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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).

Further evidence comes from a report by Smit et al. (2018) who describe and examine a patient who, following a tumor resection in the posterior parietal areas, reported full body ownership complaints. Again, drawing from the example of individuals with lower-limb BIID, McGeoch et al. (2011) revealed an absence of activity in areas of the parietal cortex (specifically the superior parietal lobule) upon touching the disowned limb in people with BIID. Therefore, it is likely that a similar system (based on the integration of several sources of sensory information) mediates feelings of ownership over both the hands and the feet. The similarities in the networks governing hand and foot ownership, and also their corresponding representations, therefore suggest that the experience of other upper body illusions, besides the rubber hand illusion, should also be transferable to the feet.

Therefore, like the rubber hand (or foot) illusion, is it possible that the disappearing hand trick (DHT) can also be applied to the foot? The illusions are similar in some ways: both rely on visual (and touch) capture, and lead to the mis-localization of limb position. But in the RHI, limb posture remains unchanged (but see Abdulkarim and Ehrsson (2016)), while in the DHT (unbeknownst to the participant) limb posture slowly changes. Moreover, in the DHT, the limb is experienced as ‘no longer there’ once this mis-location is realized (but it remains a debate whether the real hand is ‘no longer there’ for the participant in the RHI, e.g. de Haan et al., 2017; de Vignemont, 2010). Van Elk and colleagues (Van Elk et al., 2013) showed that while visuo-tactile integration around the hands is affected by changes in hand posture, visuo-tactile integration around the feet is not affected by changes in foot posture (but see Schicke and Röder, 2006). What is more, investigations of upper and lower limb proprioception show no differences in judging position sense of the arms compared to the legs (Han et al., 2013; Springer et al., 2015). And critically, the DHT depends not only on the integration of visual and tactile information at an incorrect location, but also on the mis-interpretation of proprioceptive signals of the hand's position.

Therefore, it seems plausible that the disappearing hand trick could also be applied to the feet. If the disappearing foot trick is successful, then inducing the sensation that the foot is ‘no longer part of the body’ might temporarily alleviate symptoms in those with the amputation-variant of BIID, for example. Moreover, it might provide insight into the (sensory-related) mechanisms contributing to body ownership disorders. Our primary aim of the current study was therefore to investigate if the disappearing hand trick (hereafter the disappearing limb trick: DLT) can also be applied to the feet in two separate groups of healthy participants. Based on previous studies showing similar principles of multisensory integration for the hands the feet, we hypothesized that there would be no difference in subjective experience of the illusion between the hands and the feet.

We also investigated whether one's level of sensory suggestibility (i.e. a personality trait related to how a person reacts to sensory information (Marotta et al., 2016)) affects one's illusion experience. While body ownership can be manipulated in the general population, the extent to which changes in body ownership and awareness are experienced varies among individuals (e.g. Burrack and Brugger, 2005; Haans et al., 2012; Mckenzie and Newport, 2015). As bodily illusions (like the DLT) critically rely on illusory changes in sensory perception, it is possible that this variability could be partly explained by one's sensory suggestibility. Recently, Marotta et al. (2016) explored precisely this relation using the RHI, wherein sensory suggestibility was measured using the Sensory Suggestibility Scale (Gheorghiu et al., (1995), see Appendix 2). Indeed, high sensory-suggestible individuals (subjectively) embodied the rubber hand to a greater extent than low sensory-suggestible individuals. This was not the case, however, for the objective measure (i.e. measured through proprioceptive drift, i.e. the feeling that the real hand's position has drifted towards the fake rubber hand). The question remains, however, whether this link can also be found for other bodily illusions. We were intrigued by the recent report by Marotta and colleagues, and wanted to replicate these findings under slightly different conditions, but while still testing body ownership. Previous (unpublished) observations from our lab revealed large variability in the experience of the disappearing hand trick illusion. We wanted to investigate what factors might be related to this variability. We know for the rubber hand illusion that several factors influence the experience of the illusion, including one's level of interoceptive accuracy (Tsakiris et al., 2011), age (Nava et al., 2017), mental illness and developmental disorders (like schizophrenia (Klaver and Dijkerman, 2016) or Autism (Cascio et al., 2012), hormone levels (Ide and Wada, 2017), temperament (Kállai et al., 2015), one's level of empathy (Asai et al., 2011), even one's immune system function (Finotti and Costantini, 2016). The disappearing limb trick, while rarely studied, is a good candidate for also investigating the factors that influence the overall shifts in bodily awareness during illusions. What is special about the sensory suggestibility scale is that it explicitly focuses on the experience of body sensations. The participant is explicitly told that they will experience a sensation on or within the body, and they are asked to rate the vividness of that experience. This is also how bodily illusions are generally employed. Participants are asked to make judgements about sensations they experience within and on their bodies following the induction of the illusion, usually by manipulating multisensory signals. It is feasible that there might be a link between sensory suggestibility and body illusions, as they both relate to the experience of the bodily self. Thus, the secondary aim of the current study was to examine the role of sensory suggestibility in the experience of *dis*-ownership and awareness over one's *own* hand or foot during the DLT in healthy participants, using a subjective measure (i.e. questionnaire following the illusion). As sensory suggestibility is an overall personality trait, we did not expect it to differentially impact illusion experience for the hands versus the feet. However, we did expect to find a significant correlation between sensory suggestibility and feelings of (dis)ownership over one's own limb during the DLT, particularly for the Loss of Limb subscale on the DLT-Q.

2. Methods and procedures

2.1. Participants

A principal component analysis (PCA) was performed on responses on the 20 items of the disappearing hand trick questionnaire from 150 participants (a collection of unpublished data from our lab: 50 males, 100 females, average age 22 ± 3.2 years) with the intent to extract subscales of the DLT-Q for the current study. For the experiments, we chose a between-subjects design to reduce any (unknown) effects of completing the illusion twice. Particularly, we wanted to obtain unbiased scores for the disappearing ‘foot’ trick (as outcome of this has not been formally reported before). Participants were therefore randomly assigned to the Hand or Foot group. *Hand group:* 27 individuals (7 males) between the ages of 20 and 43 (M = 23.0 ± 3.4 SD) years, with an average height of 172.0 ± 9.8 (SD) cm took part. *Foot group:* 27 individuals (6 males) between the ages of 20 and 43 (M = 25.2 ± 4.8 SD), with an average height of 173.4 ± 8.0 (SD) cm took part. The groups did not differ in terms of sex ($\chi(1) = 0.101$, $p = 0.75$), age ($t(52) = -1.9$, $p = 0.06$), or height ($t(52) = -0.5$, $p = 0.6$). All participants had normal or corrected-to-normal vision, no history of neurological or psychiatric illness, and no upper or lower body disabilities. Participants were recruited from Utrecht University, and compensated for their participation with course credit. All participants gave written informed consent in accordance with the Declaration of Helsinki and the approval of the local ethics committee (protocol number: FETC 16–048) before participating in the study. Participants were naïve to the purposes of the study.

2.2. MIRAGE multisensory illusion box

The MIRAGE multisensory illusion box (positioned vertically 80 cm from the floor) consists of mirrors, a computer monitor, and a camera that are specially positioned to display a real-time video of a person's limb from first person perspective. Participants place their hands inside of the box, wherein a camera points upwards towards a double-sided mirror (50 W x 31 L cm) lying horizontally, 25 cm above the hands (thus reflecting the position of the hands). The image from the camera is projected through a downward-facing horizontally-positioned 28-in. computer monitor screen (positioned 25 cm above the double-sided mirror) onto the other side of the double-sided mirror. Thus, while the mirror occludes the view of the hands, the projected real-time video (< 17 ms delay) of the hands elicits the feeling that you are looking directly at the hands. Thus, in the current paradigm, participants viewed their hands in this mirror in the same physical location as their real hands (viewing distance to mirror approximately 30 cm). A custom-made program in LabVIEW (Newport and Gilpin, 2011) allowed for the manipulation of the live stream video of the participant's hands. Task and stimuli were the same for both groups, except for the foot group, the box was placed on the floor (elevation ~24 cm) to accommodate the feet. To provide a full view of the feet, an additional mirror (47.5 × 22.5 cm) was placed on the edge of the top of the double-sided mirror to extend the image by approximately 7 cm. The distance between the eyes of the participant and the middle of the mirror depended on the height of the participant. See Fig. 1 for set up of MIRAGE box.

2.3. Disappearing limb trick

Participants were instructed to hover their hands (or feet) carefully above (~ 10 cm) the tabletop (or floor) in the MIRAGE, and hold them about 8 cm from the midline. They were asked to avoid elbow (or ankle) contact with the edge of the box. Participants viewed their limbs on a live video stream the double-sided mirror (reflecting the video from the suspended computer monitor screen) in the MIRAGE. Two blue bars appeared on the outer edges of the viewed image, and one blue bar appeared in the middle. The outer blue bars started moving in slowly (2.5 mm/s for 25 s) towards the limbs. Participants were instructed to maintain the position of their limbs to the best of their ability, while at the same time not allowing them to touch the blue bars. Unbeknownst to the participant, the image of the hands actually moved in towards the midline, and in order to compensate for this (and to avoid collision with the bars), participants slowly moved their hands outward (at ~ 2.5 mm/s). So although their hands appeared close together on the screen (16 cm apart), they were physically 28 cm apart. When the bars stopped moving, the experimenter placed her hand on the participants' limbs and gently placed them on the bottom surface of the box. The image of the right limb subsequently faded to black and the participants were asked to reach for their right hand (foot) with their left hand (foot), which was not there when they reached for it. See Fig. 2 for a visual depiction of illusion for the foot from a participant's perspective.

2.4. Disappearing limb trick questionnaire

The Disappearing Limb Trick Questionnaire (hereafter DLT-Q) was used to measure the participant's experience of the DLT (Newport and Gilpin, 2011). Participants were presented with 20 statements regarding their experience of the DLT and rated their experience using an 11-point Likert-scale, where the range in which they could agree with the statements was from 0 (not at all) to 10 (completely). Each statement is included in Appendix 1. Note that the word "limb" was replaced with the words "hand" or "foot", depending on illusion group.

As noted earlier, a PCA was performed on responses on the 20 items of the disappearing hand trick questionnaire from 150 participants with the intent to extract subscales of the DLT-Q for the current study. We used oblique rotation (oblimin). The initial analysis suggested 5 components with an eigenvalue greater than 1 (accounting for 63.8% of the cumulative variance), but one item (question 14) cross-loaded, and removing it would result in a component with only 2 items, which is generally inappropriate for a subscale (Little et al., 1999; Velicer and Fava, 1998). Given that the scree plot was slightly ambiguous (convergence between 4 or 5 components were unclear), given our relatively small sample size, and in order to facilitate appropriate interpretation of each component, we decided to retain only 4 components. Two items (questions 12 and 17) were removed from the analysis because their regression coefficients failed to meet the minimum criteria (> 0.4) for inclusion.

PCA with oblique rotation (oblimin) was performed on the remaining 18 items. Eigen values greater than 1 suggested a four-component solution, accounting for 63.5% of cumulative variance. Sampling adequacy was verified by the Kaiser-Meyer-Oklin value (KMO = 0.854, where > 0.8 means the degree of common variance among the items is meritorious (Kaiser and Rice, 1974). Bartlett's test of sphericity was significant (χ^2 (153) = 1310.1, $p < 0.0001$), revealing that the correlations between items were large enough for PCA (Field et al., 2012).

Therefore, we created four subscales based on the questionnaire, namely:

1) Loss of Limb (items 1, 2 (reverse-scored), 7, 8 (reverse-scored), 9, 10 (reverse-scored)): referring to the degree in which disembodiment (including feelings of disownership) of one's own hand or foot occurred during the illusion (Cronbach's $\alpha = 0.90$)

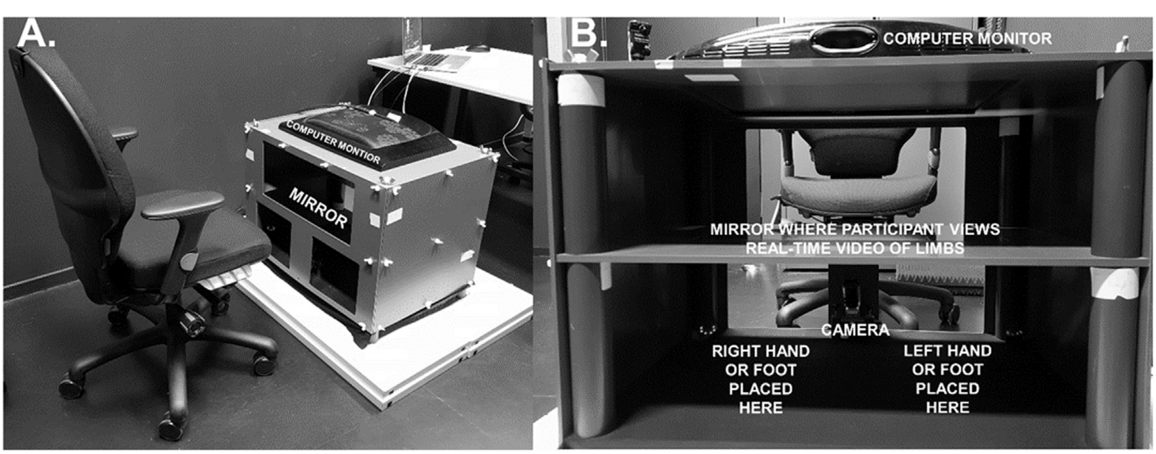

Fig. 1. Set-up of the MIRAGE Multisensory Illusion Box. (A) Side view of the box on the floor for the disappearing foot trick. Participants sat at the chair and placed their feet inside of the box. To accommodate the disappearing hand trick, the box was instead placed on top of a table top so participants could comfortably place their hands inside of the box. (B) Experimenter's view of the box.

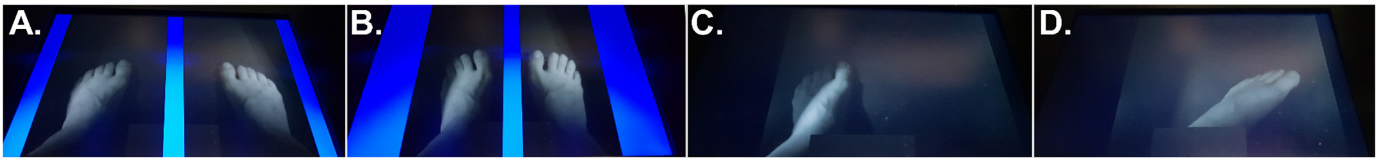

Fig. 2. Participant's view of the disappearing limb trick illusion. (A) Participants are asked to place their feet between the two blue bars overlaid on the screen, while hovering above the floor of the box. (B) The blue bars slowly close in on the feet. Participants are asked to maintain the position of their feet between the bars (C) The participants place their feet onto the floor of the box, and the right foot is faded out (D) Participants reach for their right foot with their left foot but the foot is not where they (visually) expected it to be. Note that the same procedures applied to the hands for the disappearing hand trick.

2) Loss of Location (items 3, 4 (reverse-scored), 5 (reverse-scored)): referring to the degree in which participants were unable to identify the location of their hands or feet following the illusion (Cronbach's $\alpha = 0.85$)
3) Surprise (items 6, 15 (reverse-scored), 16, 18 (reverse-scored), 19): referring to the degree in which participants were surprised by the experience of the illusion (Cronbach's $\alpha = 0.78$)
4) Illusory Sensations (items 11, 13, 14, 20): referring to the degree in which participants experienced illusory bodily sensations immediately following the illusion (e.g. warmth, numbness, an extra limb; (Cronbach's $\alpha = 0.57$)

These subscales were used to calculate illusion experience in the current study for the Hand and Foot groups. The subscale scores were calculated by summing the raw responses per item of the subscale then dividing by the total number of items in that subscale.

2.5. Sensory suggestibility scale

The Sensory Suggestibility Scale (SSS) was used to measure individual sensory suggestibility (Gheorghiu et al., 1995; Lund et al., 2015; Marotta et al., 2016). Specifically, it measures the effects of indirect suggestion on one's (sensory) perception (Gheorghiu et al., 1975). The SSS consists of 14 exercises. During the SSS, the experimenter reads each statement, demonstrates the exercise associated with the statement, and then guides the participant through the exercise. Following each exercise (e.g. "Please close your eyes and rub the outside edge of your tongue against your teeth. Concentrate now to see if you can feel a salty taste"), the participant rates the sensation on said body part associated with exercise (e.g. 0 (no sensation of a salty taste) to 4 (very strong sensation of a salty taste). Here the experimenter provides a 'suggested sensation', and the expectation is that highly suggestible individuals are more likely to report that they experienced this (improbable) sensation. However, of the 14 exercises, 4 exercises actually do evoke a sensation on/with-in the body, and thus are used as control exercises. Participants should report experiencing a sensation after the control exercises (e.g. feeling of warmth on the hands after vigorously rubbing them together). After each exercise, participants rated their sensory perception on a 5-point Likert-scale, ranging from 0 (no perception at all) to 4 (very strong perception). See Appendix 2 for the instruction and answering sheet of the SSS. The SSS total score was calculated by summing the scores of the experimental exercises. Scores could range from 0 to 40. The control exercises (summed score range 0–16) are meant to elicit higher mean scores than the experimental exercises, as they actually induce a change in sensory experience.

2.6. Procedures

The experiment took place in a dimly lit sound-shielded room. Task order (DLT or SSS) was counterbalanced between participants. During the SSS, the participant was seated comfortably and was guided through each exercise by the experimenter. During the DLT, the participant removed any jewelry (or shoes/socks if part of the Foot group) and was seated comfortably in front of the MIRAGE. After completing the DLT, the participant immediately completed the DLT-Q.

2.7. Data analysis

Data were analyzed using IBM SPSS Statistics 23 and JASP (0.8.5.1). As made evident by the Shaprio-Wilk tests, the Loss of Location and Surprise subscales were not normally distributed for both the Hand and Foot groups ($p \leq 0.02$). The Illusory Sensations subscale was not normally distributed for the Foot group ($W = 0.85$, $p = 0.001$). Thus, Mann-Whitney U tests were conducted to examine differences between the Hand and the Foot groups on average scores for each of the four subscales. Median (Med) and interquartile range (IQR) are reported where necessary. To investigate the relationship between illusion experience and sensory suggestibility, Kendall's tau correlations were conducted on the SSS scores and the subscales of the DLT questionnaire for both groups, separately (critical Bonferonni-corrected p-value = 0.012).

3. Results

3.1. Disappearing limb trick questionnaire: comparison between hand and foot group

The median scores (and IQRs) for each subscale were as follows: Loss of Limb (Hand: 5.5 (3.6–7.3), Foot: 5.1 (2.0–5.5)), Loss of Location (Hand: 8.6 (7.3 – 9.3), Foot: 8.0 (6.6–6.9)), Surprise (Hand: 7.8 (6.4–8.2), Foot: 7 (4.8–7.8)), and Illusory Sensations (Hand: 2.7 (2.2–4.7), Foot: 3 (2.0–3.7)). Separate Mann-Whitney U test were run to determine if there were differences between the Hand and Foot groups for the subscales on the DLT questionnaire. There were no differences between the Hand and Foot groups for any of the subscales: Loss of Limb ($U = 266.5$, $p = 0.09$), Loss of Location ($U = 290.5$, $p = 0.19$), Surprise ($W = 262$, $p = 0.07$), Illusory Sensations ($U = 312.5$, $p = 0.36$). See Fig. 3 for box plots.

3.2. Sensory suggestibility scale

Independent samples t-test revealed the mean scores for the control exercises were significantly higher than the mean scores for the experimental exercises both Hand ($Mean_{control} = 1.8$ (0.1 SEM), $Mean_{experimental} = 1.3$ (0.1 SEM), $t(26) = -4.6$, $p < 0.0001$) and Foot groups ($Mean_{control} = 1.9$ (0.1 SEM), $Mean_{experimental} = 1.2$ (0.1 SEM), $t(26) = -5.8$, $p < 0.0001$). Importantly, there was no significant difference between SSS total (experimental) scores between the Foot (Mean = 12.48, 1.2 SE) and the Hand (Mean = 13.15, 1.5 SE) groups ($t(52) = -0.3$, $p = 0.738$). There was also no difference between the groups for the control exercise scores ($Mean_{hand} = 7.7$, 0.5 SE, $Mean_{foot} = 7.2$, 0.6 SE, $t(52) = 0.6$, $p = 0.53$)).

3.3. Relationship between sensory suggestibility and illusion experience

3.3.1. Hand group

There were no significant correlations between SSS scores and the subscales of the DLT-Q (critical $p = 0.012$). See top rows of Table 1.

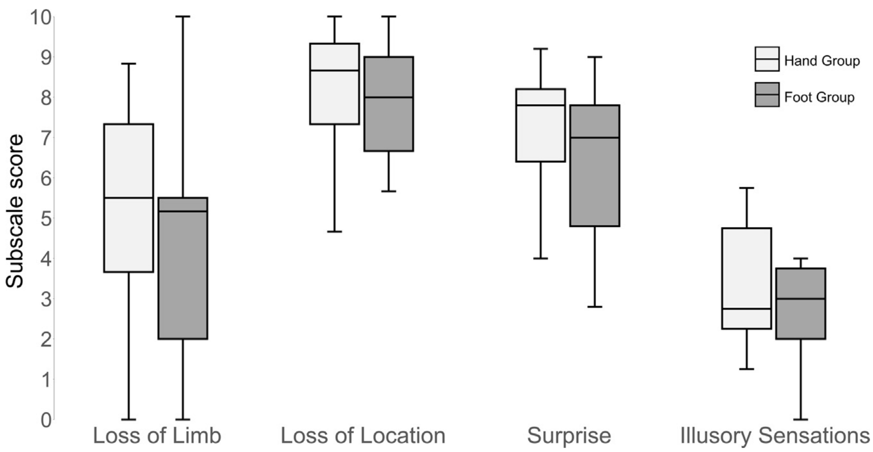

Fig. 3. Boxplots for each subscale per group. Medians for each subscale are represented as the centered lines of each box. Space within the box above the medians represent the third quartiles, and space within the box below the medians represent the first quartile. The whiskers represent maximum (above box) and minimum (below box) values. The light grey boxes represent subscale scores for the Hand group and the dark grey boxes represent subscale scores for the Foot group.

Table 1
Correlation table for total SSS scores and subscales per group (Hand, Foot). Due to multiple comparisons, p-value is significant at the level of 0.012 (Bonferroni-corrected).

HAND		Loss of Limb	Loss of Location	Surprise	Illusory Sensations
SSS Score	tau	0.176	− 0.045	0.044	0.283
	p-value	0.209	0.752	0.753	0.048
FOOT		**Loss of Limb**	**Loss of Location**	**Surprise**	**Illusory Sensations**
SSS Score	tau	0.190	0.282	0.306	0.274
	p-value	0.179	0.049	0.028[#]	0.053

[#] approaching significance.

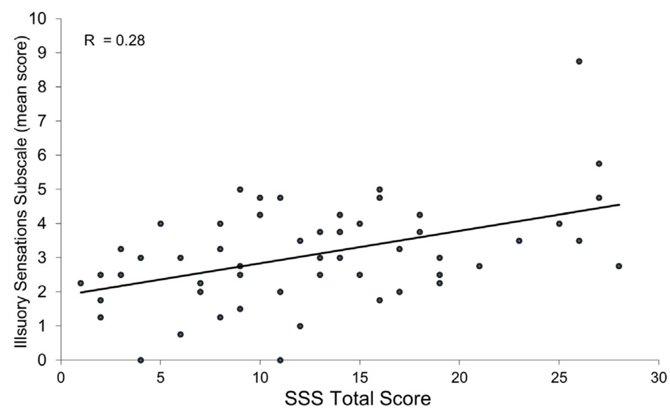

Fig. 4. Scatterplot displaying relationship between SSS total score and Illusory Sensations Subscale scores. R value for Kendall's Tau is stated in upper left corner.

3.3.2. Foot group

There were no significant correlations between SSS scores and the subscales of the DLT-Q (critical corrected $p = 0.012$). However, the correlation between the Surprise subscale and SSS score was trending towards significance, but did not survive the correction (tau = 0.3, $p = 0.028$). See bottom rows of Table 1.

3.3.3. Collapsed across groups

Since there were no differences between the Hand and Foot groups on the DLT-Q subscales or between SSS scores, we collapsed across groups and ran a correlation analysis investigating the relationship between scores on the subscales of the DLT-Q and total SSS scores (critical corrected $p = 0.012$). There were no significant correlations between the total SSS scores and the Loss of Limb (tau = 0.17, $p = 0.07$), Loss of Location (tau = 0.1, $p = 0.26$), or Surprise (tau = 0.16, $p = 0.09$) subscales. However, there was a significant positive correlation between SSS scores and the Illusory Sensations subscale (tau = 0.28, $p = 0.003$). See Fig. 4 for scatterplot.

4. Discussion

In the current study, we tested whether the disappearing hand trick could be also evoked for the foot in two groups (Hand group, Foot group) of healthy individuals. We found no differences in subjective experience between the disappearing "hand" trick and the disappearing "foot" trick, suggesting that the illusion can be used for both body parts. This might have implications for populations that suffer from body image or body ownership disorders, like Body Integrity Identity Disorder. For example, if one can induce changes in awareness (or even illusory sensations) over one's own limb, then perhaps this could alleviate symptoms associated with body disownership or even dissatisfaction. The secondary aim of the current study was to investigate the role of sensory suggestibility (SS) in illusion experience using the sensory suggestibility scale (Gheorghiu et al., 1995). We found a significant positive relationship between experiencing illusory sensations during the disappearing limb trick and one's level of sensory suggestibility when we collapsed across both Hand and Foot groups. That is, participants with higher levels of sensory suggestibility (i.e. individuals who were more likely to report perceiving a sensation following a guided exercise in which no sensations should occur) scored higher on the Illusory Sensations subscale, which included items such as "It seemed like my [limb] felt warmer than normal" or "I had the sensation that my [limb] was numb".

The primary aim of the current study was to explore whether the disappearing hand trick could also be applied to the feet. While some studies have used bodily illusions to induce embodiment over the lower limbs (Crea et al., 2015; Flögel et al., 2015; Lenggenhager et al., 2015; Pozeg et al., 2015), there are few formal reports of illusions used to induce *dis*-embodiment of the lower limbs (but see Cicmil et al., (2015) for an interesting approach). We did not find a difference between the Hand and Foot groups on subjective experience of the illusion, according to the subscales of the questionnaire, suggesting that the illusion can also be used on the feet. Because participants rate their agreement with each statement from 0 (not at all) to 10 (completely), it is difficult to discern which mean values per subscales were large enough to reliably elicit the illusion. For instance, marking a '3' on the statement "It seemed like my [limb] felt warmer than normal" suggests that the participant experienced a mild change in temperature, and thus although small in magnitude can constitute a meaningful response. One reasonable way to address this is to compare our values to previous reports using the same paradigm. There is only one formal investigation (Newport and Gilpin, 2011) that as utilized the disappearing hand trick paradigm in the MIRAGE, wherein experience was measured with this same questionnaire (but see Bellan et al., (2015) and Bellan et al., (2017) for modified versions). So we can potentially compare our questionnaire results to that of Newport and Gilpin (2011). Newport and Gilpin were the first to administer the illusion, and they did so under different conditions (disappeared hand: as we administered here, covered hand: hand is covered by a cloth when participants reached for it, or seen hand: hand is seen when participants reached for it). They showed that, compared to a covered or seen hand, the 'disappeared hand' condition scores elicited the highest, or most extreme, ratings on 16/20 items on the DLT-Q, suggesting that the participant experienced loss of ownership and awareness over their hand in the disappeared condition (confirmed by the lack of a physiological response during this condition when the location was stabbed with an animated knife). In the current study, we tested participants on the 'disappeared hand' condition only, and our questionnaire scores are, perhaps not surprisingly, similar to those of Newport and Gilpin's experimental (disappeared hand) condition (see Table S1 of Newport and Gilpin (2011). Because they provide the mean value per question on the DLT-Q in their sample of participants, we used this information to calculate (potential) mean subscale scores for their sample. While we could not conduct formal statistical comparisons between our Hand group DLT-Q responses and Newport and Gilpin (hereafter N&G)'s DLT-Q responses, the subscale scores suggest similar behaviour (i.e. Loss of $Limb_{mean}$: N&G (5.0), our sample (5.3 ± 2.1 SD); Loss of $Location_{mean}$:N&G (7.3), our sample (8.1 ± 1.9 SD); Illusory $Sensations_{mean}$ (N&G (1.8), our sample (3.2 ± 1.2); $Surprise_{mean}$ (N&G (6.26), our sample (7.2 ± 1.4). Thus, we might claim, with moderate confidence, that the illusion was effective in our Hand and, based on the insignificant difference between the two, Foot groups. This suggests that dis-embodiment of the hands or feet follows similar rules for multisensory integration, such that visual attention, touch, and proprioception can be dis-integrated to a similar degree for both body parts to achieve the same experience.

The finding that there was no difference between our Hand and Foot groups aligns with the findings of a previous investigation by Flogel et al., (2015). They showed, that by manipulating visual attention and touch, embodiment over a fake limb can be induced to the same extent for hands and feet. Flogel and colleagues induced the rubber hand illusion and the rubber foot illusion using a within-subjects design. Subjective reports revealed similar scores regarding the vividness of the illusion, wherein the questionnaire included questions such as "It seemed like the rubber hand was part of my body." They concluded that the embodiment of a limb, induced by multisensory stimulation, follows the same principles for the upper and lower body. Our results suggest that this is also the case for dis-embodiment of one's own limb (as made evident by the similarities between Hand and Foot groups on the scores on the Loss of Limb subscale, which included questions such as "My right [hand or foot] was part of my body" (reverse scored) and "It seemed like I had no right [hand or foot]". It would be interesting to explore whether there is an imbricated relationship between embodiment of another limb and disembodiment of one's own limb. Data from clinical populations suggest that this is the case. Individuals who lack ownership (or desire dis-embodiment) of one of their limbs (e.g. a leg) experience a stronger sense of embodiment over a fake corresponding limb than healthy controls do (Lenggenhager et al., 2015; van Stralen et al., 2013). One might explore this relationship in healthy participants by administering the disappearing limb trick and the rubber limb illusion in the same group of participants. One could also compare the rates at which the hands and feet are (dis)embodied, by recording the temporal window of the uncoupling of visual and touch information during the DLT, like that employed by Bellan et al. (2015) and Bellan et al. (2017). Such a comparison might shed light on the underlying mechanisms of the illusion, and on how sensorimotor recalibration works for the upper and lower limbs.

It is worth noting the reasons why it is important to further explore the efficacy and the plausibility of administering lower body illusions. Primarily, it could provide insight into the mechanisms that guide bodily self-consciousness of the legs and feet. In turn, this might have implications for populations that have an altered experience of the lower body. Recently, Scandola et al. (2017) investigated the frequency and experience of corporeal illusions in individuals with spinal cord injury in daily life (i.e. individuals with loss of touch and proprioception to their upper and/or lower limbs). Results showed that disownership over one's limb (among other body-related illusory sensations) frequently occurred more in individuals with spinal cord injury than in control participants. As SCI affects the legs (and often also the arms), paradigms involving the lower body might prove useful for mimicking a clinical picture of SCI or even peripheral neuropathy in healthy participants. Also, in populations where bodily integrity is compromised (e.g. amputees), one might envisage the utility of a reversed "disappearing foot trick", wherein a foot instead "appears" in place of the missing limb. Indeed, Ehrsson et al. (2008) showed that the rubber hand illusion can be induced in upper limb amputees, albeit less vividly than for their intact hand, and compared to traditional reports of the rubber hand illusion. Furthermore, Schmalzl et al. (2013) showed that synchronous stroking of one's intact hand and stump whilst simultaneously viewing the led to reduced phantom pain in 5 of the 6 participants. Though whether these phenomena extend to the lower body amputations remains unknown, but would be possible to explore using the MIRAGE multisensory illusion box (as used in the current study). Finally, lower body illusions might prove useful in populations where (lower) body ownership is perturbed, like in Body Integrity Identity Disorder, a condition wherein individuals desire amputation or paralysis of a healthy limb(s), often one of their legs. Specifically, individuals with BIID report feeling 'overcomplete' and have a strong desire to structurally (through amputation) or functionally (through paralysis) alter part of their bodies (Blom et al., 2012; Brugger and Lenggenhager, 2014; First and Fisher, 2012). One might imagine the utility of the disappearing foot trick in individuals with BIID who desire amputation. Only one study, to our knowledge, has investigated bodily illusions in BIID participants. Lenggenhager et al. (2015) applied the rubber foot illusion to eight individuals with BIID. They showed that participants with BIID subjectively experienced the vividness of the illusion as stronger than controls, especially for their affected limb, and the strength of the illusion (only for the affected foot) correlated with the strength of one's desire to amputate their limbs. Lenggenhager and colleagues suggest that the use of multisensory bodily illusions could have therapeutic implications for clinical populations. So perhaps future research could focus on tailoring multisensory bodily illusions (through augmented or virtual reality) to achieve this desired state for longer periods of time. Unfortunately, this will not change the physical state of the body in BIID, but given the current ethical discussions surrounding 'elective amputation' in BIID patients (Blom et al., 2016), it seems that alternatives approaches are needed to alleviate the distressing symptoms of BIID in the meantime. Recent reports have shown that the use of virtual reality can reduce phantom pain in paraplegics (Pozeg et al., 2017) or improve body size estimations in individuals with Anorexia Nervosa (Keizer et al., 2016), so therapeutic use of bodily illusions in clinical populations is becoming increasingly popular. As such, experiments in our lab examining the effects of the disappearing foot trick in individuals with BIID, particularly those with the amputation-variant, are currently underway. Modified versions of the illusion, wherein the visual image of the foot does not disappear, but rather becomes static (mimicking a paralyzed state), might be more conducive for individuals with the paralysis-variant of BIID. See Supplementary Material for some preliminary DLT results from 3 individuals with BIID (one of them with paralysis desire).

The secondary aim of the current study was to investigate the relationship between sensory suggestibility and illusion experience. A recent report showed that high SS individuals are more likely to (subjectively) experience embodiment over a fake limb than low SS individuals during the rubber hand illusion (Marotta et al., 2016). But does this hold true for *dis*-embodiment of one's *own* limb? Because the rubber hand illusion and disappearing limb trick both rely on the mis-integration of sensory (vision, touch, proprioception) signals, it is feasible that individuals who are more susceptible to the suggestion of a sensory experience would rely more on illusory sensory signals (e.g. the visual location of the limb) during the illusion, and thus would be more susceptible to the illusion. Results revealed no significant relationships between sensory suggestibility and the scores on the subscales for the Hand group, but there was a trending correlation between the Surprise subscale and the SSS score in the Foot group. Furthermore, when collapsed across group (Hand, Foot), there was a significant positive correlation between SSS score and the Illusory Sensations subscale. We did not find a correlation between the subscales measuring one's Loss of Limb, Loss of Location, or Surprise during the illusion and their level of sensory suggestibility.

When we collapsed across both groups (Hand, Foot), we found a positive significant relationship between scores on the SSS and Illusory Sensations subscale. This finding, although perhaps not surprising, is indeed novel. While the scores on the Illusory Sensations subscale are indeed low, a one-sample Wilcoxon signed ranks test revealed that they do differ from 0 (wherein 0 means that the participant did not agree with the statements at all; $W = 6.2$, $p < 0.0001$). This suggests that participant still subjectively experienced some level of illusory sensations, but the results should be interpreted with caution. Only one study, to our knowledge, has investigated the relation between sensory suggestibility and the experience of bodily illusions (Marotta et al., 2016). Marotta et al. (2016) found a significant positive relationship between SSS scores and the subjective feeling of ownership over a fake hand, measured by agreement with the statement: “I felt as if the rubber hand was my own hand”. This statement directly refers to the explicit feeling of ownership over the rubber hand. We did not find a significant relationship between one's level of sensory suggestibility and feeling of loss of limb (which included items referring to feelings of ownership over one's *own* limb) for either the Hand or the Foot groups. Noteworthy is that Marotta found a relationship between feelings of *ownership and embodiment* over another limb, rather than feelings of *disownership* or *disembodiment* over one's own limb. Participants might simply be highly resistant to losing *their own* limbs, regardless of their level of sensory suggestibility. So though on the same spectrum, ownership and disownership might be distinct in relation to sensory suggestibility. However, an alternative explanation as to why we found different results from that of Marotta and colleagues could be due to differences in illusion properties between the disappearing limb trick and the rubber hand illusion. In the rubber hand illusion, participants are passive observers of a sensory experience (i.e. felt touch on the rubber hand), which is directed by the experimenter (i.e. the experimenter is stroking the participants' hands). In the disappearing limb trick, individuals are active participants in the illusion, physically moving their own limbs into position and reaching for one limb with the other, encouraging agency over the whole experience (but see Abdulkarim and Ehrsson (2018) for a comparison of active versus passive displacement of the hands during a modified version of the procedure). Theories about (hypnotic) suggestion propose that one must partially forego ownership over one's actions, thoughts, body, etc. to succumb to hypnosis (Oakley and Halligan, 2013). While not the same as sensory suggestibility, there is a correlation between hypnotic suggestibility and sensory suggestibility (Polczyk and Pasek, 2006). Perhaps the active role of the participants during the DLT diminished the influence of sensory suggestibility in relation to illusion experience (at least for ownership, location, and surprise). A recent study showed that highly hypnotic suggestive participants are less sensitive to changes in agency when they are actively engaged in a motor task (i.e. they continue to feel in control even when they are not; Terhune and Hedman, 2017). Therefore, the different levels of agency between DLT and RHI might contribute to the discrepant findings between our study and that of Marotta and colleagues. There is also a fundamental difference between ‘feeling’ and ‘knowing’ during the rubber hand illusion that must be overcome to experience the illusion. For example, in the RHI, the individual must override the *knowledge* that the rubber hand is not his in order to surrender to the *feeling* that it is, encouraging the incorporation of a foreign hand into the sense of the bodily self. Individuals who are highly suggestible to sensory information might override this more easily in the RHI, than for the DLT, wherein the distinction between feeling and knowing might be less relevant (i.e. the participant knows and feels that it his hand during the entire illusion). In line with this, the SSS was used to measure sensory suggestibility, and in this scale, participants focus on the addition of a sensation (e.g. feeling of warmth, hearing a sound, seeing a colour, etc.). In the RHI, the illusion relies on the addition of a sensation (i.e. overall ownership over a foreign hand), whereas in the DLT, the illusion relies on the extinction of sensation (i.e. loss of one's own hand). Perhaps the overall design of the RHI capitalizes on one's level of sensory suggestibility better than the DLT does.

And while Marotta and colleagues were mainly interested in question pertaining to illusory embodiment of the rubber hand, they also found relationships between SSS scores and the participant's experience of ‘illusory’ sensations on and around one's own hand. For example, there was a relationship between total SSS scores and statements like “I felt like my hand was turning rubbery” and “I felt like my hand was drifting towards the rubber hand”, which both refer to illusory changes in sensation. Likewise, in the current study, our Illusory Sensations subscale included items relating to perceived changes in sensation (e.g. warmth, numbness, the feeling of an extra limb). Sometimes, changes in bodily sensations can be associated with the experience of embodiment, as also noted by Marotta and colleagues. One way to demonstrate this in practice is via the ‘numbness illusion’ (Dieguez et al., 2009; Martuzzi et al., 2015). Here participants place their palm against the palm of another individual, and watch the experimenter stroke the fingers of the other person. This induces the feeling that one's own hand is numb, and concurrently leads to a feeling of ownership over the other hand (although it is unknown whether the own hand is disowned in the process). However, the finding that, during synchronous stroking, participants rated questions such as “It seemed like the other's finger became my own finger” and “It seemed like I felt only one big finger was being touched” as significantly higher than during asynchronous stroking indirectly suggests that a sense of disownership over one's own hand occurred. Moreover, Pozeg et al. (2017) recently showed that participants who lack sensation of their legs are more resistant to embodying fake legs in virtual reality. Thus illusory changes in sensation over the limb might be related to body (dis)ownership. Though not reported in the results section, there was a significant positive relationship between the Loss of Limb subscale and Illusory Sensations subscale ($rho = 0.23$, $p = 0.01$) in the current study, further supporting the suggestion.

The present study is not without limitations. One might argue that a within-subjects design would be a better design for the current study. We however chose a between-subjects design because we wanted to investigate the effects of the disappearing foot trick in and of itself, as there have been no formal reports about this specific illusion to date. It is possible that conducting the illusion with the hands and then the feet (or vice versa) would influence the strength of the illusion. The only limitation about the between-subjects design is that we cannot claim whether the disappearing foot trick is experienced differently than the disappearing hand trick within the same individual. Thus, given the current set of subjective data for both the upper and lower limb illusions, future investigations could use these scores as a baseline to explore whether the experience of the illusions is similar *within* participants. Finally, the SSS focused mostly on illusory sensations of the upper limbs (e.g. shaking the hand and experiencing a ‘tingling’ sensation or the feeling of cold and numbness in the hand following the placement of a metal plate on the skin). These exercises could likely be applied to the legs/feet and thus perhaps modifying the SSS for the lower limbs would be an interesting avenue to explore in conjunction with lower body illusions.

In conclusion, the current results suggest that the disappearing hand trick can also be applied to the feet. Therefore, it might prove useful in temporarily alleviating symptoms in clinical populations, like for those with the amputation-variant of BIID. Moreover, one's level of sensory suggestibility seems to relate to their experience of illusory sensations (like numbness or warmth) during the disappearing limb trick.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neuropsychologia.2018.07.012.

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