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The visual guidance of action is not insulated from cognitive interference: A multitasking study on obstacle-avoidance and bisection

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ABSTRACT

The Perception-Action Model (PAM) considers the visual system to be divided into two streams defined by their specific functions, a ventral stream for vision and a dorsal stream for action. In this study we investigated two behavioral paradigms which according to PAM represent the two contrasting functions of the ventral and dorsal stream, namely bisection and obstacle-avoidance, respectively. It is an assumption of PAM that while ventral stream processing is ultimately linked with processing in other cognitive systems, dorsal stream processing is insulated from cognition. Accordingly it can be expected that a secondary task will interfere with bisection but not with obstacle-avoidance. We tested this prediction using a rapid serial visual presentation task as our secondary task (RSVP). Contrary to expectations we found significant interference for both bisection and obstacle-avoidance. Our findings suggest that dorsal-stream processing is not insulated from cognitive processes.

1. Introduction

Bruce Bridgeman and his colleagues were among the first to suggest a subdivision of the visual system into two functionally and anatomically separate subsystems (Bridgeman, Kirch, & Sperling, 1981; Bridgeman, Lewis, Heit, & Nagle, 1979; Ingle, 1968; Schneider, 1967, 1969). This hypothesis was further developed by Ungerleider and Mishkin (1982) who used the terms ventral and dorsal pathways to refer to occipito-temporal aspects and the occipito-parietal aspects of the visual system, respectively and extended by Livingston and Hubel (Livingstone & Hubel, 1988) who linked the ventral/dorsal subdivision to a similar subdivision in the subcortical visual structures between a parvo-cellular system projecting primarily to the ventral part of the visual cortex and a magno-cellular system projecting primarily to the dorsal pathways. The result was a subdivision that went all the way from the retina to the highest levels of the hierarchy of the visual system in the sensory cortex. It was always assumed that the two systems are not just anatomically but also functionally distinct. Ungerleider and Mishkin assumed that the two systems represent and process different attributes of the visual world. The ventral system deals with colour, shape, pattern and other features that help us to identify an object. In contrast the dorsal system deals with position and motion. Broadly speaking the dorsal system helps to determine where in the world an object is located or in the case of motion where this object will be located in the near future. As a short-hand they introduced the terms “what”-system for the ventral and “where”-system for the dorsal pathway. Milner and Goodale (1995) accepted the anatomical characterization of the two systems but suggested a different functional interpretation. They argued that the key distinction is not between visual attributes but between different behavioral functions. The two relevant functions in this case are

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visual perception and visually guided actions, accordingly Milner and Goodale's proposal became to be known as the what/how distinction. Visual perception in this case means the identification of objects and scenes. For this process a representation is useful that emphasizes features that are mostly unaffected by the specific conditions under which a given object or scene is perceived. The type of invariant representations that had been described for areas in the ventral stream seemed perfect for this task. The task of visually guided action in contrast requires that parts of our body are guided towards objects and this demands that features of the sensory input that provide information about the relationship between observer and object are maintained. This relationship between a given behavioral task and its preferred modus of sensory representation is most obvious in the case of an object's position. To recognize an apple as an apple it is not critical whether that apple is to the left or right of me. However, if I wish to grasp the apple I need to know its position relative to my grasping hand.

This example also shows that Milner and Goodale's functional redefinition of the role of the two visual systems was more than a re-branding of the what/where distinction. Crucially while the what/where distinction assigns all processing of spatial information to the dorsal stream, the what/how distinction assumes distinct visual systems for space representation in the ventral and dorsal pathways. The insight that visual cognition ('what') and visuomotor control ('how') use different spatial representations and different brain processes was supported by a seminal study published by Bridgeman and colleagues in 1997 (Bridgeman, Peery, & Anand, 1997). The illusion used in their study was based on a demonstration by Roelofs (1935). Roelofs observed that when a rectangular frame is presented with one edge directly in front of the observer, the edge is not perceived as directly in front of the observer but in fact as shifted in the direction opposite to the rest of the rectangle. Bridgeman (1991) modified this illusion. He asked participants to judge the location of a dot presented with or without a surrounding rectangular frame. It was found that when the dot was not in the center of the frame, the offset between dot-position and midpoint of the frame induced a mislocalization of the dot. This mislocalization is called the induced Roelofs effect. Bridgeman et al. (1997) demonstrated that this illusion fooled our conscious perceptual judgment but did not affect rapid reaching movements. This and other observations (Aglioti, Desouza, & Goodale, 1995) prompted a rush to find other examples where a perceptual illusion left visually guided action unaffected. Many examples were found and thus the evidence for the what/how distinction became ever more impressive (for reviews see: Bruno, 2001; Carey, 2001). Dassonville and Bala (2004) later proposed an alternative hypothesis which stated that the induced Roelofs effect was actually based on a distortion of the observer's midline. Bridgeman then suggested a further way to test this reinterpretation by using a paradigm which he had already developed in his own lab. In a multi-lab collaboration Dassonville, Bridgeman, Kaur Bala, Thiem, and Sampanes (2004) were able to show that their interpretation based on the assumption of a distorted midline explained the findings better than the what/how distinction. While this reinterpretation of Bridgeman's own earlier findings could not seriously undermine the evidence base for the what/how distinction it provided an impetus for many other researchers who argued that the failure of perceptual illusions to influence visually-guided actions reflected methodological problems and did not support theoretical subdivisions (Franz & Gegenfurtner, 2008; Smeets & Brenner, 2006). While this debate is still on-going it can be concluded that the mechanism underlying the what/how dissociations for perceptual illusions is now sufficiently marred in controversy to prevent the use of perceptual illusions as a compelling tool for examining the validity of the what/how distinction or as we will call it from now on the perception-action model/PAM (Kopiske, Bruno, Hesse, Schenk, & Franz, 2017; Kopiske, Bruno, Hesse, Schenk, & Franz, 2016; Whitwell & Goodale, 2017).

At this stage we might ask ourselves whether such a tool is actually needed. Goodale and his colleagues emphasized that it is the evidence from neurological patients which provides the backbone of support for their model (Westwood & Goodale, 2011). How else could one explain why patients with ventral damage fail to perceive aspects of visual objects while still interacting successfully with those very objects and why patients with dorsal damage fail to produce accurate movements towards visual objects despite having normal perceptual abilities? Neuropsychological evidence for the what/how distinction is certainly intriguing but it is hardly unchallenged and more importantly it is subject to a problem that affects many neuropsychological interpretations. Finding preserved function in a patient with brain damage can indicate that the damaged brain structure is not involved in this function, but it does not have to mean this. Conversely, such preserved capacity could also indicate that this function is served by a redundant brain system. If just one component of the system is affected, the loss can be compensated and the function is preserved. Schenk (2010) argued that this latter explanation provides a more plausible account for the neuropsychological evidence that has been marshalled in defense of the what/how distinction (Schenk, 2010). To sum up neuropsychological evidence does not provide unequivocal evidence that the distinction found in the case of brain-damage also applies to the healthy brain. Findings from research on illusions seemed to provide the required evidence. However, the reliability of this evidence has been questioned. This means we need to find alternative ways to test the claim that in healthy brains vision for perception and vision for action is also processed in separate pathways.

Such an alternative was suggested by Singhal, Culham, Chinellato, and Goodale (2007). The PAM suggests that only the ventral stream feeds into and has access to the cognitive system. Accordingly it can be expected that processing in the cognitive stream might interfere and interact with processing in the ventral stream but the same should not be true for the dorsal stream. This can be tested with a dual-task paradigm. Performance in a task assigned by the model to the ventral stream when carried out on its own should be significantly better than performance for the same task when carried out in conjunction with a second, cognitive task. This should not be the case for a task that is assigned to the dorsal stream. To put it differently, we expect significant multitasking costs for ventral tasks but not for dorsal tasks. We know that multitasking costs are widespread and we also know that these costs vary between tasks. Different tasks have different demands and we can expect that different tasks vary in their susceptibility to multitasking interference. If we want to claim with any confidence that the variation in multitasking costs are due to the fact that one task is processed in the ventral stream and the other in the dorsal stream, we need to ensure that the two tasks are well-matched in most respects. Singhal and colleagues achieved this by exploiting an interesting assumption of the PAM. PAM assumes that the dorsal stream has no visual memory (Westwood & Goodale, 2003). Consequently actions that are based on memorized visual information, even if that