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Optic ataxia and the dorsal visual steam re-visited: Impairment in bimanual haptic matching performed without vision

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ABSTRACT

The ‘two visual systems’ account proposed by Milner and Goodale (1992) argued that visual perception and the visual control of action depend upon functionally distinct and anatomically separable brain systems: a ventral stream of visual processing that mediates visual perception (object identification and recognition) and a dorsal stream of visual processing mediating visually guided action. Compelling evidence for this proposal was provided by the neuropsychological studies of brain injured patients, in particular the contrasting pattern of impaired and preserved visual processing abilities of the visual object agnostic patient [DF] and optic ataxic patients who it was argued presented with impaired dorsal stream function. Optic ataxia [OA] has thus become a cornerstone of this ‘two visual system’ account (Pisella et al., 2009). In the current study we re-examine this assumption by investigating how several individuals presenting with OA performed on a bimanual haptic matching task performed without vision, when the bar to be matched was presented haptically or visually. We demonstrate that, unlike neurologically healthy controls who perform the task with high levels of accuracy, all of the optic ataxic patients were unable to perform the task. We interpret this finding as further evidence that the key difficulty experienced by optic ataxic patients across a range of behavioural tasks may be an inability to simultaneously and directly compare two *spatial* representations so as to compute the difference between them.

1. Introduction

In their highly influential articles and books, Milner and Goodale proposed a distinction between a ventral stream of visual processing that mediated visual perception (object identification and recognition) and a dorsal stream of visual processing mediating visually guided action (e.g., Goodale & Milner, 1992; Milner & Goodale, 1992, 1995). This ‘two visual

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systems' account as it has come to be known argued that visual perception and the visual control of action depended upon functionally distinct and anatomically separable brain systems.

This 'two visual systems' proposal has proven to be immensely influential over the last two decades and, while this account was clearly based upon a considered review of a wide range of research findings from both humans and animals, it can be argued that its immediate and popular appeal stemmed from the compelling evidence drawn from neuropsychological studies of brain injured patients, in particular the contrasting pattern of impaired and preserved visual processing abilities of the visual object agnostic patient [DF] and optic ataxic patients. Thus, visual form agnosia has come to be viewed as the classic presentation associated with ventral stream damage whereas optic ataxia [OA] is viewed as the classic presentation following dorsal stream damage and a cornerstone of the two visual system account (Pisella, Sergio, Blangero, Torchin, Vighetto, Rossetti, 2009).

While the two visual systems account proposed by Milner and Goodale can be seen as a useful heuristic, several lines of evidence suggest that there may be cross-talk between the mechanisms responsible for visual perception and those responsible for visually guided action (e.g., Brenner & Smeets, 1996; Jackson & Shaw, 2000) and that OA should not be viewed as an impairment linked solely with dorsal stream damage (e.g., Himmelbach & Karnath, 2005; Jackson, Newport, Mort, Husain, 2005; Jackson, Newport, Mort, Husain, Jackson, Swainson, et al., 2005; Jackson et al., 2009; Pisella, Sergio, Blangero, Torchin, Vighetto, Rossetti, 2009).

OA was first described as a disorder of visually guided reaching movements that cannot be attributed to a basic motor or sensory deficit (Bálint, 1909; Rizzo & Vecera, 2002). The disorder was described initially by Bálint as one of a triad of visuospatial symptoms that can result from bilateral damage to the occipital-parietal cortex in humans (Bálint, 1909) and which has since become known as Bálint–Holmes or Bálint's syndrome (Rizzo & Vecera, 2002). A key aspect of Bálint's view was that misreaching errors occurred as a consequence of disconnection between visual processing areas and motor regions responsible for planning reaching movements. More recent studies have confirmed that optic ataxia can follow unilateral damage to the parietal cortex of either hemisphere; most frequently involving the intraparietal sulcus and superior parietal lobule [SPL] or white matter underlying these areas (Perenin & Vighetto, 1988).

In contrast to the view proposed by Bálint (1909), alternative contemporary accounts of optic ataxia argued that misreaching errors were not an independent, autonomous, symptom within Bálint's syndrome but instead arose as a consequence of impairments in visual perception (e.g., Holmes, 1918). Furthermore, recent studies have demonstrated that optic ataxic patients misreach to extra-foveal targets, irrespective of whether these targets are defined visually or in fact defined proprioceptively in the absence of vision (Blangero et al., 2007; Jackson et al., 2009).

Such observations, and in particular the key finding that optic ataxic patients typically only misreach when reaching to extra-foveal targets, led Jackson and colleagues to propose that reaching to an extra-foveal target may require additional processing steps that are not required when reaching to a foveated target, and that these additional processing steps may necessitate the simultaneous comparison of more than one visual and/or spatial representation (Jackson, Newport, Mort, Husain, 2005; Jackson, Newport, Mort, Husain, Jackson, Swainson, et al., 2005; Jackson et al., 2009). Specifically we argued that for extra-foveal reaching only, to compute a displacement vector in gaze-centred coordinates, it will first be necessary to simultaneously represent and compare the spatial location of the target in gaze-centered coordinates and the starting position of the hand in gaze-centered coordinates (Jackson et al., 2009). Importantly, this comparison may be necessary even where the target or hand location is specified initially in non-visual coordinates. This proposal was tested directly in a recent brain imaging study that hypothesized that the simultaneous representation of multiple spatial locations that must be directly compared with one another will involve increased metabolic costs relative to the case where only a single gaze-dependent location must be represented (Beurze, Toni, Pisella, & Medendorp, 2010). The study confirmed this hypothesis by demonstrating that there were significant increases in brain activity within parietal and premotor areas of cortex for those movements that required the integration of peripheral target and hand positions within a gaze-centered frame. Consistent with such evidence we have proposed that misreaching in optic ataxia may largely arise as a consequence of a limitation in the processing resources needed to simultaneously represent and compare more than one spatial representation (Jackson et al., 2009).

To further examine this issue we utilised a haptic matching task in the current study that we have reported previously (Newport, Rabb, & Jackson, 2002). Within this task participants are presented with a bar in a particular spatial orientation (the reference bar) and are then required to rotate a second bar (the test bar) to match the orientation of the first. To investigate the ability of optic ataxic patients to directly and simultaneously compare two spatial objects in the absence of vision, we conducted this haptic matching task in Experiment 1 as a bimanual matching task. In this case the participant, while wearing a blindfold, felt the orientation of the reference bar on each trial and was then required to rotate the test bar using their right hand to match the felt orientation of the reference bar. In Experiment 2 we varied the task by presenting the reference bar visually so that only one visual object was presented and could be foveated on each trial by the participant. In this case the participant's task was to rotate the unseen test bar using their right to match the orientation of the viewed visual reference bar. The results of these studies clearly demonstrated that whereas healthy controls could perform these matching tasks with a very high degree of accuracy, patients presenting with optic ataxia unable to perform that task.

1.1. *Experiment 1*

This experiment was adapted from the methods and procedures reported previously in Newport et al. (2002).