

Pointing to places and spaces in a patient with visual form agnosia

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Abstract

Previous investigations of visuospatial abilities in the visual form agnostic patient D.F. suggest that her egocentric sensorimotor processing is intact while her 'allocentric' judgments of spatial position are impaired. The current investigation extends these previous observations by comparing D.F.'s performance at pointing to a set of spatially distributed stimuli, either directly or by 'pantomiming' the responses in an adjacent homologous workspace. The results showed accurate sensorimotor localization when D.F. pointed directly to single targets or to sequences of targets, presumably as she could use egocentric visual coding. In spite of making relatively spared spatial judgments about the arrays, however, D.F. performed quite poorly when copying them and on the pantomimed pointing task. In this latter task good performance presumably depends on an ability to represent both the categorical and coordinate properties of the array (as does copying them), and to translate these into the effector-based coordinates required for accurate action. D.F.'s pantomimed pointing was similar to her copies of target arrays, as in both tasks there was evidence of spared (although somewhat degraded) appreciation of the relative spatial positions of the stimuli. Remarkably, her accuracy in this allocentric task was not worsened by longer pointing sequences. It is possible that D.F.'s degraded performance reflects a relative (though not complete) preservation of categorical coding within the ventral stream, despite a loss of coordinate coding there.

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1. Introduction

Fractionating spatial processes into dichotomous categories is not a new enterprise. For some decades, researchers on hippocampal/temporal lobe memory processing have contrasted egocentric coding (relative to a reference point on the observer) and allocentric spatial memory (relative to objects in the visual environment) in rats (Burgess, Donnett, Jeffery, & O'Keefe, 1997; Save & Poucet, 2000; Winocur, Moscovitch, Fogel, Shayna Rosenbaum, & Sekeres, 2005), non-human primates (Ludwig, Tang, Gohil, & Botero 2004; Matsumura,

Nishijo, Tamura, Eifuku, & Ono, 1999), humans with lesions to medial temporal lobe structures (Holdstock et al., 2000; Incisa della Rocchetta et al., 2004), and neurologically intact people using functional MRI (Parslow et al., 2004). Allocentric codes represent individuated objects or landmarks in a relatively viewpoint-independent coordinate frame, while egocentric schemes emphasize the position of a single target to a reference point on the observer.

In previous publications, we have applied this distinction to visuospatial functions, rather than spatial memory, and suggested that it may go some way towards describing different modes of spatial processing in the dorsal and ventral visual pathways emanating from primary visual cortex. In Milner and Goodale's (1995) functional model of the two cortical visual streams (first clearly identified by Ungerleider & Mishkin, 1982), the dorsal pathway extending from striate to posterior parietal cortex (along with associated subcortical structures such

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as the superior colliculus and cerebellum), is critical for the online visuomotor control of goal-directed action. According to the model, visuospatial perception, however, depends on ventral stream areas within the occipito-temporal cortex (along with associated cortical and subcortical structures, including medial temporal lobe systems crucial for long term storage). In humans (as opposed to monkeys) the inferior parietal cortex (areas 39 and 40), especially of the right hemisphere, may mediate more complex cognitive-spatial manipulations that depend upon inputs from both dorsal and ventral streams (Milner, Dijkerman, & Carey, 1999).

According to the theory, perceptual and visuomotor systems depend upon different classes of spatial information for performing their distinct roles. For example, motor responses like skilled reaching and grasping and the control of eye movements could not function without specific, precise *coordinate* computations that code the location of visual targets relative to some position on the body, such as the hand or the eye (i.e. egocentrically). In contrast, the semi-enduring representations of spatial layout available to the “mind’s eye” in the absence of the setting (such as the layout of a room) require less fine-grained maps of space that can be built upon the relative positions of salient objects. Such cruder but more robust (i.e. survives delays or changes in viewpoint) spatial coding based on allocentric spatial relationships would primarily require categorical rather than coordinate information (Kosslyn, 1987; Kosslyn et al., 1989; Kosslyn, Chabris, Marsolek, & Koenig, 1992). For example, although we may ‘know’ that a bedside table is within arm’s reach of the bed, most of us would be hard pressed to describe the angular position, distance and exact height of the switch of the bedside table lamp relative to the head on the centre of the pillow. And yet when reaching for the switch from the bed, these kinds of exact coordinate computations are precisely what are required. It is assumed that enduring, allocentric spatial representations are also relatively viewpoint-independent, although they can be utilized to generate any number of viewpoint-specific representations off-line (i.e. in a visual image in the mind’s eye, there is always a viewpoint).

Perceptually based categorical representations can last indefinitely, irrespective of the imagined viewpoint, whereas coordinate reporting from memory can be attempted, but is highly inaccurate (Carey, 2004; Goodale & Humphrey, 1998; Intraub, 1997). In our account, if the encoding is driving a visuomotor act, dorsal stream circuits encode targets relative to the observer, and do so in effector-specific codes egocentric that are coordinate-based (such as degrees of visual angle, or absolute distance/direction vectors from the hand or shoulder). Recent functional fMRI evidence supports the idea that egocentric spatial coding, unlike allocentric coding, is restricted to the dorsal stream (Committeri et al., 2004). Perceptual circuits associated with the occipito-temporal ventral stream encode spatial relationships in multi-purpose codes which enjoy considerable flexibility at the cost of the precision of the viewpoint-dependent, short lasting, coordinates that characterize dorsal stream function (Goodale & Humphrey, 1998; Rossetti & Pisella, 2002).

Whether or not these ventral codes are exclusively categorical or allocentric remains unknown. Our investigations of

the role of the ventral stream in such allocentric processing of visual information have focused on a patient with visual form agnosia, D.F., who has been described in great detail elsewhere (Goodale & Milner, 2004; Milner & Goodale, 1995; Milner et al., 1991). D.F. is impaired at perceptual judgments of size shape and orientation, but is relatively intact at colour perception and visuomotor tasks such as reaching and grasping. Her spatial abilities remained largely unstudied until more recently. Murphy, Carey, and Goodale (1998) required D.F. and two age-matched controls to reproduce spatial arrays (defined by coloured tokens which D.F. could individuate) in a separate location adjacent to the model. Successful copying would have depended on processing individual token locations relative to the other tokens on the model, as well as the edges of the workspace of both the model and the copy. D.F. was quite impaired on this task, in spite of unlimited free viewing of the model and unrestricted self-corrections. Nevertheless, she was somewhat sensitive to the categorical spatial structure of the arrays, in that she tended to order tokens correctly in left-to-right and top-to-bottom sequences. In sharp contrast to this crude spatial sensitivity, when required to interact with the target arrays egocentrically (by making aiming movements with her index finger) D.F.’s performance appeared flawless.

In another study, we attempted to assess D.F.’s ability to use allocentric information for the guidance of her grasping movements (Dijkerman, Milner, & Carey, 1998). We examined D.F.’s ability to adjust her grasp to take hold of objects through the two or three holes drilled in them, rather than by grasping them at their edges. In the three-holed case in particular, D.F. was completely insensitive to the orientation of the main thumb–finger axis as well as the spatial separation between thumb, index and middle fingers. D.F., however, did perform better when the discs contained only two holes. She managed to adjust her hand orientation appropriately, although she still remained unable to adjust her grip aperture to the distance between the two holes. We suggested that D.F. was unable to use information about the distance between the two holes for guidance of her grasping movement, even though she could use information about the distance between herself and the holes. This distinction is consistent with the idea that her impairment was one of processing allocentric rather than egocentric space. In a re-examination of this idea, however, McIntosh, Dijkerman, Mon-Williams, and Milner (2004) point out that control subjects report it necessary to exert effortful conscious control to direct three digits towards the three holes, unlike the effortless unconscious nature of everyday object grasping. In their Experiment 2, D.F. was simply required to grasp two rectangular blocks that were mounted on a piece of card with a 3, 4 or 5 cm separation between them. D.F. scaled her maximum grip aperture to the overall width of each object pair, in a manner identical to her grasping of solid objects (McIntosh et al., 2004).

In another series of experiments designed to investigate the role of the dorsal and ventral streams in processing spatial information, Milner and co-workers have contrasted explicit, perceptually driven bisection movements of the gap between two objects, with implicit avoidance of the same objects when reaching between them. They have found that D.F. (and a

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