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Research report

The moving phantom: Motor execution or motor imagery?

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ABSTRACT

Amputees who have a phantom limb often report the ability to move this phantom voluntarily. In the literature, phantom limb movements are generally considered to reflect motor imagery rather than motor execution. The aim of this study was to investigate whether amputees distinguish between executing a movement of the phantom limb and imagining moving the missing limb. We examined the capacity of 19 upper-limb amputees to execute and imagine movements of both their phantom and intact limbs. Their behaviour was compared with that of 18 age-matched normal controls. A global questionnaire-based assessment of imagery ability and timed tests showed that amputees can indeed distinguish between motor execution and motor imagery with the phantom limb, and that the former is associated with activity in stump muscles while the latter is not. Amputation reduced the speed of voluntary movements with the phantom limb but did not change the speed of imagined movements, suggesting that the absence of the limb specifically affects the ability to voluntarily move the phantom but does not change the ability to imagine moving the missing limb. These results suggest that under some conditions, for example amputation, the predicted sensory consequences of a motor command are sufficient to evoke the sensation of voluntary movement. They also suggest that the distinction between imagined and executed movements should be taken into consideration when designing research protocols to investigate the analgesic effects of sensorimotor feedback.

1. Introduction

In the mid 16th century the French surgeon Ambroise Paré provided the first clinical description of the phenomenon in which amputees continue to perceive the presence of their missing limb. It wasn't until over 2 centuries later, however, that the first complete clinical description of the phantom limb was published by the American neurologist Silas Weir Mitchell (see Wade, 2009 for a review). Mitchell wrote that after amputation there is often a continued perception of the

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missing limb and that this phantom limb occupies a distinct body space, and has a particular size, shape, and posture. He also noted that his patients reported that the phantom limb had certain sensory properties like touch and pain, as well as kinaesthetic properties like being able to be moved voluntarily (1882). Despite clearly stating that he was of the opinion that the phantom limb arose from changes in the central and peripheral nervous systems, Mitchell described the phantom as a "sensorial delusion", the result of which was that the majority of physicians considered phantom limbs as a figment of the amputee's imagination, and amputees were therefore referred to mental health practitioners for many years.

Today it is generally accepted that the phantom arises from physiological changes that occur after amputation (Melzack, 1992; Ramachandran and Hirstein, 1998). Despite this, the idea that the phantom is imaginary still lingers. For example, voluntary movements of the missing limb are still described as imaginary movements in the majority of scientific papers (Ersland et al., 1996; Hugdahl et al., 2001; Lotze et al., 2001; Rosen et al., 2001; Roux et al., 2001; Roux et al., 2003; MacIver et al., 2008). The use of this terminology reflects the influence of early psychological theories of the phantom (Wade, 2009), probably persists as a result of the lack of a more descriptive set of terms to describe the phantom, and is reinforced by studies on motor imagery which describe the ability of normal subjects to evoke kinaesthetic sensations without producing any overt movement (e.g., Jeannerod and Decety, 1995). Indeed, since amputees experience kinaesthetic sensations but no movement (because their limb is no longer present) most researchers assume that these sensations fall into the category of motor imagery. This classification implicitly assumes that these sensations arise from the same processes as those involved in motor imagery in normal subjects. One problem with this assumption is that imagined movements in normal subjects do not, by definition, evoke any visible movement or substantial muscle activity (Gandevia et al., 1997; Hashimoto and Rothwell, 1999; Lotze et al., 1999; Lacourse et al., 2005) but see (Guillot et al., 2007; Lebon et al., 2008) for a different opinion. Mitchell noted, however, that voluntary movements of the missing limb were sometimes accompanied by stump movements and substantial activity in stump muscles (Mitchell, 1872), observations that were recently verified using electromyographic recordings (Reilly et al., 2006). Thus, voluntary movements of the missing limb should not necessarily be classified as imagined movements, but might instead be *real movements without an effector*. Indeed, in a recent review Lotze and Halsband state that "amputees generally perceive movement (sic) of the phantom hand as real movements rather than imaginary movements,..." (2006 p. 391). If this is the case then amputees should be able to distinguish between an imagined movement of the missing limb and a voluntarily executed movement of the phantom limb. In both cases there would be no overt movement of the limb (as it is no longer present), but voluntary movements of the phantom would be associated with the sensation that the phantom limb moved whereas imagined movements would not.

Nico et al. (2004) examined the ability of upper-limb amputees to judge the laterality of pictures of hands in various orientations and found that amputation did not affect laterality judgements, suggesting that implicit motor imagery processes are preserved after amputation. In a more recent study, Malouin et al. (2009) examined the impact of lower-limb amputation on explicit motor imagery processes. They found that imagined movements of the amputated limb were less vivid than those of the intact limb, but concluded that explicit motor imagery could still be performed despite the absence of the limb. Our conversations with patients undergoing treatment for phantom limb pain using visuomotor therapy (as described in Giraux and Sirigu, 2003) suggest that explicit motor imagery processes might also be preserved after amputation of the upper-limb; the majority of patients makes a clear distinction between executing and imagining a movement with their missing limb and report that the kinaesthetic sensations evoked in both cases are distinctly different. For example, executed movements of the phantom hand are often slower and of smaller amplitude than those of the intact hand (Gagné et al., 2009), require intense effort, and result in the feeling that the position of the limb has changed in the same way as it would have changed if they had moved their intact limb (Reilly et al., 2006). In contrast, imagined movements require much less effort and the kinaesthetic sensations they evoke are different from those experienced during executed movements. In particular, imagined movements do not produce the sensation that the limb's position has changed. Furthermore, while amputees have difficulty moving their phantom limb voluntarily, our clinical experience (unpublished observations) suggests that their ability to imagine moving the missing limb is preserved.

There are no reports in the literature directly comparing the ability of amputees to both execute and imagine a movement with their missing limb. The aim of the present study was to investigate whether amputees can indeed distinguish between executing a movement of the phantom limb and imagining moving the missing limb. We hypothesised that amputees would be capable of performing imagery and execution with the phantom limb, with substantial stump muscle activity during execution and none during imagination. We further hypothesised that the absence of the limb would not perturb motor imagery processes but would reduce the speed of motor execution with the phantom.

2. Methods

2.1. *Subjects*

Nineteen upper-limb amputees were recruited from the outpatient clinic of our institution (4 females and 15 males; mean age 37.2 years, SD 14.1). On average, the accident occurred 9 years and 10 months before testing (range: 5 months–39 years). The Edinburgh Handedness Inventory (EHI) revealed that 18/19 amputees were right hand dominant prior to the amputation. Eighteen age-matched healthy right-handed volunteers (8 females and 10 males; mean age 37.9 years, SD 18.9) were recruited as controls. Neither amputees nor controls had suffered a brain lesion or had a history of neurological or psychiatric illness. The nature of the experimental procedures was explained to all subjects who gave their written informed consent prior to participating in the