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What Is It Like to Have a Body?

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Abstract

Few issues in psychology are as fundamental or as elusive as the sense of one's own body. Despite widespread recognition of the link between body and self, psychology has only recently developed methods for the scientific study of bodily awareness. Experimental manipulations of embodiment in healthy volunteers have allowed for important advances in knowledge. Synchronous multisensory inputs from different modalities play a fundamental role in producing *body ownership*: the feeling that my body is "mine." Indeed, appropriate multisensory stimulation can induce a sense of ownership over external objects, virtual avatars, and even other people's bodies. We argue that bodily experience is not monolithic, but rather has measurable internal structure and components that can be identified psychometrically and psychophysically, which suggests that the apparent phenomenal unity of self-consciousness may be illusory. We further review evidence that the sense of one's own body is highly plastic, with representations of body structure and size particularly sensitive to multisensory influences.

Keywords

body image, body representation, embodiment, rubber hand illusion, self-consciousness

"Everyone," William James (1890, p. 402) famously asserted, "knows what attention is." The same is true of the experience of embodiment: Everyone knows what it's like to have a body. The body is a ubiquitous element in perceptual experience and is the most familiar object people encounter. The ubiquity of experience of the body, however, has not translated into clarity or consensus about its fundamental nature. On the contrary, research on bodily awareness has historically been and continues to be plagued by disagreement, confusion, and inconsistent terminology. Despite these difficulties, recent investigations have shed new light on bodily awareness, providing rich insight into this fundamental underpinning of psychological life.

The central difficulty in any empirical study of bodily awareness is the control condition. An ideal experimental investigation would compare two conditions: one in which the participant has a body and another in which he or she does not. For obvious reasons, such "brain-in-a-vat" studies are restricted to thought experiments. The body, as James (1890, p. 242) memorably stated, is "always there." Recent progress in the study of bodily awareness has resulted from the development of novel methods for circumventing this dilemma and allowing experimental manipulation of bodily awareness and of our conscious model of our body (the *body image*). Such methods include perceptual techniques, such as the rubber hand illusion (Botvinick & Cohen, 1998), and emerging technologies, such as virtual reality (Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2009), in which the usual physical laws affecting the body can be altered.

In the rubber hand illusion (Fig. 1), synchronous touch to a prosthetic hand and one's own, unseen hand produces the compelling feeling that the rubber hand actually is one's hand. In contrast, asynchronous touch produces no such experience. Thus, these conditions allow for an elegant experimental manipulation of embodiment. Recent research using virtual reality has extended the rubber hand illusion to the whole body (Lenggenhager, Tadi, Metzinger, & Blanke, 2007). Such techniques have transformed research on bodily awareness by allowing researchers to systematically investigate human embodiment. In this article, we review recent research investigating the fundamental structure of bodily awareness and show how specific components of bodily awareness are influenced by various experimental manipulations.

Components of Bodily Awareness

Is embodiment a monolithic experience? At first sight, the phenomenal unity of self-consciousness suggests that it is: We experience a single coherent, conscious self that is continuously linked to our body. However, recent converging evidence has indicated that bodily awareness is a rich, complex experience that can be decomposed into distinct and

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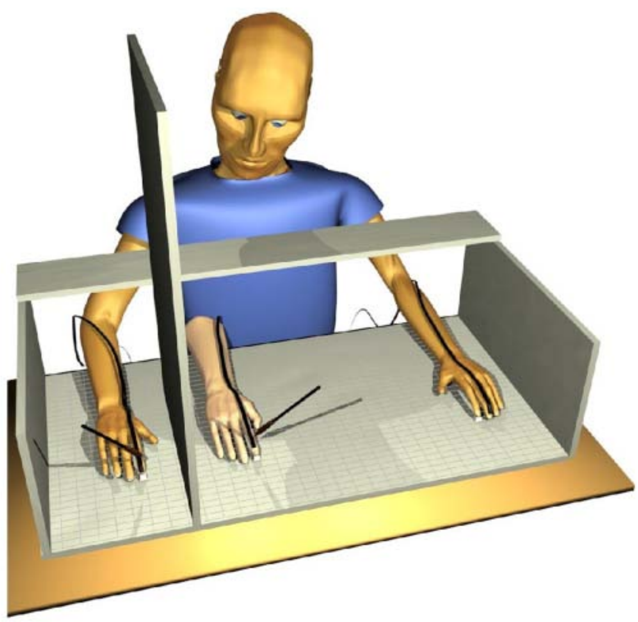

Fig. 1. A canonical setup to elicit the rubber hand illusion. The participant sees a rubber hand aligned in a similar orientation to his or her actual, unseen right hand. In the *synchronous* condition, the two hands are touched at the same time with identical brushes at identical locations. For many participants, this visuo-tactile match generates the compelling feeling that the rubber hand really is their hand (i.e., the sense of ownership). In the *asynchronous* condition, in contrast, the two hands are touched at different times, eliminating the multisensory match between vision and touch and the participant's feeling of ownership over the rubber hand. Reprinted from "The Rubber Hand Illusion in Action," by M. P. M. Kammers, F. de Vignemont, L. Verhagen, and H. C. Dijkerman, 2009, *Neuropsychologia, 47*, pp. 204–211, with permission from Elsevier.

dissociable components with important functional differences. Clearly, these elements cannot simply be the different *parts* of the body: The experiences I have of my left leg are similar to the experiences I have of my right leg. Rather, the constituent elements of bodily awareness are the different feelings, beliefs, and attitudes that one has toward one's body.

Psychometric decomposition of subjective reports

One approach to decomposing bodily awareness is based on the measurement of psychometric dependent variables rather than the experimental manipulation of independent variables. Whereas many rubber-hand studies have used questionnaires assessing subjective experiences (e.g., Botvinick & Cohen, 1998), recent studies have employed formal methods to systematically reveal the characteristic structure of bodily awareness. For example, we (Longo, Cardozo, & Haggard, 2008; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2009) used the rubber hand illusion to combine the experimental manipulation of embodiment with the psychometric decomposition of structured questionnaire data using principal component analysis.

In a sample of 131 participants, we identified four distinct components of bodily awareness during both synchronous and asynchronous visuo-tactile stimulation: *embodiment of rubber hand*, *loss of own hand*, *movement*, and *affect* (Longo, Schüür, et al., 2008). Further analysis of the *embodiment of rubber hand* component revealed that in both conditions, it could be further decomposed into three subcomponents, which we termed *ownership*, *agency*, and *location*. The synchronous- and asynchronous-stimulation conditions differed in terms of how strongly each component was present or absent; such differences confirm that the manipulation succeeded in altering bodily awareness. Nevertheless, the common set of components suggests a shared underlying structure to both experiences. A further component, *deafference* (so named because it related to perceived loss of sensory inputs), emerged only after asynchronous stimulation, indicating that experiences of embodiment may differ qualitatively as well as quantitatively.

Stimulation of distinct sensory-motor pathways

Another method for decomposing bodily awareness involves inducing bodily illusions by stimulating different sensory and motor pathways. This method has been used to investigate perhaps the most salient distinction between aspects of bodily awareness: between the sense of *ownership* over the body, or the feeling that one's body is one's own, and the sense of *agency*, or the feeling that one is in control of one's body and its actions. Tsakiris, Prabhu, and Haggard (2006) showed participants either a real-time or a delayed video image of their hand while their finger moved either actively or passively. In the passive condition, their finger was lifted by a thread like the limb of a marionette, producing a purely sensory match between proprioception and vision. In the active condition, participants moved the finger themselves, adding a motor command to visual and proprioceptive feedback. Subjective reports in the passive condition confirmed that participants felt as though they were looking directly at their own hand, but did not feel that they had control over the hand: an experience of ownership without agency. In the active condition, in contrast, participants reported clear experiences of both ownership and agency (Longo & Haggard, 2009; Tsakiris, Longo, & Haggard, 2010).

Such results constitute empirical support for the dissociability of ownership and agency, which had previously been distinguished only on purely conceptual grounds. Agency and ownership have also been found to have different functional effects on proprioception (Kammers, Longo, Tsakiris, Dijkerman, & Haggard, 2009; Tsakiris et al., 2006) and manual reaction time (Longo & Haggard, 2009). Further, neuroimaging studies have identified largely independent brain networks underlying these experiences. Ownership has been linked to the insula, frontal operculum, and cortical midline areas (Ehrsson, Spence, & Passingham, 2004; Tsakiris, Hesse, Boy, Haggard, & Fink, 2007, Tsakiris et al., 2010), and agency has been linked to motor preparatory areas and the inferior parietal lobe (Nahab et al., 2011; Tsakiris et al., 2010).

These findings reveal that bodily awareness has measureable structure and can be decomposed into dissociable components. At one level, this suggests that the apparent phenomenal unity of bodily awareness, linking the body to a single "I," is illusory. However, these individual elements might form holistic Gestalts that are experienced as distinct from the sum of their parts. Investigating the processes that might produce such Gestalts would be an interesting focus for future research. Although illusions such as the rubber hand illusion may not reflect the full diversity of embodiment, they nevertheless provide a valuable model case. In this sense, they may be to bodily awareness what the fruit fly is to genetics.

Plasticity of Embodiment

Our bodily form is generally stable from moment to moment. Nevertheless, changes in physical bodily structure do occur, both during development and as a result of diet, exercise, or trauma. Veridical body representation thus requires some degree of plasticity so that changes in actual bodily form can be mirrored by corresponding changes in both the brain's maps of somatosensory inputs and in the conscious body image. Understanding how such plasticity arises and develops is important for understanding both normal development and pathological distortions of body image associated with conditions such as eating disorders (Eshkevari, Rieger, Longo, Haggard, & Treasure, in press). Recent studies have found striking evidence for remarkably rapid and profound plasticity of body representation.

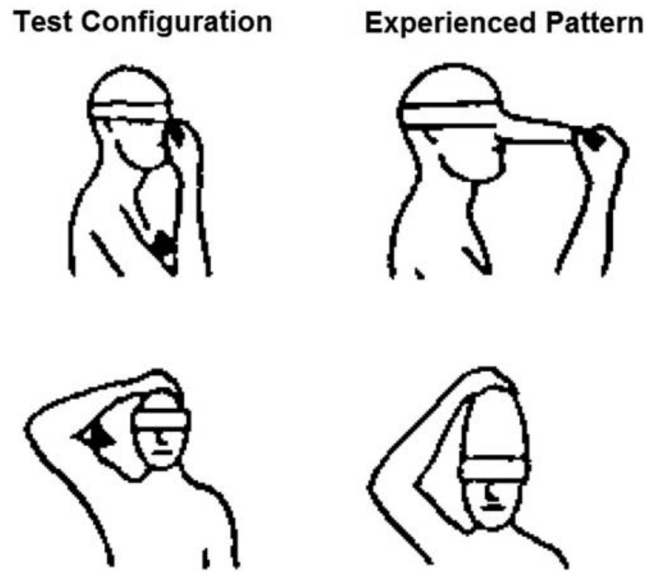

Fig. 2. Illustrations of test configurations and participants' experiences in the "Pinocchio illusion." In both test configurations shown here, vibration is applied to the tendon of the biceps muscle (indicated by the black triangles), generating the proprioceptive illusion that the elbow joint is extending. The participant's hand, however, remains in constant contact with another body part, such as the nose (illustrations at top) or the scalp (illustrations at bottom). In these conditions, a sensory conflict is created, because if the arm were truly moving, the only way it could remain in contact with the other body part is if that body part were growing. Indeed, many participants report feeling as though their nose or head is getting longer, suggesting that the perceptual conflict is resolved by altering the representation of bodily form. Adapted from "Some Proprioceptive Influences on the Perceptual Representation of Body Shape and Orientation," by J. R. Lackner, 1988, *Brain*, *111*, pp. 281–297, with permission from Oxford University Press.

Measuring bodily plasticity

Gandevia and Phegan (1999) measured the perceived size of body parts by having participants select from an array of body-part pictures the picture that most closely matched their own body part. When local anesthesia was used to cut off sensory signals, perceived body-part size increased. This phenomenon will be familiar to many people who have experienced dental anesthesia, which often makes the mouth and teeth feel swollen. This result was experimentally confirmed by a study in which participants who had received local anesthesia of the gums selected an image of a set of teeth that matched their own (Türker, Yeo, & Gandevia, 2005). Intriguingly, anesthesia of the thumb has been shown to produce a smaller increase in perceived lip size (Gandevia & Phegan, 1999). Although the thumb and lips are not adjacent on the actual body, they *are* adjacent in maps of the body in somatosensory cortex (or *Penfield's homunculus*), suggesting that body-image changes may result from plasticity in somatosensory cortex.

Results from studies using postural illusions further suggest that conflict between sensory signals can induce plasticity in body representations. In the *Pinocchio illusion* (Fig. 2), illusory arm movement is generated by vibrating muscle tendons; such vibration generates signals indicating muscle lengthening even though no actual muscular change occurs, resulting in postural illusions. Thus, vibrating the biceps tendon produces illusions of forearm extension, and vibrating the triceps tendon produces illusions of forearm flexion. But what if the hand perceived as moving is touching another body part, such as the nose? For the forearm to be moving away from the face while maintaining contact with the nose, the nose would have to be growing. Dramatically, many participants indeed report feeling that their nose is getting longer (Lackner, 1988)! Similarly, tendon vibration can induce illusions of a shrinking or widening waist in participants whose hands are placed on their hips (Ehrsson, Kito, Sadato, Passingham, & Naito, 2005) and can also induce illusions of individual fingers shortening or lengthening (de Vignemont, Ehrsson, & Haggard, 2005).

In these situations, immediate proprioceptive input requires an adjustment in body representation to resolve an apparent conflict. Recently, we showed that plasticity occurs as a result of such conflict, even when the altered percept does not directly resolve the conflict (Longo, Kammers, Gomi, Tsakiris, & Haggard, 2009). We vibrated tendons of antagonistic muscles (biceps and triceps) simultaneously. In these conditions, the brain receives contradictory signals indicating that the arm is simultaneously flexing and extending. Such proprioceptive conflict produces perceived arm *contraction*, as if the lack of a coherent sense of body location causes body representation to shrink inward on itself. Although people experience their bodies as stable objects with spatio-temporal continuity from one moment to the next, the experience of what one's body is like is, to a large degree, constructed on the basis of the real-time signals continuously reaching the brain from throughout the body.

The rubber hand illusion also provides evidence for plasticity of embodiment, given that the rubber hand generally differs in appearance from participants' own hands. Indeed, visual characteristics of the rubber hand, such as skin color (Holmes, Snijders, & Spence, 2006; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2009), have surprisingly little influence on the illusion. Similarly, participants can easily be made to experience embodiment over graphical arms in virtual reality (Perez-Marcos, Slater, & Sanchez-Vives, 2009; Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2008). The rubber hand illusion can even be induced in amputees who have no actual hand at all (Ehrsson et al., 2008).

Virtual reality allows especially dramatic manipulations of embodiment, given that virtual worlds are not necessarily subject to the usual laws of physics. Recent studies have shown that embodiment can be elicited not just over individual body parts but over entire virtual bodies (Slater et al., 2009), even bodies radically different from one's own. Petkova and Ehrsson (2008) attached cameras to a mannequin where the eyes would be and fed the signals to a head-mounted display, so that participants saw the mannequin in stereo, from a first-person perspective. Synchronous touch of the mannequin's and participant's torsos produced the illusion that the mannequin's body actually was the participant's body: a whole-body analog of the rubber hand illusion. Likewise, attaching cameras to another person, even a person of the opposite sex, produced an illusion of "body swapping," whereby participants experienced themselves as being inside another person's body and shaking their own hand. Similarly, Slater, Spanlang, Sanchez-Vives, and Blanke (2010) found that adult male participants could experience ownership over an avatar of a young girl.

Limitations on bodily plasticity

People are intimately familiar with their bodies. The English idiom "to know something like the back of one's hand" suggests that people have an excellent representation of the back of their actual hand. Nevertheless, the findings we have reviewed here show remarkable lability of bodily awareness. The representation of the body can flexibly incorporate body parts and even whole bodies that are very different from one's own body, even when this incorporation conflicts dramatically with stored knowledge about the body. Such findings may give the impression that bodily awareness is infinitely malleable, inconstant, and ever-changing. Are there any limits on embodiment?

In fact, recent research has demonstrated that there are limits to embodiment. Both the rubber hand illusion (Tsakiris & Haggard, 2005) and whole-body analogs (Lenggenhager et al., 2007) are eliminated when the rubber hand or avatar is replaced with a non-body object. These findings suggest that some form of "body model" serves as a perceptual filter, allowing certain types of stimuli to become incorporated while filtering out others. However, similarity of skin color between the participant's hand and the rubber hand has no reliable effect (Holmes et al., 2006; Longo, Schüür, et al., 2009), suggesting that the body model is relatively generic—consistent with anything that looks like *a* body, regardless of whether it looks like *one's own* body. Although people know what their own bodies are like, the limits of bodily awareness appear to be set by a categorical representation of what people's bodies are like in general.

Other studies have suggested different limitations on bodily plasticity. Tsakiris, Tajadura-Jiménez, and Costantini (2011) found reduced susceptibility to the rubber hand illusion in participants with high interoceptive awareness on a heartbeat-detection task. Analogously, Eshkevari and colleagues (in press) found heightened sensitivity to the same illusion in individuals with eating disorders, with interoceptive deficts being a highly significant predictor of such sensitivity. These results suggest that the conscious awareness of the physiological state of one's body serves as a limiting factor on body plasticity. Body representation may become plastic when internal signals from the body itself are weak and external, visual evidence about the body therefore dominates.

Finally, a different sort of limit seems to concern which type of body representation is modified in illusions like the rubber hand illusion. For example, although the illusion generates clear proprioceptive biases when measured perceptually (e.g., Botvinick & Cohen, 1998; Longo, Schüür, et al., 2008; Tsakiris & Haggard, 2005), Kammers, de Vignemont, Verhagen, and Dijkerman (2009) found no such biases when participants made reaching movements immediately after induction of the rubber hand illusion, suggesting that the motor system might resist the illusion. However, this dissociation is eliminated when the induction of the illusion is itself based on viewing one's own active movement (i.e., agency; Tsakiris et al., 2010). In such conditions, clear effects of the rubber hand illusion have been found on subsequent manual reaction time (Longo & Haggard, 2009) and on pointing (Newport, Pearce, & Preston, 2010). Similarly, Kammers, Kootker, Hogendoorn, and Dijkerman (2010) showed that when participants made grasping actions following the induction of the illusion, their grip aperture was scaled according to the rubber hand's grip aperture. These findings suggest that active motor control can both induce bodily illusions and be sensitive to them.

Conclusion

The experience of having a body is so familiar and so fundamental as to be inexpressible. Nevertheless, significant progress has been made in developing measures and manipulations of bodily awareness. Recent studies have revealed that bodily awareness has measureable structure, with distinct and dissociable components, and that body image is characterized by remarkable plasticity, flexibly changing in response to the immediate sensory-motor context. Investigating how this structure and plasticity arise, interact, and develop remain important goals for future research, and may contribute to our understanding of the many psychological conditions in which bodily awareness is disturbed.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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