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Anosognosia for hemiplegia as a global deficit in motor awareness: Evidence from the non-paralysed limb

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ABSTRACT

The current study adds to the growing empirical research into the mechanisms underlying unawareness of paralysis following stroke (anosognosia for hemiplegia or AHP) by investigating action awareness for the non-paralysed limb in a single AHP patient. Visual feedback representing patient GG's goal-directed reaching movements was either modified by a computer or left unperturbed. Unlike healthy and brain-damaged controls, GG was unable to detect computer-generated visual perturbations as large as 20°. GG also failed to report awareness of the large on-line corrective movements that he made when compensating (often unsuccessfully) for the visual perturbations. These results suggest that the motor comparators implicated in AHP are functioning, but not at optimum levels. Moreover, because the current findings reveal a deficit in awareness for reaches with the unimpaired limb, it is suggestive of common right hemisphere networks for motor awareness in both limbs and that AHP may be a global deficit in motor awareness as opposed to a specific lack of awareness for a particular motor deficit.

1. Introduction

The past decade has seen remarkable growth in our understanding of the way in which we move and interact with the world around us. This subject is not only central to identifying the mechanisms responsible for our own actions, but provides considerable insight into how we interpret the intentions and desires of other people (Blakemore & Decety, 2001; Blakemore, Winston, & Frith, 2004). These abilities are fundamental to human social interaction.

A driving force behind recent discoveries has been the development of a computational 'forward' or 'comparator' model of motor control, based on well-established engineering principles (Miall & Wolpert, 1996). According to this model, the control and awareness of movement relies on the comparison of information derived from various sources (see Fig. 1).

Provided that we reach our desired state, such comparisons typically occur with limited conscious awareness (Fourneret & Jeannerod, 1998). The comparisons are thought to serve several crucial functions, such as allowing the continual fine-tuning of movements during their planning and execution, detecting when errors in movement occur, and correctly discriminating our own actions (self) from those of another person (other) (Wolpert, 1997). These proposals are supported by the evidence from healthy and brain-injured populations using behavioural experiments (e.g. Blakemore, Frith, & Wolpert, 1999), functional neuroimaging (e.g.m), cortical stimulation/disruption (e.g. Preston & Newport, 2008a) and neuropsychological data (Fotopoulou et al., 2008; Synofzik, Thier, Leube, Schlotterbeck, & Lindner, 2010). However, the exact number, functions, and underlying brain mechanisms of the comparators remains equivocal.

Patients with abnormal motor awareness provide a unique opportunity to cast light on these unresolved issues. In particular, stroke patients who are not aware of severe motor impairments (i.e. patients with anosognosia for hemiplegia, or AHP) can help us to better understand the functional neuroanatomy of motor awareness. Recent forward/comparator model accounts of AHP suggest that the underlying cause of the disorder is a failure to detect discrepancies between patients' predicted and (estimated) actual state (Berti & Pia, 2006; Frith, Blakemore, & Wolpert, 2000). Erroneous claims that the patient can move their paralysed limb are believed to occur because awareness in AHP is constructed entirely from intact predictions of intended movement (Fotopoulou et al., 2008; Jenkinson, Edelstyn, & Ellis, 2009)). Such discrepancies usually trigger the mechanism responsible for conscious awareness and self-correction of the error (Fourneret & Jeannerod, 1998); however, AHP seems to represent an instance of pathological (lesion-induced) unawareness of large discrepancies between the predicted and actual state of the body, such that normal monitoring

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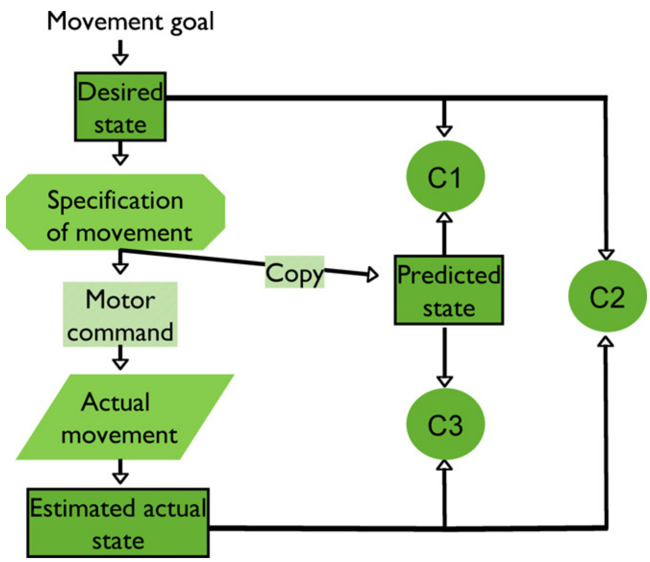

Fig. 1. It is generally accepted that the motor control system contains at least three comparators comparing and responding to differences between the desired and predicted state (C1) the desired and estimated actual state (C2) and the estimated actual and predicted states of the movement effector (C3). Frith's version argues that gross discrepancies in C2 and C3 are ignored or are unavailable whereas Berti and Pia argue that comparator C3 itself is damaged. Crucially, for comparator models of agency, it is discrepancies in comparator C3 that indirectly evokes the evaluation that a movement or event has been externally produced (Synofzik, Vosgerau & Newen, 2008).

is impaired and awareness is deceived (Jenkinson & Fotopoulou, 2010).

Accounts of AHP disagree on the source of this failure to detect errors. Frith et al. (2000) propose impaired input to the comparators responsible for monitoring concordance of the estimated actual state of the limb with the predicted and desired states. Alternatively, Berti and Pia (2006) suggest that the actual vs. predicted states comparator itself is damaged with the main distinction between the two theories being the certainty with which the comparator is held responsible (see Fig. 1 and Jenkinson & Fotopoulou, 2010 for further discussion of this point). However, no study to date has directly assessed the functionality of the comparator(s) in AHP. What is more, the suggestion of an impaired motor comparator may not be so straightforward. The observed specificity of AHP (e.g. differential perceived abilities for the arm and leg within patients; Marcel, Tegner, & Nimmo-Smith, 2004), and apparent independence of verbal/behavioural (Jehkonen, Laihosalo, & Kettunen, 2006) or implicit/explicit awareness (Cocchini, Beschin, Fotopoulou, & Della Sala, 2010) suggests that certain comparators may be impaired in AHP, while others remain intact. Furthermore, reports of AHP following unilateral left-hemisphere lesions (Cocchini, Beschin, Cameron, Fotopoulou, & Della Sala, 2009) argue against explanations that have located the mechanisms responsible for conscious error detection exclusively in the right hemisphere (e.g. Preston & Newport, 2008b; Ramachandran, 1995). More experiments are needed to further investigate these unresolved issues.

Observations in patients with AHP, such as those described above, have been useful in providing insight into the workings of the healthy motor system; however, they present only indirect evidence regarding the possible operation of comparator mechanisms. The current experiment directly explores the functioning of the motor comparator (s) in a case of chronic AHP, primarily using a movement agency task to assess the patient's ability to detect and correct movement errors, by examining the performance using the unimpaired limb. AHP performance was compared with that of a group of hemiplegic patients without anosognosia (patient controls), and young healthy controls. The task involved making self-other judgements about observed reaching movements involving the intact (non-hemiplegic) hand, during which the participants received visual feedback of a visually coincident cursor that was spatially perturbed or unperturbed. The ability to detect discrepancies was assessed by asking the participants to state whether the movement seen was self (unperturbed) or other (perturbed). Furthermore, kinematic data regarding the participants' movement trajectory was used to objectively assess reach accuracy and on-line correction.

If damage to a general right-hemisphere motor comparator is responsible for impaired awareness in AHP, then self-other judgements should be selectively disrupted in the AHP patient regardless of which arm was involved in reaching. That is, if awareness of motor actions for both the left and right hands predominantly involves a right hemisphere network (e.g. Preston & Newport, 2008a, 2008b; Ramachandran, 1995), then damage to this network should also have implications for awareness of movements performed by the non-paralysed limb and should not be restricted to the paralysed contralesional limb for which the patient exhibits anosognosia. Furthermore, selective impairment of the comparator that provides information for high-level monitoring of self-other judgements might spare other low-level comparators responsible for the automatic updating and correction of movement errors, in which case subjective self-other judgements and reach accuracy measures should dissociate. The current study considered both of these measures in order to tease apart the different components of motor awareness.

2. Methods

2.1. Subjects

2.1.1. AHP patient

Patient GG was a 64-year-old right-handed male who suffered an extensive right-hemisphere frontoparietal haemorrhage focused at the level of the lentiform nucleus 1 year prior to testing (Fig. 2). GG's brain damage resulted in unilateral visual neglect and left-sided hemiplegia such that he had no volitional movement in his left arm or left leg (power = 0; Medical Research Council scale). On examination of his intact right arm GG was found to have no significant motor deficit (power = 5; Medical Research Council scale) and, while he was poor at two point discrimination, he appeared to have preserved position sense (for example, he was able, with his eyes closed, to point accurately to tactile targets on both sides of his body and to accurately detect small, passive changes in limb posture). No significant cognitive impairment was identified using the mini mental state examination (MMSE, Folstein, Folstein, & McHugh, 1975). GG also suffered from chronic anosognosia for his left-sided hemiplegia, as demonstrated by frequent spontaneous comments that suggested impaired awareness regarding his injuries. The most striking of these involved aspects of gardening which, given his dense hemiplegia and wheelchair/carer dependence, were clearly beyond his capabilities. For example, GG was noted as saying *"I think I am going to move the lettuces nearer to the house so that we don't have to walk as far to get to them"* and *"This year I am going to build a cold frame for the garden"*. GG also lives in a residential home due to his ongoing hemiplegia, but when asked why he had to live there he reported that it was due to his wife being unwell, although he sometimes referred to the home as a hospital and he now admits that he has had a stroke. In addition to these informal measures, GG's anosognosia was confirmed by formally assessing his awareness (or lack thereof) when asked directly about his injuries (Marcel et al., 2004, see below). GG was also unaware of his visual neglect and neither did he spontaneously mention anything wrong with his vision or attempt to employ strategies on clinical tests for neglect.

2.1.2. Upper limb awareness

Although GG reported some problems with his left hand such as limited movement and pain they were greatly understated. In the verbal assessment of his upper limb paralysis he claimed to have movement in his left arm (in fact, GG had no volitional movement of his left hand) but refused to attempt to point with it claiming that he could not do it *"with any degree of accuracy"*. GG's anosognosia was most evident when asked about his ability to perform actions: when asked to rate on a scale from 0 to 10 his ability to perform actions with, or involving, his left hand (0 = not at all, 10 = very well) he frequently gave scores of 5/10 or greater. For example, GG scored 5/10 for opening a door and lifting up a small object with the left hand only and 10/10 for clapping, saying that he could clap as well now as he could before he was in hospital. Across all of the 14 action questions, GG gave a median response