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The disappearing limb trick and the role of sensory suggestibility in illusion experience

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ABSTRACT

Body ownership (the feeling that my body belongs to me) can be easily perturbed in healthy individuals by inducing bodily illusions. For example, dis-integrating vision, touch, and proprioception can produce the feeling that your limb is 'lost', such as in "the disappearing hand trick" (DHT). Following this illusion, participants report that the hand feels as though it is no longer part of the body, that it does not belong to them anymore, and that they do not know its location. However, it remains unknown whether this illusion can also be applied to the feet. Lower body ownership is disturbed in some populations, such as in Body Integrity Identity Disorder (BIID), where people have a longstanding desire to paralyze or amputate a (disowned) part of their body (i.e. usually the legs), thus exploring the efficacy and utility of lower body illusions might be useful for populations like such. In the current study, we induced the disappearing hand and foot trick in two groups of healthy adults. As the illusion crucially relies on illusory sensory feedback, we also explored if one's level of sensory suggestibility influenced the experience of the illusion. Questionnaire data showed that the DHT can be applied to the feet, as there was no difference in experience between those who experienced the illusion for the hands and those who experienced the illusion for the feet. Moreover, one's level of sensory suggestibility correlated positively with the experience of illusory sensations (like warmth, numbness, or the presence of an extra limb) following the illusion. We discuss the implications of bodily illusions in clinical populations and emphasize the critical role that sensory signals (even illusory) play in creating the bodily experience.

1. Introduction

Intuitively, we feel that our body is a part of us and belongs to us. This "special perceptual status of one's own body, which makes bodily sensations seem unique to oneself" (Tsakiris, 2010)" is known as body ownership. Many investigations have focused on uncovering the underlying mechanisms that contribute to this feeling that the body is "my body" (Apps and Tsakiris, 2014; Limanowski and Blankenburg, 2015; Longo et al., 2008; Petkova, 2011; Tsakiris, 2010; Tsakiris et al., 2007) and have revealed that the integration of multisensory signals plays a critical role. One elegant method to investigate body ownership (or the process of embodying a body part) in healthy individuals is to induce the illusion of owning a foreign limb (e.g. via The Rubber Hand Illusion (RHI): Botvinick and Cohen, 1998). Watching a fake rubber hand being stroked synchronously with one's real (unseen) hand induces a relocation of the sensed feeling of touch and position of one's own hand towards the seen rubber hand, resulting in a feeling of ownership over the rubber hand (Botvinick and Cohen, 1998). This suggests that the mis- and subsequently re- alignment of vision, touch, and proprioception (albeit mis-localized) are necessary for manipulating body ownership in healthy participants (Tsakiris et al., 2007). However, in clinical populations, body ownership issues often present as *dis*ownership and *un*-awareness, or an overall sense of *loss*, over of one's own body part (rather than ownership over another limb (but see supernumerary phantom limb syndrome, e.g. Bourlon et al. (2017)), such as in Asomatognosia (specifically Somatoparaphrenia) or Body Integrity Identity Disorder (BIID). Asomatognosia (including Somatoparaphrenia) usually manifests following right-hemisphere brain damage (e.g. stroke; Vallar and Ronchi, 2009) involving the insula (e.g. Cereda et al., 2002) and the white matter around the basal ganglia (Moro et al., 2016). Asomatognosia refers generally to the loss of awareness over part of the body, whereas Somatoparaphrenia is a subtype of this and refers more specifically to loss of ownership over part the body, usually the arm (Feinberg et al., 2010; Jenkinson et al., 2018). More specifically, in Somatoparaphrenia, this loss of ownership is often accompanied with delusional beliefs about who the arm belongs to (e.g. the nurse, a friend). Somatosensory deficits are also sometimes present (Vallar and Ronchi, 2009). Somatoparaphrenia usually spontaneously resolves

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itself, or symptoms can be reduced through the use of mirror therapy (Fotopoulou et al., 2011; Jenkinson et al., 2013). BIID, on the other hand, is a rare condition wherein individuals experience a mismatch between the mental and physical boundaries of the body and thus desire amputation or paralysis of a healthy limb (usually the leg(s); Blom et al., 2012). Individuals with the amputation-variant experience a sense of disownership over the affected limb(s). In contrast to Asomatognosia or Somatoparaphrenia, BIID manifests before adolescence, is not a product of any apparent brain damage, is not accompanied with any delusional beliefs about the disowned limb or somatosensory deficits, and currently cannot be effectively (or safely) treated (Blom et al., 2016, 2012; Brugger et al., 2016). We also know that there are structural and functional alterations of brain areas that contribute to creating a coherent representation of the body, including within the network of body ownership in individuals with BIID (Hänggi et al., 2017; Hilti et al., 2013; McGeoch et al., 2011; van Dijk et al., 2013).

Thus, another way to investigate body ownership might be to diminish it. One can experimentally mimic this loss of awareness and ownership over a body part by instead *dis*-integrating vision, touch, and proprioception via an intriguing illusion called the Disappearing Hand Trick (Newport and Gilpin, 2011). While hovering the hands above a tabletop surface (inside of the MIRAGE multisensory illusion box), participants enjoy a real-time video of their hands, that through a covert process of sensory adaptation and disintegration, visually appear to be closer together than they physically are. When the image of the hand is faded out and the participant is asked to reach for it, it is not where he (visually) expects it to be. Individuals report that from this experience, the hand feels as though it is no longer part of the body (nor that it belongs to them), that it feels cooler than normal, and that they do not know its location. These components are critically linked to the feeling of body ownership and partly mimic the feelings associated with body ownership disorders. Modified versions of the illusion have recently been employed by others (e.g. Abdulkarim and Ehrsson, 2018; Bellan et al., 2017, 2015). For instance, Bellan et al. (2015) investigated how vision and proprioception discretely contribute to the overall loss of location of the hand during the illusion. In their study, the image of the hand was also faded out, but participants were not asked to reach for it. Instead, they had to make verbal judgements about its position over the following three minutes while remaining completely still. Initially, participants relied on the last seen visual location of their hand, but over the three minutes, the reliance shifted proprioception (i.e. felt position) leading to more accurate judgements of hand location. Recently, Bellan et al. (2017) further explored the underlying spatial and sensory-related mechanisms of this procedure, and found that participants were more accurate at making judgments about the hand's location if the participants first made a reach for the disappeared hand and realized that it was not actually there. However, they revealed that this accelerated increase in accuracy was also achieved by simply reaching for a coin, rather than the hand, on that side of space. The recalibration of sensory and motor information towards the body part's actual position that occurs after engaging the sensorimotor system, even when prior knowledge about the part's position is not (dis)confirmed, outlines the critical role that this system plays in updating one's awareness of the body in space. This process of sensorimotor recalibration might also be important when reflecting on populations with body ownership disorders. A slower (or absent) recalibration period perhaps contributes to the emergence of body ownership disturbances in individuals with body ownership disorders. Overall, these studies, like Newport and Gilpin's, reveal the delicate, but complex, interplay between vision, proprioception, and touch (and the timing of integration for such senses) for overall bodily awareness. The disappearing hand trick illusion, like the RHI, relies on a mismatch of vision (removed), proprioception (realigned) and touch (absent), but instead leads to a feeling of 'loss' (Newport and Gilpin, 2011). Moreover, it reinforces the suggestion that changes in sensory perception are necessary to manipulate body ownership (and awareness) in healthy participants.

But are the multisensory processes that contribute to body ownership of the hand, and the underlying representations of the hands, different from other parts of the body, like the feet? Indeed, several investigations have focused on the neural representation of the hands (e.g. Martuzzi et al., 2014; Overduin and Servos, 2004; Sanchez-Panchuelo et al., 2010; Stringer et al., 2014), of the feet and overall lower limbs (Akselrod et al., 2017; Bao et al., 2012; Dietrich et al., 2017; Meier et al., 2016), or of the hands *and* feet (e.g. Dall'Orso et al., 2018; Ehrsson et al., 2003, 2000; Rijntjes et al., 1999). The representation of the hand and foot, while similar in the overall degree of functional activation in response to touch/movement, show several differences in structure. For instance, the representation of the hand in the primary motor and sensory cortices is larger (i.e. takes up more cortical space) than the representation of the foot (Penfield and Boldrey, 1937). In turn, the hands are more tactually sensitive than the feet (Weinstein, 1968). Moreover, the location of these representations is different: the hand representation is located laterally along the sensory and motor cortical strips, adjacent to the representation of the face, while the leg/foot representation are located more medially, adjacent to the representation of the genitals (Catani, 2017; Penfield and Boldrey, 1937). In line with this, activation of primary motor areas during mental imagery of finger and toe movements reflect this pattern of organization (Ehrsson et al., 2003). The hand and foot areas are also functionally connected in the brain. For instance, Kato and Kanosue (2017) showed that simply imagining the contraction of one's foot muscles elicited a motor evoked response of the hand muscles, highlighting the intimate corticospinal connection between the representations. Both hand and foot representations also show cortical reorganization after an amputation, but people with an upper limb amputation are more likely to experience phantom limb pain than those with lower limb amputation (Davidson et al., 2010). This could be related to the overall differences in the size of cortical space that needs to be compensated for in the upper versus lower limbs. So overall, while there are few studies directly comparing the neural representation of the hands are feet, their overall representations seem to play distinct but overlapping roles in the human sensorimotor system.

In terms of body ownership, investigations comparing the neural processes of upper versus lower body ownership are lacking. Most investigations utilizing body ownership illusions have examined the upper (Abdulkarim and Ehrsson, 2016; Botvinick and Cohen, 1998; Folegatti et al., 2009; Marotta et al., 2016; Newport and Gilpin, 2011; Ocklenburg et al., 2011; Smit et al., 2017) or full (Ehrsson, 2007; Keizer et al., 2016; Lenggenhager et al., 2007; Maselli and Slater, 2014) body, while few investigations have focused on the lower limbs (Crea et al., 2015; Flögel et al., 2015; Lenggenhager et al., 2015; Pozeg et al., 2015). Of the few, Pozeg et al. (2015) revealed that ownership over virtual legs is easily induced through multisensory stimulation, and Flögel et al., (2015) showed that the rubber hand illusion can be transferred to the foot, and is experienced to the same extent as the rubber hand illusion. This is likely due to an overlapping ownership system governing the whole body. For example, activity of the premotor cortex (PMC) is associated with ownership over the rubber hand during the rubber hand illusion (Ehrsson et al., 2004). Clinical reports, like that of Arzy et al. (2006) describe a woman with ventral PMC damage who felt like her arm has 'disappeared' also support the role of the PMC in overall feelings of ownership. While studies on the neural underpinnings of lower body illusions are lacking, evidence from individuals who lack ownership over their legs (i.e. people with BIID) show reduced activity in the PMC in response to tactile stimulation on the disowned limb (van Dijk et al., 2013). Parietal areas are also critical for the feeling of body ownership (Brozzoli et al., 2012; Grivaz et al., 2017; Tsakiris et al., 2007). For instance, repetitive transcranial magnetic stimulation over the inferior parietal lobule decreases the strength of the RHI, as revealed through a reduction in the perceived proprioceptive drift of the real hand towards the rubber hand following the illusion (but not through the subjective questionnaire ratings; Kammers et al., 2009).