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Research report

Object and space perception – Is it a matter of hemisphere?

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ABSTRACT

In the 1980s, following Newcombe's observations, Ungerleider and Mishkin put forward the functional subdivision of the visual system into a ventral stream dedicated to object perception and a dorsal stream dedicated to space perception. Ten years after this discovery, the *perception-action model* re-defined the dorsal stream as responsible for non-conscious visual guidance, and most recently a tripartition has been put forward to account for a variety of visuospatial functions. Here, we investigated the neural underpinnings of object and space perception by combining the administration of the Visual Object Space Perception (VOSP) battery with a voxel-based lesion symptom mapping (VLSM) approach in a large sample of patients with penetrating traumatic brain injury (pTBI). First, our results provided new support for the complementary role of both hemispheres in object recognition. The right lateral occipital complex was found to be critical in early perceptual discrimination, whereas more anterior temporal and frontal regions in the left hemisphere were found to be critical in more complex forms of object discrimination and recognition Second, our findings confirmed that space perception depended on the integrity of the right inferior parietal lobe (IPL) and revealed that a network linking the right IPL with the right premotor cortex was critical for the perception of spatial relationships in both 2D and 3D representations. Taken together, our results supported the functional

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subdivision of the visual system and shed new light on the specific processes involved along both the dorsal and the ventral streams.

1. Introduction

Years after the *what and where* hypothesis suggested a functional partition of the visual system into two streams – a *ventral stream* subserving object perception and a *dorsal stream* subserving space perception (Mishkin, Ungerleider, & Macko, 1983; Newcombe, 1969; Ungerleider & Mishkin, 1982), new frameworks have emerged refining this subdivision both anatomically and functionally. Notably, the perception-action model defines the dorsal stream as responsible for non-conscious visual guidance of action and the ventral stream for conscious perception (Goodale & Milner, 1992; Milner & Goodale, 2006). Recently, Kravitz et al. (Kravitz, Saleem, Baker, & Mishkin, 2011) suggested a tripartition of the dorsal stream to account for the variety of visuospatial functions. Three distinct pathways originating in the posterior parietal cortex (PPC) mediate different visuospatial abilities: (i) a parieto-premotor pathway for eye movements, several forms of visually guided action, and grasping; (ii) a parieto-prefrontal pathway for top-down control of eye movements and spatial working memory; and (iii) a parieto-medial temporal pathway for spatial abilities related to navigation. Likewise, the same group proposed a refinement of the ventral object representation pathway, which is subserved by distinct cortical and subcortical structures (Kravitz, Saleem, Baker, Ungerleider & Mishkin, 2013).

Evidence about hemispheric dominance for object perception and recognition is controversial. Some neuropsychological and neuroimaging studies point toward a right hemisphere dominance in object perception (Acres, Taylor, Moss, Stamatakis, & Tyler, 2009; Konen, Behrmann, Nishimura, & Kastner, 2011), while others suggest a left hemisphere dominance (Price, Moore, Humphreys, Frackowiak, & Friston, 1996; Sergent, Ohta, & MacDonald, 1992; Stewart, Meyer, Frith, & Rothwell, 2001; Zelkowicz, Herbster, Nebes, Mintun, & Becker, 1998). These conflicting findings can be reconciled by the fact that object recognition involves hierarchically organized processes (Ungerleider & Haxby, 1994) that depend on either the left or the right hemisphere. According to this view, the right posterior occipital and temporal regions are specialized for the discrimination of basic features, while more anterior left temporal regions are specialized for assigning a meaning to objects for categorization and recognition (De Renzi, 1982).

In contrast, general consensus exists on the prominent role of the right hemisphere in controlling visuospatial attention (De Renzi, 1982; Kinsbourne, 1987; McCarthy & Warrington, 1990; Mesulam, 1981; Newcombe, 1969). A series of behavioral experiments have demonstrated a relative right hemisphere advantage for processing relationships between spatial coordinates (i.e., distance evaluation) (Kosslyn et al., 1989). The right hemisphere's dominance in spatial attention, especially the involvement of the right parietal cortex, is supported by an abundant literature in neglect patients (e.g., Heilman & Van Den Abell, 1980; Vallar & Perani, 1986) and by recent evidence from functional neuroimaging (Thiebaut de Schotten et al., 2011) and transcranial magnetic stimulation (TMS) (Brighina et al., 2002; Fierro et al., 2000; Hilgetag, Théoret, Pascual-Leone, & others, 2001; Müri et al., 2002; Rounis, Yarrow, & Rothwell, 2007) studies in healthy subjects.

In this study, we investigated the neural underpinnings of object and space perception by employing the Visual Object Space Perception (VOSP) battery (Warrington & James, 1991) and a voxel-based lesion symptom mapping (VLSM) approach in a large sample of patients with penetrating traumatic brain injury (pTBI). VLSM studies are of importance in identifying regions necessary for cognitive processes and corroborating evidence from single case, clinical, and neuroimaging studies (Bates et al., 2003). In our study, we addressed the following two questions: 1) What are the anatomical correlates of both object and space perception and 2) Do subjects with lesions in both hemispheres exhibit any hemispheric dominance in object and space perception? Our results supported the complementary role of both hemispheres in object recognition and identified key regions associated with different cognitive processes along the ventral stream that depended on task demand. Our findings confirmed that space perception depended on the integrity of the right IPL within the dorsal stream, and demonstrated that a network linking the right IPL with the right premotor cortex was critical for the perception of spatial relationships in both 2D and 3D representations.

2. Material and methods

2.1. Subjects Q2

Participants were drawn from Phase III of the W.F. Caveness Vietnam Head Injury Study (VHIS) registry, which is a prospective, long-term follow-up study (Raymont, Salazar, Krueger, & Grafman, 2011). Out of the 254 veterans, 247 completed the VOSP battery and were divided into two groups based on the presence or absence of pTBI: a lesion group (LG = 192) and a control group (CG = 55). All veterans gave their written informed consent before participating in this study, which was approved by the Institutional Review Board at the National Naval Medical Center and the National Institute of Neurological Disorders and Stroke, Bethesda, MD.

2.2. Neuropsychological assessment and behavioral analysis

All participants underwent a 5–7 day neuropsychological assessment. As the experimental measure, we employed the