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Research report

Optic ataxia affects the lower limbs: Evidence from a single case study

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ABSTRACT

Optic ataxia represents a spatial impairment of visually guided reaching following bilateral or unilateral damage to the posterior parietal cortex that is independent of purely motor or visual deficits. Research to date has focused on reaching actions performed with the upper limbs but has neglected to explore whether or not optic ataxia affects the lower limbs, that is, whether it is effector-specific. We asked patient M.H., who suffers from unilateral optic ataxia from left hemispheric damage, and eight age-matched controls, to perform leg movements by stepping down from a wooden block towards a visually presented target. Steps were performed using the left or the right leg, in conditions of central fixation or free viewing. Patient M.H. performed significantly worse than controls. His errors in step accuracy were most pronounced when stepping into the visual periphery (during central fixation), particularly while using the contralesional right foot towards the contralesional right hemispace. This behaviour is consistent with M.H.'s impairments in optic ataxia previously recorded for reaching and grasping actions with the upper limbs. The lesion affecting M.H.'s brain is quite large, encompassing functional areas associated with visuomotor transformations performed with different effectors such as arm and eye (superior parietal-occipital cortex and medial intraparietal sulcus). Our data suggest that optic ataxia is not completely effector-specific, and that neurons encoding visuomotor transformations for both arm and leg are probably both affected by the damage. Our results support the notion that lesions affecting the medial portion of the left posterior parietal cortex similarly affect different effectors (arm and leg) when visually guided actions are directed towards the same contralesional hemispace. In addition they may help explain why patients with optic ataxia have been reported to have difficulties in certain aspects of visually guided locomotion.

1. Introduction

Optic ataxia (OA) is an impairment in visually guided reaching due to a failure to combine visual and motor functions (Balint, 1909; Harvey, 1995). It follows bilateral or unilateral damage to the posterior parietal cortex (PPC) of either hemisphere, commonly involving medial portions of the superior parietal lobule, intraparietal sulcus (IPS), or the underlying white matter (Karnath and Perenin, 2005). Research to date has focused on reaching actions performed with the upper limbs

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but has neglected to explore whether OA affects the lower limbs and therefore whether or not it is effector-specific.

OA patients show distinct impairments in reaching accurately for objects, particularly when presented in the periphery, whilst often maintaining the ability to accurately reach towards foveated objects (Perenin and Vighetto, 1988; Pisella et al., 2009). These impairments are specific to immediate real-time visuomotor guidance; for example, patients fail to quickly adjust on-going actions in response to perturbations of the target (Grea et al., 2002; McIntosh et al., 2011; Pisella et al., 2000), but show improved accuracy when there is a delay between target perception and movement execution (Milner et al., 1999; Rice et al., 2008). This kind of real-time visuomotor processing is believed to be carried out by the dorsal stream within the PPC, which maintains a good representation of the visual periphery (Milner and Goodale, 2006).

It remains unclear, however, whether the deficits presented in OA are effector-specific. In other words, are visually guided actions impaired only when reaching with the upper limbs (as appears so far), or are lower limbs also affected? Deficits in visually guided lower limb movements have been described before in patients with bilateral OA, including difficulties in pointing with the toe (Rondot et al., 1977), and in descending stairs (e.g., Michel and Henaff, 2004), but they have never been addressed using quantitative methods. Addressing this question would further illuminate the more general issue of whether or not visuomotor transformations in the intact PPC are effector-specific. While some evidence indicates the existence of multiple and separate representations associated with arms, hands and eyes in both human and monkeys (Andersen and Buneo, 2002; Cavina-Pratesi et al., 2010b; Connolly et al., 2003; Gallivan et al., 2011; Graziano and Gross, 1998; Prado et al., 2005) others have found evidence for overlapping representations for more than one effector (Colby and Goldberg, 1999; Hinkley et al., 2009; Levy et al., 2007; Riddoch et al., 2001; Snyder et al., 1997).

Current neuroimaging research exploring the role of the PPC in the visuomotor control of the lower limbs offers insight into whether OA may influence other effectors. Heed et al. used functional Magnetic Resonance Imaging (fMRI) while participants were planning goal-directed movements with the right hand, the right foot or their eyes (Heed et al., 2011). Consistent with previous results of overlapping representations for different effectors, results showed that during the programming of hand and foot movements, responses within the PPC were not significantly different. This suggests that the PPC does not have an effector-specific, but rather a function-specific organisation. Interestingly, within the context of action observation, Jastorff et al. (2010) found similar results showing that while activations within the PPC clustered according to the goal of the observed motor act (for example grasping and pulling *vs* pushing away from the body), only premotor cortices clustered according to the effector used to perform the action (mouth, hand and foot).

The current study aimed at establishing whether or not there is a visuomotor deficit affecting the lower limbs by testing a unilateral OA patient, M.H. We measured M.H.'s behaviour when stepping with the foot towards a visual target, and compared his pattern of performance with previous research using the arm and hand to perform reaching actions towards visual targets, to avoid obstacles (Rice et al., 2008), or to grasp objects (Cavina-Pratesi et al., 2010a). If M.H.'s impairments while stepping with the foot are similar to the impairments previously shown for reaching with the hand, then we can argue that his OA is not effector-specific. Given that M.H. shows a very clear and distinctive pattern of OA, whereby a profound reaching deficit is present only when he reaches towards targets in his right visual hemifield while using his right hand, he offers a very useful "experiment of nature" for us to test the similarity of the pattern of any foot reaching deficits he may have to those shown during manual reaching.

2. Methods

2.1. *Participants*

In the present experiment, we tested patient M.H. and eight age-matched controls. M.H. suffered an anoxic episode 16 years prior to current testing. This resulted in bilateral atrophy in posterior parietal and frontal regions, but markedly more pronounced on the left side. MRI scans revealed a large lesion in and surrounding the intraparietal sulcus in the left hemisphere with some extension onto the medial aspect and into the inferior parietal lobule. Subcortical atrophy was located bilaterally in the lentiform nucleus and claustrum, with less extensive damage in the left frontal and frontotemporal regions (see Cavina-Pratesi et al., 2010a; and Rice et al., 2008 for an image and description of the lesion). Although surrounded by regions of atrophy, right and left motor cortices appeared intact. Importantly, the occipital lobes were largely unaffected too. Behaviourally, M.H. suffered from right-sided muscle weakness and raised sensory thresholds (Cavina-Pratesi et al., 2010a). The patient maintained the ability to walk and use both hands, but reported difficulties with everyday living activities, such as dressing, eating with a knife and fork, writing with his right hand, and walking up or down stairs without support. Previous clinical assessment found evidence of right-sided extinction (Kitadono and Humphreys, 2007), unilateral neglect (Humphreys and Heinke, 1998; Snow et al., 2013), and impairments in spatial perception (Riddoch et al., 2004). Symptoms of contralateral optic ataxia were exhibited, which were most pronounced when using his right hand and when reaching for targets in the right hemispace during central fixation.

Eight right-handed (Edinburgh laterality quotient: 91.25) neurologically intact age-matched controls were tested (age range of 50–65 years – mean 56.2 years, six males). All participants were in good health with normal or corrected-to-normal visual acuity.

M.H. was tested at the University of Birmingham and control participants were tested at Durham University. Informed consent was obtained prior to testing. Durham University's Department of Psychology ethics advisory sub-committee approved the project.

2.2. *Apparatus*

Participants stood on a wooden block the height of an average step (39.6 × 30 × 6.5 cm). Along one edge, starting positions for