



The egocentric reference for visual exploration and orientation

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ARTICLE INFO

Article history:

Accepted 16 July 2008

Available online 26 August 2008

Keywords:

Spatial representation

Navigation

Orientation

Visual exploration

Perceptual neglect

Representational neglect

Social cognition

Perspective changes

Parietal lobe

ABSTRACT

Clinical signs of damage to the egocentric reference system range from the inability to detect stimuli in the real environment to a defect in recovering items from an internal representation. Despite clinical dissociations, current interpretations consider all symptoms as due to a single perturbation, differentially expressed according to the medium explored (perceptual or representational). We propose an alternative account based on the functional distinction between two separate egocentric mechanisms: one allowing construction of the immediate point of view, the other extracting a required perspective within a mental representation. Support to this claim comes from recent results in the domain of navigation, showing that separate cognitive mechanisms maintain the egocentric reference when actively exploring the visual space as opposed to moving according to an internal map. These mechanisms likely follow separate developmental pathways, seemingly depend on distinct neural pathways and are used independently by healthy adults, reflecting task demands and individual cognitive style. Implications for spatial cognition and social skills are discussed.

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The more accurate the map, the more it resembles the territory. The most accurate map possible would be the territory, and thus would be perfectly accurate and perfectly useless.

N. Gaiman, American Gods.

1. The egocentric perspective

Our direct visual experience of the world is strictly egocentric: visual scanning of the environment and memory of a visual scene appear to rely on an implicit, automatic coding mechanism, view-dependent in nature (Chua & Chun, 2003; Waller, 2006). This is possible thanks to a reliable inner sense of spatial framing according to which we automatically construct a reference system in the three dimensions. This system of egocentric coordinates heavily depends on retinal, proprioceptive and vestibular inputs. The advantage of such an egocentric automatism is the creation of an immediate correspondence between the location of a visually perceived object, and the spatial frame in which a potential action is executed.

However, the original point of view from which a scene has been experienced can be manipulated, and stored representations need not be automatic and implicit. Studies in the domain of spatial memory and orientation show a clear distinction between viewpoint-dependent and viewer-independent representations of

space, the latter providing a more general and durable layout (Burgess, 2006). Indeed, a representation in a non-egocentric spatial reference incorporates a portion of space that exceeds locomotion or the limited perspective of the viewer. In addition, it allows a stable representation in memory that can be shared, and transferred to other individuals. Studies with functional techniques provide suggestions that distinct neural circuits subserve egocentric and non-egocentric representations of space (Gramann, Müller, Schönebeck, & Debus, 2006; Neggers, Van der Lubbe, Ramsey, & Postma, 2006), which may coexist (Burgess, 2006; Gramann, Müller, Eick, & Schönebeck, 2005).

Although efficient, use of viewer-independent representations pay high cognitive costs, as they depend on multiple spatial transformations aimed at adapting the original perspective to an egocentric frame (Waller, 2006). Quoting Burgess: “whereas egocentric systems can be used alone, the egocentric nature of perception and imagery require that input to and output from allocentric [viewer-independent] systems are mediated by transient egocentric representations” (Burgess, 2006).

For instance, the ability to plan a navigational strategy (such as using short-cuts) requires a mental representation of the environment that should include all the relevant items, a target location, and knowledge of their relative position. Successful orientation relies on the ability to store and use this mental representation in order to plan and guide displacement towards the desired location. Importantly, following an internal representation of the environment requires the continuous assessing of our changing position according to the stored map, in order to hold to the intended

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course. In other words, at any given moment we need to know our position inside the mental map. This would mean deriving an inner egocentric perspective that can be compared with the actual view of the surroundings. Hence, the proper path can be selected and orientation can be maintained according to the goal.

In ecological terms, visual exploration and orientation both respond to the need of learning the spatial organization of the environment in order to plan human activities outside the limits of the peripersonal space. Exploration provides a continuous flow of information automatically framed in egocentric coordinates. A sufficient number of such subjective perspectives allow creating a stable representation of the environment. Several observations suggest that knowledge of complex visual scenes may not require previous experience of all possible subjective viewpoints (Hock & Schmelzkopf, 1980; Intraub, Bender, & Mangels, 1992; Intraub & Bodamer, 1993; Intraub & Richardson, 1989). In fact, few snapshots could suffice to infer information on the relationships between elements and to allow reconstruction of the entire layout. As a consequence, the resulting representation would describe the relative location of salient items in a viewer-independent fashion. In contrast, the cognitive mechanism of orientation would be responsible for recovering the egocentric perspective required to spatially localize a target (i.e. an intended landmark, a heading direction, and so on). Hence, differently from exploration, in which the egocentric reference is physiologically determined, in orientation the same reference should be cognitively inferred. We propose that the mechanism responsible for deriving an egocentric point of view from stored spatial representations is a highly specialized, cognitively demanding, and relatively independent skill.

In the next sections, we will discuss the hypothesis that separate systems subservise extraction of the subjective point of view for visual exploration and orientation. We will provide evidence in favor of this distinction from various domains. First, we will analyze current data from neuropsychology showing how these two systems can be selectively affected by brain damage. Second, we will report data from the developmental literature suggesting the possibility that spatial competences for orientation follow a separate, and longer, maturational path compared to those involved in visual exploration. Third, we will discuss the issue of inter-individual ability in navigational skills as further evidence of the relative functional separability of the two systems. Next, we will describe the main features of the systems responsible for extraction of the subjective point of view and speculate on their putative neuro-anatomical basis. In this framework, we will reconsider the clinical distinction between perceptual and representation neglect and attempt to extend this perspective from visual to social space. Namely, we will suggest that the ability to abstract from and derive a subjective point of view shares similarities with the capacity to operate perspective changes in a broader sense. In this view, extracting an intended social perspective (i.e. to anticipate and/or understand others' intentions) could require cognitive operations bearing close resemblance to those involved in spatial orientation. As elegantly stated by Pine and colleagues: "map-guided navigation represents a specific example of a broader set of skills requiring extrapolation between abstract representations and actual constructs" (Pine et al., 2002).

2. Distinct mechanisms for egocentric orientation: Evidences from neuropsychology

Evidences from brain-damaged patients support the existence of two distinct egocentric mechanisms, one serving actual exploration of space, the other allowing to derive the subjective point of view from an internal representation. The issue of egocentric orientation has been largely addressed by studies on spatial hemineglect following lesion to the posterior part of the right

hemisphere. Hemineglect is a pervasive disorder affecting the egocentric space (Kerkhoff, 2001). The most typical symptom is a defective ability to report stimuli during overt exploration of the contralesional side of the egocentric space (Heilman, Watson, & Valenstein, 2003; Parton, Malhotra, & Husain, 2004), but the disorder can selectively affect only mental scanning of an inner layout (Beschlin, Cocchini, Della Sala, & Logie, 1997; Guariglia et al., 1993; Ortigue et al., 2001; Ortigue et al., 2003). This clinical diversity is thought to reflect the different level at which the representation of space is damaged (perceptual and representational neglect, respectively).

Interestingly, recent findings report that, in spite of their defective ability to explore and detect contralesional stimuli, patients with perceptual neglect can show some basic navigational skills. For instance, they can retrace from memory the path followed during a simple passive displacement (including turns towards both sides of egocentric space) in order to indicate the starting point (Bisiach, Pattini, Rusconi, Ricci, & Bernardini, 1997). Similarly, they can retain the ability to store in memory the egocentric position of a target in order to retrieve it without the help of vision (Philbeck, Behrmann, & Loomis, 2001). They can also maintain the capacity to judge the extent of a passive displacement, independently from its relative direction in egocentric coordinates (Pizzamiglio, Iaria, Berthoz, Galati, & Guariglia, 2003). These observations suggest that in perceptual neglect, the ability to orient according to an inner representation of space may be preserved, in spite of a defective egocentric mechanism for actual exploration.

In contrast, patients suffering from representational hemineglect can perform faultless explorations but are strongly impaired in reporting contralesional details when required to describe a well-known place from memory in a given perspective (Bisiach & Luzzatti, 1978). As stored representations are critical for navigation in known environments, one would expect these patients to be impaired in finding their way from memory. Indeed, recent studies using a modified version of the Morris' maze have shown that representational neglect patients are unable to perform successful memory-based navigation (Guariglia, Piccardi, Iaria, Nico, & Pizzamiglio, 2005; Nico et al., 2008). The Morris' maze (Morris, 1981) is a well-known paradigm used to investigate these abilities in rats. In the typical maze, rats must find a small, submerged platform in a circular swimming pool. Visual cues are variously manipulated to assess in which conditions the animals can learn the platform's location. The same paradigm has been applied to humans (Bohbot et al., 1998) and recently transferred to hemineglect patients in order to explore the nature of their egocentric perturbation.

The studies by Guariglia et al. (2005) and Nico et al. (2008) required patients with perceptual or representational neglect to locate an acoustically triggered spot in a rectangular room by moving freely on a robotized wheelchair driven by a joystick. Following this initial exploration, patients were required to memorize the spot's location, in order to rapidly retrieve it in the following trials using the shortest path. For this purpose, patients could memorize target's location according to room's shape (Guariglia et al., 2005) or to salient landmarks (Nico et al., 2008). In line with clinical data, perceptual neglect patients showed a pattern of exploration characterized by frequent asymmetrical displacements (i.e. with prevalent rightwards turns), as expected from an impaired egocentric organization of the incoming visual information. Yet, they could successfully retrieve the target location in the delayed attempt, indicating that they maintained a preserved ability to code target's location in a long lasting representation. This was not the case for the representational neglect patients. Despite a normal pattern of exploration, when starting position was changed, and in all delayed trials, they failed in readily retrieving the target and behaved as when performing their first searching attempt, i.e. when target location was unknown. This dissociation

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