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The role of agency for perceived ownership in the virtual hand illusion

Ke Ma, Bernhard Hommel *

Leiden University, Institute for Psychological Research & Leiden Institute for Brain and Cognition, Leiden, The Netherlands

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ABSTRACT

The rubber hand illusion shows that people can perceive artificial effectors as part of their own body under suitable conditions, and the virtual hand illusion shows the same for virtual effectors. In this study, we compared a virtual version of the rubber-hand setup with a virtual-hand setup, and manipulated the synchrony between stimulation or movement of a virtual "effector" and stimulation or movement of people's own hand, the similarity between virtual effector and people's own hand, and the degree of agency (the degree to which the virtual effector could be controlled by people's own movements). Synchrony-induced ownership illusion was strongly affected by agency but not similarity, which is inconsistent with top-down modulation approaches but consistent with bottom-up approaches to ownership. However, both agency and similarity induce a general bias towards perceiving an object as part of one's body, suggesting that ownership judgments integrate various sources of information.

1. Introduction

How do we come to experience ourselves as independent individuals? According to Jeannerod (2003), self-perception relies on two ingredients: experiencing oneself as the owner of one's body (ownership) and experiencing oneself as the agent of one's actions (authorship or agency). Recent research on body ownership has made use of the rubber hand illusion (RHI). In the classical RHI study design, a person's real hand is hidden from his or her view and a static rubber hand is being placed in front of his or her—often in close distance to the real hand. Then the real and the rubber hand are synchronously or asynchronously stroked or otherwise stimulated (e.g., Botvinick & Cohen, 1998; Ehrsson, Spence, & Passingham, 2004; Tsakiris, 2010; Tsakiris & Haggard, 2005). After receiving synchronous (but not asynchronous) stimulation for several minutes or even shorter time periods (Kalckert & Ehrsson, 2014; Tsakiris, Prabhu, & Haggard, 2006), participants start to feel the stimulation at the location of the rubber hand, rather than on their real hand, and report perceiving the rubber hand as their own hand (sense of ownership) and as more controllable (sense of agency) (Kalckert & Ehrsson, 2014). More recently, various researchers were able to replicate the RHI in virtual environments by replacing the rubber hand by a virtual hand—which often can be controlled by the participants by means of a data glove (the virtual hand illusion or VHI; see Ma & Hommel, 2013, 2015; Sanchez-Vives, Spanlang, Frisoli, Bergamasco, & Slater, 2010; Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2008). The main question the present study aimed to address was whether the RHI and the VHI are the same. While this might be considered a rather methodological question, we think it relates to two major theoretical issues that are dominating research on

* Corresponding author at: Leiden University, Institute for Psychological Research, Cognitive Psychology Unit, Wassenaarseweg 52, 2333 AK Leiden, The Netherlands.

E-mail address: hommel@fsw.leidenuniv.nl (B. Hommel).

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body ownership: the relevance of bottom-up and top-down factors in creating ownership illusions, like the RHI and the VHI, and the relationship between ownership and agency.

1.1. Bottom-up and top-down factors

With regard to the first question, one can distinguish two general approaches, one assuming that bottom-up information (such as created by synchronous stroking) is sufficient to create the illusion of body ownership and another that assumes an interaction between bottom-up information and top-down-operating schemata representing body characteristics. Botvinick and Cohen (1998) and Armel and Ramachandran (2003) proposed versions of a bottom-up account, that assumes that the processing of spatially and temporally matching multisensory information, such as coming from the seen stroking of a rubber hand and the felt stroking of one's own hand, is sufficient to perceive an object as part of one's body. In support of that assumption, Armel and Ramachandran (2003) provided some preliminary evidence that participants can perceive ownership for a wooden table and feel nervous when they see the table being "hurt"—even though the experimental design of this study was likely to invite transfer effects. Later research revealed a number of further constraints that seem to limit the impact of bottom-up information, such as the anatomical and postural properties of the artificial hand in relation to one's own hand (De Vignemont, 2011; Haans, IJsselsteijn, & de Kort, 2008; Lloyd, 2007; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2009; Makin, Holmes, & Ehrsson, 2008; Pavani & Zampini, 2007; Tsakiris, 2010; Tsakiris, Carpenter, James, & Fotopoulou, 2010; Tsakiris & Haggard, 2005; Tsakiris, Schütz-Bosbach, & Gallagher, 2007).

These and other observations have been taken to imply contributions of a relatively permanent body representation that gates the processing of bottom-up information. For instance, Makin et al. (2008; Ehrsson et al., 2004; Maravita, Spence, & Driver, 2003) have suggested that ownership illusions can only be created if the rubber hand is placed in an anatomically and postural plausible (i.e., expected, given the current position of one's real hand) position, and if the synchronous stimulation is presented near to the artificial hand. Another, even more top-down-heavy model was proposed by Tsakiris (2010). He assumes that people possess a relatively permanent model of their own body, which contains information about both the structural aspects of the body in general and about the current states and effector positions. Bottom-up information will consistently be checked for a match with information from the body model and censored in the case of a mismatch (Costantini & Haggard, 2007; Haans et al., 2008; Lloyd, 2007; Tsakiris, 2010; Tsakiris & Haggard, 2005; Tsakiris et al., 2007, 2010). According to this approach, the resemblance between the visible artificial effector and the real hand/body part is a predominant factor for RHI illusions (Tsakiris et al., 2010): Artificial effectors are perceived as body parts only if they are sufficiently similar to the content of the internal body model, which in turn represents the person's actual body. However, in contrast to this prediction, the similarity between real and artificial effectors failed to play a decisive role in several studies. For example, using a rubber hand with a skin color or roughness different from the participant's real hand did not reduce the strength of the ownership illusion (Farmer, Tajadura-Jiménez, & Tsakiris, 2012; Longo et al., 2009; Schütz-Bosbach, Tausche, & Weiss, 2009; White, Davies, Halleen, & Davies, 2010) and even balloons and geometric objects (Ma & Hommel, 2015) or empty spaces (i.e., objects bearing no similarity to people's real effectors) can be incorporated by healthy participants (Guterstam, Gentile, & Ehrsson, 2013). These findings do not support the idea that artificial effectors are accepted as body parts only if they are sufficiently similar to components of internally stored body representations.

1.2. Ownership and agency

While earlier studies tended to consider body ownership and agency as separate components of the self (see Gallagher, 2000; Jeannerod, 2003; Tsakiris et al., 2007), there is increasing evidence that these two factors interact in producing ownership illusions (Burin et al., 2015; Dummer, Picot-Annand, Neal, & Moore, 2009; Kokkinara & Slater, 2014; Ma & Hommel, 2013, 2015; Tsakiris et al., 2006, 2007). However, the relationship between sense of ownership and sense of agency is still not clear: Some studies showed greater sense of illusory ownership with greater sense of agency, some studies showed the opposite relationship between the two senses, and some studies showed no correlation at all.

For example, Burin et al. (2015) found that patients with left upper limb hemiplegia display stronger illusory effects than healthy participants when the affected hand is stimulated but no effects when the unaffected hand is stimulated, and concluded that active movement plays a role for body ownership maintenance. Along the same lines, Kokkinara and Slater (2014) observed higher ownership for a virtual leg in active-movement than visuotactile-stimulation conditions. Caspar et al. (2014) also report a positive correlation between agency and ownership ratings. However, Walsh, Moseley, Taylor, and Gandevia (2011) showed that ratings for passive-stimulation conditions were higher than for active-movement conditions and Dummer et al. (2009) found more pronounced ownership illusions for visuotactile stimulation than for active and passive movement conditions. Lastly, Riemer, Kleinböhl, Hölzl, and Trojan (2013) report equally strong subjective ratings for active-movements and visuotactile-stimulated conditions and both Tsakiris et al. (2006) and Kalckert and Ehrsson (2012, 2014) found no difference in ownership ratings or proprioceptive drift between three conditions that differed in activity. To add to the confusion, Braun, Thorne, Hildebrandt, and Debener (2014) found some associations and some double-dissociations between sense of agency and sense of ownership.

What might be the reason for these confusing, seemingly inconsistent findings? We suggest that terminological confusion may be the main culprit. As discussed elsewhere (Hommel, in press), objective ownership and agency is often confused with the subjective experience of ownership and agency, commonly called the sense of ownership and the sense of agency,