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Reaching a moveable visual target: Dissociations in brain tumour patients

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ABSTRACT

Damage to the posterior parietal cortex (PPC) can lead to Optic Ataxia (OA), in which patients misreach to peripheral targets. Recent research suggested that the PPC might be involved not only in simple reaching tasks toward peripheral targets, but also in changing the hand movement trajectory in real time if the target moves. The present study investigated whether patients with a lesion arising from operation for prefrontal, premotor or parietal tumours are selectively impaired in three experimental pointing conditions: (i) pointing to peripheral targets, (ii) pointing to fixatable targets, and (iii) pointing to moved targets (on-line movement corrections). The study confirmed the selective importance of the parietal cortex in all three tasks. Surprisingly, given clinical claims about OA, the degree of peripheral reaching errors correlated strongly in parietal patients with that to fixatable targets. However, there was no relation between peripheral reaching errors and the 'shift cost' of making on-line correction to moved targets, and classical double dissociations between the two skills were observed. The findings suggest that deficits in pointing to peripheral and to moved targets reflect two at least partly independent processes.

1. Introduction

It has long been known that damage to the posterior parietal cortex (PPC) can lead to Optic Ataxia (OA) (Bálint, 1909; Ratcliff & Davies-Jones, 1972), a neuropsychological disorder in which patients typically make errors when reaching to peripheral targets. Misreaching errors in OA patients are usually found to be independent of any primary motor, sensory, praxis or attentional deficit (Battaglia-Mayer & Caminiti, 2002; Bálint, 1909; Coulthard, Parton, & Husain, 2006; Perenin & Vighetto, 1988; Ratcliff & Davies-Jones, 1972; Striemer et al., 2009) and are less frequently observed when patients are asked to point to fixatable targets. Ratcliff and Davies-Jones (1972) observed that patients with damage to the posterior cortex significantly misreach to targets located in the visual field controlateral to the lesion, whereas no reaching disorders were observed in patients with anterior lesions. Some years later, Perenin and Vighetto (1988) showed that in addition to the contralateral visual field impairments, patients with a unilateral lesion often make a significantly higher number of misreaching errors when asked to reach to objects with their contralesional (right) hand; this was specifically so for their left parietal patients. These two hemispherical effects in pointing conditions to peripheral targets are called '*visual field effects*' and '*hand effects*', respectively.

As previously mentioned, in contrast to their poor peripheral reaching performance, most OA patients appear clinically intact in reaching for objects presented in central vision (Gréa et al., 2002; Milner, Paulignan, Dijkerman, Michel, & Jeannerod, 1999), although a few cases of foveal OA (misreaching to fixatable targets) coexisting with non-foveal OA (misreaching to peripheral targets) have been observed (Buxbaum & Coslett, 1998; Perenin & Vighetto, 1988; Rondot, de Recondo, & Dumas, 1977; Rossetti, Pisella, & Vighetto, 2003). This apparent dissociation between impairments in peripheral reaching tasks and good reaching performance to fixatable targets could be held to support the existence of two distinct cortical networks subserving foveal and peripheral reaching, as suggested by a brain imaging study of Prado et al. (2005). Using fMRI, the research team found that reaching to fixatable targets activated a network including the medial intraparietal solcus (mIPS) and the caudal part of the dorsal premotor cortex (PMd). By contrast, reaching to peripheral targets activated a more extensive area. In addition to the mIPS and the caudal part of the PMd, it also activated the rostral part of the PMd and the medial part of the parieto-occipital junction (POJ).

One widely accepted claim is that the posterior parietal cortex (PPC) is not just involved in simple reaching toward fixatable and peripheral targets, but is also a key structure for making on-line corrections to the hand movement trajectory during reaching

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(reaching to moved targets) (Archambault, Caminiti, & Battaglia-Mayer, 2009; Desmurget et al., 1999; Gréa et al., 2002; Pisella et al., 2000). Support for this claim comes, for instance, from two major neuropsychological studies on optic ataxic patient IG, who suffered from bilateral posterior parietal lesions. In the pioneering study of Pisella et al. (2000), on most trials, IG was required to point to fixatable targets (*unperturbed condition*). However, on 20% of the trials, the patient was asked to correct the hand trajectory on-line, as the target suddenly moved at the time of movement onset (*perturbed condition*). On perturbed trials, IG produced a very low number of fast 'automatic' movement corrections and a higher percentage of slow corrective movements compared to controls, resulting in increased total movement duration. In contrast, no major abnormal effects were observed in the unperturbed (foveal) condition. Similar findings were also observed in a following study of Gréa et al. (2002), in which IG was required to perform a grasping movement toward fixatable or moved objects. Converging evidence that the PPC has a critical role in reaching to moved targets has been obtained from a transcranial magnetic stimulation (TMS) study in healthy subjects (Desmurget et al., 1999) and from a recent neurophysiological study with monkeys, which provided evidence of the importance of area 5 in the superior parietal lobe (SPL) in making fast on-line corrections of hand trajectories to moved objects (Archambault et al., 2009).

Rossetti et al. (2003) held that the impaired performance of OA patients in tasks requiring on-line movement corrections to moved objects could be explained by a deficit in the process of fast on-line visuomotor control, which is involved in rapid motor correction of the ongoing action. Moreover they held that as a peripheral target provides much less precise visual information, such a visuomotor control process would also be necessary for accurate reaching to peripheral targets. On this hypothesis, one would predict that two types of impairments should be found in association in OA patients, namely (i) when reaching is directed specifically to peripheral targets, and (ii) in experimental conditions requiring on-line movement corrections to moved targets.

A more specific theoretical proposal along these lines was made by Blangero et al. (2008). They suggested that two distinct modules could be involved in reaching. One module, possibly in the POJ, would be required for processing the position of the target in gaze-centred coordinates (spatial map for *target location*) (see also Khan et al., 2005). This system would be needed not only for reaching peripheral but also moved targets. A second system, possibly located in the medial part of the intraparietal sulcus (mIPS), is held to be required for processing the location of the hand (spatial map for *hand location*). Damage to this latter module, but not the former, would cause impairments in reaching to fixatable targets.

Supporting evidence for both the broader and the more specific hypotheses have come from Blangero et al.'s study of optic ataxic patient CF, who was found to be impaired in both reaching towards peripheral and moved targets. Moreover, in both tasks, the same combination of hand and visual field effects was present. By contrast no signs of Optic Ataxia for fixatable targets were found. CF thus would have damage to the first of the two systems.

As far as they are based on neuropsychological studies, the provisional conclusions so far drawn need to be subject to certain standard caveats concerning the methodology of drawing inferences to normal function from neuropsychological studies. The first concerns the use of single case studies. The second concerns the drawing of theoretical conclusions from single dissociations.

Much of our neuropsychological knowledge about reaching impairments in OA patients, and all that has been concerned with on-line movement corrections to moved objects has come from single case studies. It is now widely agreed that while the single case study is very valuable as a source of novel hypotheses, it is not completely reliable as a source of corroboration or falsification of theoretical conclusions concerning the organisation of the cognitive system; at the very least any theoretical conclusions need to be corroborated by evidence from an unselected case series (see Schwartz & Dell, 2010; Shallice & Buiatti, 2011; Shallice & Cooper, 2011; Woollams, Lambon Ralph, Plaut, & Patterson, 2007). This is particularly so when theoretical conclusions depend on the existence of impairments on two different tasks, such as that between impairments in reaching to peripheral and to moved targets. The alternative hypothesis of associated deficits due to anatomical proximity of the underlying systems cannot be ruled out by single case methodology (see Shallice, 1988).

The second methodological issue concerns the argument from single dissociations, which as far as the inference to separable subsystems is concerned, is potentially subject to a task difficulty artifact (Shallice, 1988). Indeed, where peripheral reaching and reaching to fixatable targets are concerned, there is clearly a prima facie possibility that the former may simply be more quantitatively resource demanding than the latter. At the very least, it is necessary to make a comparison between the two not in terms of absolute error, but in terms of the degree of impairment by comparison with controls.

In the present study we investigated whether there was neuropsychological evidence on two issues. The first was whether there were differences in the systems underlying pointing (a) toward peripheral, and (b) to moved targets. Do they dissociate or instead are the two functions strongly correlated, and if so is the same pattern of visual field and hand effects found? The second concerned the analogous relation between the ability to point (a) toward peripheral, and (c) to fixatable targets. In other words, is the pattern of effects found in CF, with respect to these two issues, typical of optic ataxic patients more generally?

As we wish to make comparisons across different measures, the basic analyses were carried out in terms of fixed traditional groups. In order to obtain a sufficiently large case series, tumour patients with lesions located in the prefrontal, premotor and parietal cortices were studied. In addition, we adopted a case series methodology and examined the performance across tasks within each individual parietal patient (see Shallice & Buiatti, 2011). We used the performance of the behaviourally intact group of patients, namely those with prefrontal and premotor lesions, to provide *z*-scores through which we could conservatively determine whether individual patients in the critical parietal group were impaired or intact on the tasks. This is more appropriate than using healthy subjects as the patients were tested 2–6 days post-operation, a situation in which there are psychological and physiological factors that cannot be matched to the healthy controls.

There were two experiments in the study. The first experiment involved a standard Optic Ataxia procedure in which the target was presented in the periphery and the patient must reach to it while maintaining central fixation (*Pointing to peripheral targets*). This allowed us to do a basic check that the parietal and non-parietal groups with this aetiology behaved in a similar fashion to those patients investigated in previously described Optic Ataxia studies, including information on the lesion sites giving rise to Optic Ataxia. To this end *Voxel Lesion–Symptom Mapping* (VLSM, Rorden, Karnath, & Bonilha, 2007) analyses were used. In addition, an aim of the first experiment was to further confirm the findings of Ratcliff and Davies-Jones (1972), namely that Optic Ataxia was not found in the premotor and prefrontal patients. This justified the use of the prefrontal and the premotor groups as controls in what we called 'the *basic group analyses*' and allowed us to treat the parietal group as the critical group to enter 'the *case series analyses*', the primary methodology to be used following Experiment 2 for drawing substantive functional conclusions. In the second experiment, the patients were allowed to move their eyes to fixate the target, but on about 30% of trials the target moved at the onset of the hand