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Dissociating body representations in healthy individuals: Differential effects of a kinaesthetic illusion on perception and action

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Abstract

Evidence from neuropsychological patients suggests that multiple body representations exist. The most common dissociation is between body schema to guide limb movements, and body image used to make perceptual judgements. In the current study we employed a kinaesthetic illusion in two experiments to dissociate body representations in healthy individuals. Tendon vibration creates an illusory lengthening of the muscle and an illusive displacement of the limb. In Experiment 1 two conditions were used. In the 'direct' condition the biceps of the dominant right arm of blindfolded participants was vibrated, creating illusory elbow extension. In the 'indirect' condition the right knee was held with the vibrated right arm, creating illusive lowering of the leg and knee. In both conditions, subjects performed with the non-vibrated arm a reaching as well as a matching response, theorized to be based on the body schema and body image, respectively. Results showed that the illusion was significantly larger for the matching as compared to the reaching response, with the most pronounced difference observed in the direct condition. In Experiment 2 reaching and matching without vibration and a passive matching response were implemented in the direct condition. The same differential effect of the illusion was found. Results further showed that passive and active matching were statistically similar but significantly different from the reaching response. In conclusion, these findings suggest that the effect of the kinaesthetic illusion on reaching and matching differed, consistent with the idea of separate underlying body representations for both responses.

Keywords: Body image; Body schema; Perception; Action

1. Introduction

For almost all motor behaviour we rely on internal representations of the current spatial configuration of our body. These internal body representations enable us to guide limb movements and to make perceptual judgements about the location of different body parts with respect to each other. Disruption of body representations can result in a variety of disorders, including autotopagnosia (Buxbaum & Coslett, 2001) and phantom limb phenomena (Ramachandran, 1998).

There is now a growing body of evidence suggesting that multiple body representations exist (Paillard, 1999; Schwartz, Moran, & Reina, 2004; Schwoebel & Coslett, 2005). Neuropsychological studies have provided evidence for a dissociation between at least two body representations; one which is used during motor action and one underlying perceptual judgement (Gallagher & Cole, 1995; Graziano & Botvinick, 1999; Paillard, 1991). This dissociation is largely based on neurological patients with numbsense who are unable to perceive proprioceptive and tactile stimuli, but are nevertheless able to point to these targets (Paillard, 1999; Rossetti, Rode & Boisson, 1995, 2001), and patients with autotopagnosia who are impaired in localizing perceptually different body parts, but remain able to guide their actions (Buxbaum & Coslett, 2001).

The current most commonly used classification between different body representations is that of body schema and body image. Although there is no consensus among researchers of their definitions, body schema is generally regarded as an unconscious, bottom-up, dynamic representation, relying on proprioceptive information from the muscles, joints and skin. The body schema is thought to be used to govern posture and motor actions. The body image, on the other hand, is considered to be a more conscious, top down, cognitive representation, incorporating semantic knowledge of the body, and mostly used to make perceptual judgements (Gallagher, 1986; Head & Holmes, 1911–1912; Paillard, 1999).

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The idea of different representations underlying perceptual judgement and guiding action is not new and has previously been suggested for the visual system (Jeannerod & Rossetti, 1993; Milner & Goodale, 1995). Visual illusions have been used to dissociate between automatic, accurate calibration required for actions and conscious visual perception for perceptual judgements in healthy subjects (Aglioti, DeSouza & Goodale, 1995; Haffenden & Goodale, 2000; Westwood & Goodale, 2003) (although this is not undisputed, see for example: Dassonville & Bala, 2004; Smeets, Brenner, de Grave, & Cuijpers, 2002).

Considering the growing body of evidence from neuropsychological patients and in parallel with the application of illusions in the visual system, we reasoned that one possible way to dissociate between different body representations in healthy individuals might be to evoke a kinaesthetic illusion which affects both representations differently. One well known illusion involves tendon vibration. Vibration of ∼75 Hz on the sinew of a limb causes an illusory lengthening of the muscle, creating an illusory movement and (eventually) displacement of the limb (Cordo, Gurfinkel, Brumagne, & Flores-Vieira, 2005; Eklund, 1972; Goodwin, McCloskey & Matthews, 1972). The muscle spindles excited by the vibration signals to the brain that the muscle is stretched and thus the limb must have moved, while it actually has remained stable. Although a considerable number of studies have assessed different aspects of this illusion, including the involved neural correlates (Cordo et al., 2005; de Vignemont, Ehrsson & Haggard, 2005; Naito & Ehrsson, 2001; Naito, Ehrsson, Geyer, Zilles, & Roland, 1999), it has, to our best knowledge, not yet been used to dissociate action and perception based body representations in healthy individuals.

In the present study vibration of the biceps brachii tendon of the dominant right arm of healthy, blindfolded subjects is used to induce an illusory displacement of the forearm. Participants were required to make a reaching as well as a matching response. The matching response consisted of mirroring the position of the unstimulated arm to the perceived location of the stimulated arm. For the reaching response, subjects had to point with their left index finger to the felt location of the index fingertip of the stimulated right arm. Previous research has shown that the illusion can be transferred to another limb or body part causing a distortion of body size (de Vignemont et al., 2005; Lackner, 1988). Therefore, we also tested the effect of the illusion on both responses in an indirect condition wherein the ipsilateral knee was held with the vibrated arm, causing a transferred 'indirect' illusion of lowering of the upper leg and knee.

The idea is that within a body representation all proprioceptive information together with the knowledge we have about our body is used to minimize uncertainty about the body's spatial organisation. During the vibrotactile illusion, however, the central nervous system receives conflicting information about the movement and location of the stimulated limb, since only one tendon provides information that it is stretched while information from the joint, other tendons and the skin suggests that it has remained stable.

An important prediction of the supposition of two different body representations is that both may be differentially influenced by the illusion, since one is only based on proprioceptive information while the other also incorporates stored experiences and semantic knowledge of our body.

The body schema, on the one hand, is thought to be based solely on (conflicting) proprioceptive information. This representation might weight the proprioceptive input to minimize uncertainty about the current spatial position of the forearm, as has been suggested by optimal integration and computational models of sensory integration and action (van Beers, Sittig & Gon, 1999; van Beers, Wolpert & Haggard, 2002; Wolpert, 1997; Wolpert, Ghahramani & Jordan, 1995). Since there might be more proprioceptive input suggesting that the arm is stationary (signals from triceps, elbow joint, skin), instead of moving (signals from the biceps), the reaching movement might be more accurate towards the actual stationary arm position, rather than towards the illusory displacement.

The body image, on the other hand, is considered to be a more top down, higher order, cognitively shaped body representation (Paillard, 1999; Tsakiris & Haggard, 2005). As a consequence it might use stored knowledge from experience that stretching of the biceps is caused by lowering of the forearm, to override the conflicting information and in this way minimize uncertainty. Consequently, the body image may indeed incorporate the illusory displacement of the forearm, and the matching response may thus be lowered/dropped compared to the actual limb position. Accordingly, our first hypothesis is that the body image based matching response will be more influenced by the illusion than the body schema based reaching response. Our second hypothesis concerns the effect that transfer of the illusion to another body part might have on this dissociation. We reasoned that in the indirect condition there is even more proprioceptive input suggesting that the limb has remained stationary (since, there is no direct proprioceptive input from the knee itself suggesting that it has moved). As a consequence of this augmentation of conflict within the proprioceptive signal, we predict that the incorporation of the illusion will be less apparent for both representations in the indirect compared to the direct condition.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Twenty-five right-handed healthy subjects (21 female and 4 male, with overall group mean age 20.8 years, S.D. 1.9) participated in the study. All participants gave their informed consent prior to the experiment. Right-handedness was assessed with the Dutch handedness questionnaire (Van Strien, 1992). The inclusion criterion was an overall score of seven or more, indicating a strong preference for the right hand in daily activities. Subjects were selected without consideration of tendon vibration sensitivity. Finally, the participants were unaware of the rationale of the experiment and received a small fee for their participation. The study was in accordance with the ethical advisory committee of the Faculty of Social Sciences of the Utrecht University, the Netherlands, and with the declaration of Helsinki (1964).

2.1.2. Apparatus

The apparatus to induce the illusion was a vibration device (Brual & Kjaer type 4809) which was modified with an adapted extension containing a counterweight to keep the stimulation device steady on the right biceps brachii tendon