., 2016). The contrasting findings in healthy participants and in patients with unilateral extinction indicate that attentional competition clearly limits integration processes. Thus, the study by Gögler et al. (2016) critically adds to the body of evidence suggesting that attentional resources are necessary for integrating parts of visual objects into coherent wholes.

While research on attentional selection and spatial priority maps predominantly focuses on the role of the parietal lobes, the report by Smith and colleagues examined the role of the Lateral Occipital Cortex (LOC) in object-based attentional facilitation and inhibition (Smith et al., 2016). Based on the examination of a patient with visual form agnosia resulting from bilateral occipital lesions, the authors provide evidence that the LOC is involved in object-based attentional facilitation, whereas object-based attentional inhibition does not depend on the integrity of this cortical area. The findings are compatible with prior neuropsychological evidence, suggesting a key role of the parietal cortex in mediating object-based inhibition, and proposing functional dissociations between object-based attentional facilitation and object-based attentional inhibition (e.g., Vivas et al., 2008).

Another critical issue for understanding human attentional abilities is related to the temporal aspects of visual perception and attention. The temporal dynamics of attention can be described with respect to two different timescales (i.e., two different temporal frames): a very short timescale, measured in intervals of milliseconds, and a longer timescale, measured in intervals of minutes or even hours. These two timescales are labelled as so-called phasic alertness and tonic alertness/sustained attention, respectively (e.g., Coull et al., 2001; Posner, 2008; Sturm et al., 1999; Sturm and Willmes, 2001). A novel measure for evaluating sustained attention is presented in this special issue by Shalev, Demeyere, and the late Glyn W. Humphreys. Shalev et al. (2016) argue that their task, a variation of the frequently used Continuous Performance Task (CPT; Conners and Staff, 2000), provides a reliable and accurate measure of sustained attention, which is free from the issues resulting from the reliance on estimates based purely on reaction times. Moreover, Shalev et al. (2016) found significant correlations between sustained attention, as measured by their task, and self-reported distractibility, in both elderly participants and in chronic stroke patients. The findings are discussed in relation to the applicability of this novel task for the evaluation of attentional problems in clinical populations.