Embodiment, ownership and disownership

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ABSTRACT

There are two main pathways to investigate the sense of body ownership, (i) through the study of the conditions of embodiment for an object to be experienced as one's own and (ii) through the analysis of the deficits in patients who experience a body part as alien. Here, I propose that E is embodied if some properties of E are processed in the same way as the properties of one's body. However, one must distinguish among different types of embodiment, and only self-specific embodiment can lead to feelings of ownership. I address issues such as the functional role and the dynamics of embodiment, degrees and measures of ownership, and shared body representations between self and others. I then analyse the interaction between ownership and disownership. On the one hand, I show that there is no evidence that in the Rubber Hand Illusion, the rubber hand replaces the biological hand. On the other hand, I argue that the sense of disownership experienced by patients towards their body part cannot be reduced to the mere lack of ownership.

1. Introduction

Our body may be the object we know the best, from which we constantly receive a flow of information from vision, touch, proprioception, the vestibular and the interoceptive systems. Not only do we receive more information on our body than on any other objects, but we also have an internal access to it that we have to no other bodies. What makes our body so special may thus be that unlike other physical objects and other bodies, we perceive it from the inside. Only in our body, or at least in what we represent as our own body, do we feel bodily sensations. We also care for our body like we care for no other bodies, let alone other objects. Finally, it seems that it is only our own body that obeys our will with no intermediary.

Yet, the relation between the body and the self is complex, giving rise to vivid philosophical debates (see Table 1).

Some debates have been going on for centuries like questions about the ontological nature of the self and personal identity or about the epistemological certainty we have that this is our own body with no possible doubt. Other debates have emerged from recent scientific progress like issues about the moral and legal status of body parts in a time of research on biological materials or questions about the sensory and cognitive underpinnings of the sense of body ownership following a booming of studies in cognitive psychology and neuropsychology these last 10 years.

Here, I shall set the agenda for the investigation of the sense of ownership of body parts.[1] I shall focus on two main pathways, through the study of embodiment and through the study of disownership (see Table 2). However, the relation between embodiment, ownership and disownership is too often left unarticulated. In the paper, I shall bring out some of the main lines of force in this literature and lay the foundation for a proper theory of the sense of ownership. Two questions are of particular interest. First, are embodiment and ownership a matter of all-or-nothing or does it come in degrees or in various types? Second, what is the relationship between experiences of ownership and experiences of disownership?

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[1] I shall not address the question of embodiment and ownership of the body as a whole. For such an account, see for instance Blanke and Metzinger (2009).

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Table 1
Sample of issues concerning the body and the self.

Ontological questions	Am I a body or do I own a body? If I own a body, which body is mine? What grounds personal identity? Memory or the body?
Ethical and legal questions	Can one have property rights upon body parts? If so, who owns the human body? Does the status of the body vary whether it is the living body, separated tissues, human fluids or the body after death? Can the body be commercialized like any object?
Psychological questions	Is there a positive phenomenology of ownership? What grounds the sense of ownership? What is the functional role of the sense of ownership? How is the sense of ownership related to (a) bodily sensations, (b) action, and (c) emotion? Can one feel ownership towards any object?
Epistemological questions	Can bodily self-ascriptions be immune to error through misidentification relative to the subject? What guarantees bodily immunity to error?

Table 2
Artificial embodiment and pathological disembodiment.

Embodiment		References
Allograft	Transplantation of a limb that belonged to another individual	e.g., Dubernard et al. (2003), Farnè, Roy, Giraux, Dubernard, and Sirigu (2002)
Prosthesis	Appropriation of prosthetic limbs in amputees	e.g., Lotze et al. (1999), Murray (2004)
Virtual avatar	Perception and control of a body (or a part of a body) through virtual reality apparatus	e.g., Cole et al. (2009)
Supernumerary limb	Hallucinatory experience of additional limbs	e.g., Khateb et al. (2009)
Rubber Hand Illusion (RHI)	Illusion of ownership of a fake hand induced by the sight of brushing of a rubber hand at the same time as sensations of brushing of the person's own hidden hand	e.g., Botvinick and Cohen (1998), Tsakiris and Haggard (2005)
Full-body illusion	Out-of-the body experience or body swapping induced by synchronous stroking of one's body and a virtual body.	e.g., Ehrsson (2007), Lenggenhager et al. (2007), Petkova and Ehrsson (2009)
Tool	Modification of the representation of the peripersonal space and the personal space after tool use	e.g., Cardinali, Frassinetti et al. (2009), Cardinali, Brozzoli (2009), Farne and Ladavas (2000), Maravita and Iriki (2004)
Disembodiment		
Segmental exclusion syndrome	Under-utilization of the limb after recovery following the lack of use of the limb caused by a traumatic or infectious affection	e.g., Sacks (1984)
Peripheral deafferentation	Loss of tactile and proprioceptive information	e.g., Cole (1995)
Somatoparaphrenia	Denial of ownership of one's body part	e.g., Vallar and Ronchi (2009), Feinberg (2009)
Depersonalization	General alteration of the relation to the self: anomalous bodily experiences, emotional numbing, sensation of alienation from surroundings and anomalous subjective recall	e.g., Sierra et al. (2005)
Body Integrity Identity Disorder (BIID)	Urge to be amputated of one's own perfectly healthy limb(s)	e.g., First (2005), Brang et al. (2008)

2. The sense of body ownership

Before investigating the grounds of the sense of body ownership, one must distinguish between feeling of ownership and judgement of ownership (for a similar distinction within the sense of agency, see Bayne & Pacherie, 2007). Some philosophers, however, take the sense of ownership to be exclusively judgmental (Bermudez, in press). On the deflationary conception of ownership, there is no such thing as a feeling of body ownership, that is, a positive phenomenology of 'myness' that goes beyond the mere experience of bodily properties. We are aware that this body is our own in the sense that we know it, not in the sense that we feel it. This may be true for some parts of the body, like internal organs. However, as O'Shaughnessy (1980, p. 211) says: "While my gall-bladder is a part of me that I know exists, my leg is that and more". What is the difference? I believe that my gall-bladder is a part of my body and that it belongs to me. But in the case of my leg, it is not just something that I believe. It is something that I immediately feel, though it may not be phenomenologically intense. My leg strikes me as my own in the same way that the color of the ocean strikes me as blue. My body is manifested to me in a

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more primitive form that beliefs or judgments. It is manifested in the form of feelings of ownership (de Vignemont, 2007). There is something it is like to experience parts of my body as my own, some kind of non-conceptual intuitive awareness of ownership.

The recent re-discovery of the Rubber Hand Illusion (hereafter RHI) has opened a new path for the study of the feeling of body ownership (Botvinick & Cohen, 1998). Briefly, in the classical set-up, participants sit with their arm resting on a table, hidden behind a screen. They look at a rubber hand presented in front of them, and the experimenter simultaneously strokes both the participant's hand and the fake hand. Participants report feeling as if they were touched on the rubber hand and as if the rubber hand were part of their body. Thanks to the RHI, the feeling of body ownership has become a scientific object of investigation. One should thus be able to determine the perceptual, motor and cognitive conditions for a body part to be experienced as one's own.

Yet, after more than 10 years of studies manipulating the RHI, are we closer to understanding the feeling of ownership? I would like to stress three difficulties. First, the sense of ownership is rated by questionnaires in RHI studies, but it is unclear whether participants report their feeling of ownership or their judgment of ownership. One may even challenge that they experience any ownership feelings towards the rubber hand. A second related worry concerns the scale of ownership used in questionnaires, which often goes from −3 (strongly disagree) to +3 (strongly agree). For instance, in a study with 131 subjects, ownership was rated only at +0.4 in synchronous condition and at −1.2 in asynchronous condition (Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008). These results are difficult to interpret. Do they reflect the vividness of the feeling of ownership experienced by the participants and/or the feeling of confidence in their judgment of ownership? Furthermore, although considered as *the* experimental paradigm to study ownership, the RHI induces only a very weak ownership, so elusive that one may even question whether it induces an illusion of ownership at all. Conversely, in the asynchronous condition, one may wonder why participants do not strongly disagree that the rubber hand felt like their own hand. Finally, those results seem to indicate that the sense of ownership is a matter of degree, as if there were no strict boundary between what one experiences as one's own and what one does not experience as one's own.

A third possible impediment to the understanding of ownership is the almost exclusive focus on the RHI. Indeed, it seems that it is only by confronting the RHI with other cases of embodiment that one could achieve a real understanding of the grounds of ownership. For instance, one needs to explain how it is possible that it takes less than two minutes to induce ownership of a rubber hand while it takes months for a hand transplant to be experienced as one's own, or that one can experience sensations at the tip of a tool and modify the representation of the boundary of one's body to include it, and still not feel ownership towards it. What is at stake here is to understand the relation between ownership and embodiment. Recent evidence of embodiment of external objects has added complexity to an already quite intricate picture. It is now largely accepted that the representation of one's body can stretch to include allograft, prostheses, rubber hands, virtual avatars and tools (see Table 2). What is included can be in flesh and blood, in rubber, in metal, or even virtual. It may be anatomically shaped or not. It may be controlled, or internally felt, or both. Despite their differences, the allograft, the prosthesis, the rubber hand, the virtual avatar and the tool are said to be 'embodied', though the notion of embodiment is too often left undefined, and its relation to ownership is rarely explicitly spelled out.

The relation between embodiment and ownership has been conceived in at least three different ways. First, ownership and embodiment are conceived as synonymous. But this view seems to be incompatible with the embodiment of tools with no associated ownership. Second, ownership and embodiment are conceived in opposition: ownership consists in self-attribution of the body whereas embodiment consists in self-localization (Lopez, Halje, & Blanke, 2008). But this view uses a narrow definition of the notion of embodiment, restricting it to spatial aspects. Third, ownership is conceived as a subcomponent of embodiment: the sense of embodiment consists in what it is like to have a body, and includes the sense of ownership among other experiences (Longo et al., 2008). I am more sympathetic with the latter conception, which uses a notion of embodiment wide enough to capture the peculiar relation to the body of all the various described cases, from allograft to tool. However, one should not confuse embodiment and the sense of embodiment. Embodiment corresponds to a specific type of information processing, whereas the sense of embodiment corresponds to the associated phenomenology, which includes feelings of body ownership. More particularly, I propose the following definition of embodiment:

Embodiment: E is embodied if and only if some properties of E are processed in the same way as the properties of one's body.

In more philosophical terms, embodiment corresponds to a specific mode of presentation of the property of an object, which results from a specific way the property is processed. For instance, the location of the rubber hand can be presented either like the location of any object in the world (external mode of presentation) or like the location of a part of my body (embodied mode of presentation). And in the same way that I do not necessarily know that Hesperus refers to the same planet as Phosphorus, I may not be aware that the rubber hand presented under the external mode refers to the same object as the rubber hand presented under the embodied mode. Now, an object can be presented under the embodied mode, and yet not be experienced as one's own. The notion of embodiment and the notion of the sense of ownership are at different levels of analysis. The properties of E can be processed in the same way as the properties of my body without E being experienced as my own body part. This seems to be the case for tool embodiment. But can I have a sense of ownership of E without E being embodied? I can judge that E is mine on the basis of further grounds than embodiment. But I cannot feel that E is mine without E being embodied. Embodiment is a necessary condition for the feeling of ownership. However, as we shall see, the notion of embodiment is not homogeneous. The agenda for any theory of ownership is thus twofold. First, one needs to analyse the notion of embodiment. Second, one needs to contrast embodiments that lead to ownership feelings and those that do not lead to ownership feelings.

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Table 3
Measures of embodiment.

Spatial	If E is taken into account by the representation of the body space, by replacing a missing body part, by adding a body part, or by stretching an existing body part, If one is able to localize bodily sensations in E, If the location of E within the external frame is processed in the same way as the location of a part of one's body, If the space surrounding E is processed as peripersonal space,	**Then E is embodied**
Motor	If one feels that E directly obeys one's will, If one feels that a part of one's body is moving when E is moving, If E is taken into account as an effector by the motor system in action planning,	
Affective	If E is protected from hazardous situations, If one reacts in the same way when E is threatened or hurt and when a part of one's body is threatened or hurt,	

3. The measures of embodiment

The definition of embodiment in terms of the types of processing that characterize the representation of one's body does not inform us about the specific way the properties of one's body are processed. One possible strategy to address this question is to analyse the various attempts to operationalize the notion of embodiment in clinical and experimental studies. Unfortunately, most studies on amputees merely rate the patients' degree of satisfaction with the graft or the prosthesis or the frequency of use of the prosthesis. The only objective measure comes from brain imaging studies that show brain plasticity, especially of the primary somatosensory and motor areas, which integrate the graft/prosthesis in the neural representation of the body (Giraux, Sirigu, Schneider, & Dubernard, 2001; Lotze et al., 1999; Maruishi et al., 2004). More interesting are the studies with the RHI, with tools and with virtual reality, which have proposed several implicit measures of embodiment that can be grouped into three categories: spatial measures, motor measures and affective measures (see Table 3).

3.1. Spatial measures of embodiment

The spatial measures are the most preponderant in the literature. The embodied object E can be considered within three different spatial frames of reference: the bodily frame, the external frame and the peripersonal frame.

The *bodily frame* is the frame of the body space, as defined by its boundaries and by its internal segmentation into body parts. Body geometry (i.e. the size of body parts) is especially important when acting. To reach successfully for an object, one needs to know the length of one's arm. If E is taken into account by the representation of the body space, by replacing a missing body part, by adding a new body part, or by stretching an existing body part, then E can be said to be embodied. For instance, it was shown that prosthesis users overestimated the length of their residual limb as the result of prosthesis use (McDonnell, Scott, Dickison, Theriault, & Wood, 1989). Similarly, a recent study by Cardinali, Frassinetti and coll. (2009) showed an increase of the represented length of the arm after tool use. As Butler (1872, p. 267) noted in *Erewhon* more than a century ago, "Observe a man digging with a spade; his right fore-arm has become artificially lengthened, and his hand has become a joint".

Furthermore, the representation of the body space is also the representation of the space where one can feel bodily sensations. Hence, to be able to localize bodily sensations in E shows that E is taken into account by the representation of the body space and that E is embodied. And indeed this has been found with tools (e.g., Yamamoto, Moizumi, & Kitazawa, 2005), rubber hands (e.g., Botvinick & Cohen, 1998; Durgin, Evans, Dunphy, Klostermann, & Simmons, 2007), virtual hands (Ramachandran & Rogers-Ramachandran, 1996), and prostheses (Murray, 2004). As reported by an amputee, "I can actually 'feel' some things that come into contact with the prosthesis, without having to see them" (in Murray, 2004, p. 970).

The *external frame* is the frame of the external world within which one navigates. If the location of E within the external frame is processed in the same way as the location of a part of one's body, then E is embodied. For instance, after a few minutes of remote control of a robot arm through a virtual reality apparatus, one participant was afraid to drop the object held by the robot hand for fear that it might fall on his foot, as if his own foot were below the robot arm (Cole, Sacks, & Waterman, 2000). This spatial response of embodiment is reflected by proprioceptive drift (i.e. mislocalization of one's touched hand or one's body towards the rubber hand or the virtual body) in the RHI and in full-body illusions (e.g., Botvinick & Cohen, 1998; Lenggenhager, Tadi, Metzinger, & Blanke, 2007). The proprioceptive drift in the RHI, however, was found only when participants gave perceptual responses, but not when they gave motor responses (e.g. moving one's touched hand or reaching for it with the contralateral hand, cf. Kammers, de Vignemont, Verhagen, & Dijkerman, 2009).

The *peripersonal frame* is the frame of the space immediately surrounding a specific part of one's body ($\leqslant$30–50 cm). When a threatening object enters the spatial margin of safety around their body, animals engage in a range of protective behaviors (Cooke & Graziano, 2003). The representation of such a narrow sector of space is grounded on the activity of multisensory neurons whose activity decreases as the distance between visual stimuli and tactile stimuli increases. In humans, it was found that the location of visual stimuli interfered with tactile performance, but only when the visual distractor was close to a part of the body (i.e. cross-modal congruency effect, cf. Spence & Walton, 2005). Hence, if the space surrounding

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E is processed as peripersonal space, then E is embodied. A number of studies have shown that the peripersonal space is increased by tool use (e.g., Cardinali, Brozzoli, & Farnè, 2009; Farnè & Làdavas, 2000; Maravita & Iriki, 2004). In addition, in RHI and full-body illusion studies, participants showed cross-modal congruency effects: visual stimuli close to the rubber hand (or the virtual body) affected tactile perception (Aspell, Lenggenhager, & Blanke, 2009; Zopf, Savage, & Williams, 2010).

3.2. Motor measures of embodiment

Motor measures often constitute key measures of embodiment in virtual reality studies and in tool studies. However, they are less used to evaluate the RHI, and when they are, it is often with little success (Longo et al., 2008; Schütz-Bosbach, Mancini, Aglioti, & Haggard, 2006). Embodiment has consequences both on action awareness and action planning.

At the subjective level, one feels that one's body directly obeys one's will. There is no need to be actually moving to experience the sense of bodily obedience. The body is experienced as directly available to carry out actions. Although related like two sides of the same coin, the sense of bodily obedience is distinct from the sense of control. Unlike the sense of control, which is primarily about movements, the sense of bodily obedience is primarily about the effectors that perform the movements. Hence, if one feels that E directly obeys one's will, then E is embodied. A further dimension of action awareness is the experience that one's body is moving. If one feels that a part of one's body is moving when E is moving, then E is embodied.

Both the sense of bodily obedience and the sensation of movements can be found in amputees when they see a virtual arm moving (Cole, Crowle, Austwick, & Slater, 2009; Ramachandran & Rogers-Ramachandran, 1996). This is consistent with the restoration of motor cortex activity in amputees with phantom limbs during observation of virtual hand movements (Giraux & Sirigu, 2003). Similarly, it was found that hemiplegic patients with anosognosia vividly felt having generated a movement of their paralyzed arm after seeing a prosthetic arm moving (Fotopoulou et al., 2008, p. 3438): "Sometimes I had the impression that even if I had closed my eyes I would feel it move. I mean I felt the movement in my hand. I didn't just see it". Finally, healthy individuals can feel that they control the movements of a virtual hand if they match their own bodily movements (Short & Ward, 2009) or their motor imagery (Perez-Marcos, Slater, & Sanchez-Vives, 2009), no matter the visual resemblance and the spatial proximity between the real hand and the virtual hand.[2]

At the level of motor planning, the motor system must take into account the properties of the effector such as its size, its strength, its location, its posture, etc. Hence, if the motor system takes the properties of E into account as properties of the effector in action planning, then E is embodied. For instance, Cardinali, Frassinetti and coll. (2009) showed that using a long mechanical tool to grasp objects altered the kinematics of subsequent free-hand grasping movements and of other non-trained movements like pointing.

The motor responses are more contrasted in RHI studies than in tool studies. On the one hand, participants report feeling no control over the rubber hand (Longo et al., 2008). Furthermore, the location of the rubber hand is not taken into account by the motor system (Kammers, de Vignemont et al., 2009). On the other hand a further study showed that the size of the grip aperture of the rubber hand affected subsequent grasping movements (Kammers, Kootker, Hogendoorn, & Dijkerman, 2010). Finally, there is some debate whether one can induce motor facilitation effect in RHI studies. Motor imagery and action observation induce corresponding motor activity in subjects (i.e. motor facilitation effect). In line with these results, it was found an increased tendency of muscular activity when participants saw a virtual arm slowly rotating after synchronous stimulation of the biological arm and the virtual arm (Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2008). However, in Schütz-Bosbach and coll. (2006), the reverse effect was found: the observation of the rubber hand in movement induced a motor facilitation effect only after asynchronous stimulation. It is unclear, however, whether motor facilitation effect should be accepted as a measure of embodiment.

3.3. Affective measures of embodiment

The affective measures evaluate behavioral and physiological responses when the body is put in dangerous situations that can potentially harm it. By self-preservation, one avoids such situations as much as one can (e.g., one does not use one's hand to stoke a campfire or to stir a pot of boiling soup) and one reacts vividly when it happens, showing an increase of heart rhythm and of skin conductance reaction (SCR), as well as brain activity of the pain network. Hence, if E is protected from hazardous situations and one reacts to threats to or injuries of E in the same way as one reacts when a part of one's body is threatened or hurt, then E is embodied. One can immediately see that the embodiment of tools fails to meet the affective criteria (Povinelli, Reaux, & Frey, 2010). Roughly speaking, one uses spoons to stir the pot of boiling soup. By contrast, when participants see the rubber hand being hit by a hammer or penetrated by a needle, they show a strong SCR (Ehrsson, Wiech, Weiskopf, Dolan, & Passingham, 2007). Similarly, when participants see their virtual avatar in a stressful virtual height situation, they show an affective reaction similar to the one that occurs when one experiences vertigo (Meehan, Razzaque, Insko, Whitton, & Brooks, 2005).

To conclude, there is a wide variety of measures of embodiment based on what is known about the specific ways one represents the space of one's body and one's body in space, one experiences one's body in relation to action and one reacts to harmful situations for one's body. The problem, however, is that the responses are not always correlated. That does not

[2] It is worth noting that in all the studies, subjects always had the intention to perform the movement they saw performed by the prosthetic or virtual hand. One may wonder what would happen if they did not intend to move. Would they still feel that they are moving?

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Table 4
Differences between rubber hand embodiment and tool embodiment.

	Rubber hand embodiment	Tool embodiment
Mechanism	Passive process of visual capture of touch	Active process of motor learning
Spatiality	Incorporation	Extension
Anatomical shape	Yes	No
Affective response for harmful situations	Yes	No
Sense of bodily obedience	No	Yes
Sense of body ownership	Yes	No

show that the object is not embodied. Those responses are indeed sufficient conditions for embodiment, but not necessary conditions. But the lack of correlation questions the homogeneity of the notion of embodiment.

4. The manifold of embodiment

There are many differences between the artificial embodiment of allograft, prostheses, rubber hands, virtual avatars and tools, and at various levels. To start with, some artificial embodiments occur in amputees with missing limbs (e.g., graft, prosthesis), while others occur in healthy individuals with a fully functioning body (e.g., RHI; virtual avatar). What is embodied can be the whole body (e.g., virtual avatar, full-body illusion) or merely a body part (e.g., rubber hand, prosthesis, graft). And whereas in most situations the external objects have to be bodily shaped to be embodied, though not necessarily visually resembling the subject's biological limb, this is not true for tools. As for the dynamics, embodiment may take from no more than a couple of minutes (e.g., RHI) to a couple of months (e.g., graft). This huge variability goes along with differences at the level of the associated phenomenology. It starts from "I feel that it is an extension of my body" to "I feel that it is part of my body", from "I feel that it is mine" to "I feel that it is me". Although a recent study showed similar enhancement of visual detection when visual stimuli were projected on a rubber hand and on a gardening tool after training (Kao & Goodale, 2009), one of the most important contrasts may be between the embodiment of rubber hands in RHI and the embodiment of tools after tool use (see Table 4) (for more detail, see de Vignemont & Farnè, 2010). The most striking difference may be the lack of ownership feeling for tools. As Botvinick (2004, p. 783) noted, "the feeling of ownership that we have for our bodies clearly does not extend to, for example, the fork we use at dinner". In the face of these differences, the alternative is the following. Either one claims that tools are not really embodied (Povinelli et al., 2010) or one claims that there is more than one type of embodiment. I shall adopt the latter solution and propose a taxonomy of the manifold of embodiment to capture the diversity of phenomena at stake.

4.1. A few distinctions

First, we need to contrast embodiment with what I call *full embodiment*: E is fully embodied if and only if all its properties are processed in the same way as the properties of one's body. I suspect that only one's own biological limbs under normal circumstances fit this definition. On the contrary, for being embodied, there is no need for all the properties of E to be taken into account by the corresponding type of bodily processing. It suffices that some are. And indeed the lack of correlation between the various measures shows that an object can be embodied for some tasks, but not for others.

One may believe that differences among the various types of embodiment result exclusively from differences between the mechanisms that induce embodiment. On this view, the differences between rubber hand embodiment and tool embodiment are the direct consequences of the differences between multimodal sensory integration and action. However, recent versions of the RHI involve action (e.g. participants actively stroked a toothbrush with their unseen biological hand while seeing the rubber hand performing the same movement, synchronously or not) (Kammers, Longo, Tsakiris, Dijkerman, & Haggard, 2009; Newport, Pearce, & Preston, 2010; Tsakiris, Prabhu, & Haggard, 2006). Yet, in the motor version of the RHI, the rubber hand is not taken into account to a greater extent by the motor system (Newport et al., 2010). The difference with tool embodiment has not been erased.

Rather than analysing the various types of embodiment in terms of triggering mechanisms, I suggest appealing to their functional role(s). The key question then is why E is embodied. For what reasons and in what contexts should the brain process E in the same way as one's body? In line with the Perception–Action model of vision, I suggest distinguishing between perceptual embodiment and motor embodiment. An object is *perceptually embodied* if it is processed in the same way as a part of one's body for perceptual tasks. An object is *motorically embodied* if it is processed in the same way as a part of one's body for motor tasks. The distinction between perceptual and motor embodiment is linked to the specific type of body representations within which E is integrated. Although controversial, it is classically assumed that there are at least two types of body representations (de Vignemont, 2010; Gallagher, 2005; Paillard, 1999). The body schema is an umbrella term that refers to sensorimotor representations of bodily properties, both when the body is the goal and when it is the means of the action. Action-oriented body representations are required at several stages in action planning and control. By contrast, the body image groups all the other representations about the body that are not used for action, whether they are perceptual, conceptual or emotional. One may then suggest that perceptual embodiment consists in representing the object within the body image, whereas motor embodiment consists in representing the object within the body schema. Perceptual embodiment and motor embodiment are always associated when it comes to one's biological body, but not for objects like tools,

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prostheses or rubber hands. For instance, the location of the rubber hand is perceptually embodied, but not motorically (Kammers, de Vignemont et al., 2009).

In addition to functional distinction, one may differentiate distinct types of body representations on the basis of their respective dynamics (O'Shaughnessy, 1980). Short-term body representations consist in constantly updated on line representations of bodily properties, such as posture. Long-term body representations consist in relatively stable representations of long-term bodily properties such as the spatial organization of the body parts and their respective size. The body image is often conceived as a long-term body representation (e.g., body structural description, cf. Schwoebel & Coslett, 2005), whereas it is classically assumed that the body schema is a highly dynamic body representation, built up at time *t*, stored in working memory, and erased at time $t + 1$ by the next one. However, this view is misleading. The functional and the temporal distinctions are orthogonal. On the one hand, the body image is exploited for any perceptual task, including for instance judgments about short-term bodily properties (e.g., hand location). On the other hand, for any action, one needs to know long-term bodily properties (e.g., what effectors one has, their size, the degree of freedom of the joints). The size of one's limbs can be temporarily altered for the sake of one action, if for instance one uses a tool. However, it is quite costly to compute the size of body parts each time one plans to move. Rather, it seems more likely that one exploits a default long-term body representation of one's stable bodily parameters, which is indefinitely reusable. We may think of it in terms of plastic bands: we can stretch them as much as we want but they always come back to their default size.

Hence, in addition to motor embodiment and perceptual embodiment, one should distinguish between *short-term embodiment* (i.e., short-term properties of E processed in the same way as properties of one's body) and *long-term embodiment* (i.e., long-term properties of E processed in the same way as properties of one's body). This distinction might explain why the location of the rubber hand is perceptually embodied, but not its rubbery texture. The embodiment of the rubber hand would be only short-term.

On the basis of this rough taxonomy,[3] one may start offering an account of the sense of ownership. In particular, I shall discuss a recent hypothesis, which I shall call the Body model hypothesis, which posits integration within a long-term body representation at the core of the sense of ownership (Tsakiris, 2010; Tsakiris & Haggard, 2005).

4.2. The body model hypothesis

To account for the fact that one does not feel ownership towards tools, although one does towards rubber hands, it has been suggested that tools are not 'incorporated', that is, are not integrated within the 'body model' (de Preester and Tsakiris, 2009). Tools are represented as extrinsic extensions of the body, and not as intrinsic parts of the body. According to the proponents of the Body model hypothesis, the body model is supposed to determine what can or cannot be experienced as one's own. Although the description of the body model is often left incomplete, a minimal requirement seems to be that it represents a template of the anatomical structure of the human body. For instance, according to the Body model hypothesis, only objects that are anatomically shaped can be incorporated. I shall focus here on a different constraint, namely the two-hand constraint: one cannot have more than two hands, and thus one cannot feel ownership towards more than two hands (for discussion of further constraints, see de Vignemont & Farnè, 2010). It has the immediate consequence that one should not be able to feel ownership towards rubber hands except if one is amputated of one hand or if one does not feel ownership towards one biological hand. The proponents of the Body model hypothesis thus conclude that the RHI is not only an ownership illusion, but also a disownership illusion. On this view, one would no longer feel ownership towards the hand that has been stimulated in synchrony with the rubber hand (Tsakiris, 2010).

The fate of the biological hand during the RHI has been experimentally investigated, but with controversial results. In questionnaires, participants disagree when asked if they felt as if their biological hand had disappeared, but they also disagree when asked if they felt as if they had three hands (Longo et al., 2008). At the physiological and behavioral level, it was found a decrease in skin temperature of the biological hand following the RHI, as well as a slowing down of tactile processes (Folegatti, de Vignemont, Pavani, Rossetti, & Farnè, 2009; Moseley et al., 2008). These results have been interpreted by Moseley and coll. as evidence that the biological hand is replaced by its artificial counterpart. However, a similar slowing down of tactile processes was found following prismatic displacement (Folegatti et al., 2009).[4] It should thus be related to visuo-proprioceptive conflict rather than to disownership. Not only is there no evidence of disownership of the biological hand, but also two recent studies showed the possibility of simultaneously feeling ownership towards multiple rubber hands (Ehrsson, 2009; Newport et al., 2010). The two-hand constraint seems thus to be invalidated.

I propose an alternative interpretation of the RHI on the model of supernumerary limbs. Some patients experience the presence of phantom hands or legs, in addition of their own biological hands and legs. Hence, one can feel ownership towards supernumerary limbs at no cost for the ownership of biological limbs. It can be explained in two ways. Either there are some degrees of liberty relative to the anatomical template of the human body, and at one level, one can represent one's body with three or even four hands. Or patients with supernumerary limbs have two distinct body models, one representing the extra limbs, and the other representing the biological limbs. There is then more than one body model, each respecting the

[3] The functional and the temporal distinctions do not exhaust the variety of embodiment. For instance, the location of the rubber hand is not motorically embodied, while its posture is (see Kammers et al., 2009a, 2010). Yet, both tasks seem to depend on short-term motor embodiment.

[4] Like the RHI, prismatic displacement involves a cross-modal mismatch between the seen and felt position of the hand. However, unlike the RHI, there is no fake hand involved, only one's own hand seen at a different location than where it is felt thanks to prismatic goggles.

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two-hand constraint. In any case, it seems that we can be quite generous with our feelings of ownership. We are not limited to two hands, two legs, but we can extend to three or even four of each.

To conclude, the results I described do not infirm the Body model hypothesis, but rather invite its proponents to refine their characterization of the body model and of the constraints that it lays upon ownership. In particular, they need to explain (i) the difference between tool and rubber hand if both are processed as supplementary body parts and (ii) the reason why the body model cannot integrate tools, while other types of body representations can. Indeed, it was found that after tool use, subjects localized touches delivered on the elbow and middle fingertip of their arm as if they were farther apart (Cardinali, Frassinetti et al., 2009). This result at a perceptual task can be taken as evidence that tools can be integrated not only within the body schema, but also within the body image. Why not then within the body model?

4.3. Self-specific embodiment

Instead of appealing to a putative body model, one may exploit a further distinction among the different types of embodiment to study the sense of ownership. Some processes do not make a difference between processing properties of one's body or properties of other bodies, like probably visual processing of eye color. They constitute what I call neutral bodily information processing, no matter whose body it is. Other processes are self-specific, that is, they exclusively process the properties of one's body, or they process them differently than the properties of other people's bodies. In other words, these processes are not shared between self and others. They are the only ones that can ground the feeling of ownership. It is not sufficient for an object to be processed like a body among others for the object to be experienced as one's own. It must be processed like only one's own body is. Self-specific processes thus indicate that E is not only a part of a human body, but also a part of one's own body, and of no other bodies. The underlying assumption is that what is specific to the processes and the experiences of one's own body – whether it is the specific way one perceives it, one controls it, and/or one affectively reacts to what happens to it – indicates which body one experiences as one's own. One must thus distinguish between *neutral embodiment* and *self-specific embodiment*. Only self-specific embodiment is a necessary condition of the feeling of ownership. And only self-specific embodiment can make the difference between what is merely embodied, and what is embodied and experienced as one's own.

Interestingly, however, it is controversial whether the measures that have been qualified as implicit measures of ownership are self-specific. For instance, it is now largely accepted that affective response to pain is shared between self and others. Strong affective responses and cortical activity of the pain network have indeed been found not only when one's body is injured and when one sees a rubber hand's being injured in synchronous condition, but also when one knows that another individual is being injured (e.g., Singer et al., 2004). Similarly, it has been suggested that measures of the peripersonal space could constitute measures of ownership (e.g., Zopf et al., 2010), but cross-modal congruency effects were found after the mere observation of visual stimuli close to a picture of a hand with no ownership illusion involved (Igarashi, Kimura, Spence, & Ichihara, 2008). Furthermore, if measures of the peripersonal space were measures of ownership (and not merely of embodiment), it remains to be explained why one does not feel ownership towards tools though they displace the peripersonal space.

One may reply that it is not the responses that are self-specific, but their strength. For instance, it is not as if either one reacted to threat or not, but to what extent one reacts, and in particular in comparison between synchronous and asynchronous conditions. On this view, the strength of the response accounts for the intensity of the ownership feeling. Although interesting, this view faces serious difficulties. First, it was found that the more empathetic participants were, the stronger their affective response (Singer et al., 2004). It thus seems that far from being linked to the self, the strength of the affective response is correlated with the propensity to care for others. Second, it may happen that one reacts only weakly to one's body being injured. If body ownership was decided on the basis of the intensity of the response, then one should not feel ownership towards one's body in this case. This conclusion, however, sounds unlikely. The difference between feeling pain in my body and feeling your pain, so to speak, is not a mere matter of degree (de Vignemont & Jacob, submitted for publication). More generally, it remains to be empirically shown that all the so-called measures of ownership are really more intense for one's body and that the responses are correlated with the sense of ownership. In particular, this seems to be challenged by dissociations between the proprioceptive drift and the sense of ownership (Holmes, Snijders, & Spence, 2006; Kammers, Verhagen et al., 2009).

But if self-specificity cannot be always reduced to a mere matter of response intensity, how to account for degrees of ownership? I suggest that the answer can be found in the literature on multimodal integration, which also comes in degrees. In particular, Welch and Warren (1980) propose that integration between various sensory inputs requires what they call the 'assumption of unity', that is, the assumption that the inputs carry information about the same object. Furthermore, they claim that the extent of the integration depends on the reliability of the assumption. The more reliable the assumption that the two sensory inputs are about the same object, the more unified and integrated the two percepts. Similarly, I propose that the feeling of ownership is based on the *assumption of ownership* (i.e. E belongs to one's own body), and the stronger the reliability of the assumption that E belongs to one's own body, the greater the feeling of ownership. The reliability of the assumption of ownership is a function of the number of processes of E that are self-specific relative to the weighting assigned to these processes. For instance, it is likely that the reliability of the assumption of ownership for the rubber hand is weaker than the reliability of the assumption of ownership for the biological hand stimulated in synchrony. If so, the rubber hand could not take over the biological hand.

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To conclude, in order to ascertain the grounds of the feeling of ownership, one needs to determine the types of processing of bodily properties that are self-specific. This can be done only by comparing various cases of embodiment together as well as by analysing similarities and differences between the representation of one's body and the representation of other people's bodies. I shall now explore a different path to investigate the sense of ownership, switching from ownership of fake body parts to disownership of one's body parts. What it is like to experience our body as alien is indeed more vivid and intense than what it is like to experience our body as our own. The study of pathological feelings of disownership can thus shed light on the phenomenal content of feelings of ownership. And arguably, what is missing in patients experiencing disownership may constitute the grounds of the feeling of ownership. Yet, very few attempts have been made to link the two phenomena (e.g. de Vignemont, 2007). It might be partly because there is almost no experimental way to induce disownership in healthy subjects, and thus to operationalize the notion of disownership (if one rules out the RHI as a real disownership illusion).[5] It might be also because there is some uncertainty about the relation between the lack of ownership feelings and disownership feelings (Bermudez, in press).

5. Ownership and disownership

Although the sense of body ownership may appear as a given, various pathological conditions reveal the possibility of feeling disownership towards one's body (see Table 2). For example, patients suffering from the psychiatric disorder of depersonalization experience a general alteration of their relation to the self, such that they often feel as if their body did not belong to them or as if it had disappeared, leading them to compulsively touch their body and pour hot water on it to reassure themselves of their bodily existence (Sierra, Baker, Medford, & David, 2005). Similarly, following brain lesion or epileptic seizure, patients with somatoparaphrenia (also sometimes called asomatognosia or alien hand sign) deny ownership of one of their limbs and often attribute it to another individual (Vallar & Ronchi, 2009). However, it is with Body integrity identity disorder (BIID) that the sense of disownership leads to the most tragic consequences. Patients with BIID feel the overwhelming desire to be amputated of one(s) of their perfectly healthy limbs, partly because it feels alien (Brang, McGeoch, & Ramachandran, 2008; First, 2005). Can one provide a unified account of these experiences of disembodiment and disownership? And if so, what are the implications for a theory the sense of ownership?

5.1. The manifold of disembodiment

There are important differences between the various disorders. The etiology varies, from peripheral motor and sensory deficits to more central deficits, from neuropsychological syndromes to psychiatric conditions. In most cases, the experience of disembodiment affects a single limb, but it can sometimes affect several body parts (e.g., depersonalisation, BIID), or almost the whole body (e.g., deafferentation). More importantly, the experience of disembodiment includes a variety of distinct feelings:

(i) *Feeling of unfamiliarity*: Some properties of the body feel abnormal so that patients barely recognize their body. The awareness of abnormality can result from a mismatch between past and present bodily experiences. It can also result from a lack of consistency within the overall experience of the body as a whole. For instance, a patient with somatoparaphrenia compared the temperature of his two hands and said about his 'alien' hand: "Feel, it's warmer than mine" (Bisiach, Rusconi, & Vallar, 1991, p. 1030).
(ii) *Feeling of unreality*: The patients acknowledge the presence of the limb, but they do not experience it as a living body part. Rather, the limb feels like a dead body part or a fake body part made of chalk or rubber. Their 'real' limb, their living body part, feels absent or missing.
(iii) *Feeling of uselessness*: The body part is left out as lazy or worthless, like a sack of coal (Feinberg, 2009). This feeling often reflects the actual paralysis of the limb, except in psychiatric conditions.
(iv) *Feeling of disownership*: The body part feels alien. It does not feel like a part of their body, although the patients can acknowledge that it is contiguous with the rest of their body. They experience that the body part does not belong to them.

A last difference among the patients is that in addition to feelings of disownership, some patients are delusional and make judgments of disownership. One should thus distinguish between three scenarios of disownership.

1. Patients experience their limb as alien, but they still believe that it belongs to them (e.g., depersonalisation, deafferentation).
2. Patients experience their limb as alien, and they believe that it does not belong to them, and possibly attribute it to someone else (e.g. somatoparaphrenia).
3. Patients experience their limb as their own, but despite that, they judge that it does not belong to them (e.g., possibly BIID, although it is unclear).

[5] Local anaesthesia can sometimes induce disownership in healthy subjects. But in Paqueron and coll (2003), only 5 out of 36 subjects denied the ownership of their limb (Paqueron et al. 2003).

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Disownership can thus occur either at the phenomenological level (feeling of disownership) or at the doxastic level (judgment of disownership) or at both. In (1) and (3), patients do not take their own bodily experiences at face value, because they are overridden by other factors.

Among the disorders I described, somatoparaphrenia may be the most fascinating because the feeling of disownership is often accompanied by delusional beliefs, which are firmly sustained despite incontrovertible and obvious evidence to the contrary: "Feinberg: Suppose I told you this was your hand? Mirna: I wouldn't believe you" (Feinberg, DeLuca, Giacino, Roane, & Solms, 2005, p. 104). The content of the delusions is of two types. On the one hand, the patients entertain *disownership delusion*. They believe that this body part does not belong to them. On the other hand, they entertain *confabulatory delusion*. Either they believe that the body part belongs to another individual or they personify it. One cannot account for those delusions solely in terms of disownership feelings. The abnormal feeling of disownership may account for the specific content of the disownership delusion (i.e. this is not my hand), but it cannot account for the feeling of confidence associated with it. And it seems unlikely that it can account for the content of the confabulation either. Why does the patient attribute the hand to her niece or to a dead husband?

According to the most influential theory of delusion, the two-factor model, one should distinguish between the factors that trigger an initial implausible thought (and thus contribute in explaining the thematic content of a particular delusion) and the factors that explain the uncritical adoption of an implausible thought as a delusional belief (Langdon & Coltheart, 2000). The two-factor model appeals to sensory, motor and reasoning deficits to account for delusions. However, one should consider as well the role that affective factors may play in the etiology of somatoparaphrenic delusions. Indeed, patients rarely feel indifferent towards their 'alien' limb, and their affective attitude varies from friendliness to hate (i.e. misoplegia).

Hence, any account of somatoparaphrenia must be threefold. It must explain (i) the feeling of disownership, (ii) the delusion of disownership, and (iii) the confabulatory delusion. Here I shall limit myself to investigating the feeling of disownership. In particular, do I feel that this hand does not belong to me because it feels *alien* and/or because it does not feel like mine?

5.2. From lack of ownership to disownership

What is the relation between feelings of disownership and feelings of ownership, or the lack of them? There are three possibilities: (i) the Independent Account theory; (ii) the Unified Account theory; (iii) The Discovery theory.

Let us first consider the *Independent Account theory*. On this view, feelings of disownership are grounded on some features of bodily experiences indicating alienation, and those features are unrelated to the absence of feeling of ownership. If this is true, then one needs two distinct accounts, one of disownership feelings and one of ownership feelings. Cases of bodily alienation would be interesting in themselves, but they would have no relevance for the study of ownership. However, if disownership feelings and ownership feelings were fully independent, they should be able to coexist. There should be individuals who report that their body feels alien while simultaneously feeling as their own. Instead, there seems to be a systematic negative correlation between the two types of phenomenology.

Alternatively, one may defend a unified account of ownership and disownership feelings. According to the *Unified Account theory*, disownership feelings result from the disruption of self-specific embodiment, which constitutes the necessary grounds of ownership feelings. On this view, if I do not feel ownership towards a body part that I used to feel as mine, then I must feel disownership. This prediction seems to go in line with the negative correlation between the two types of phenomenology I just highlighted. However, it may be too extreme. Arguably, there are situations where one feels nor ownership nor disownership towards a body part. There may be no distinctive attributive phenomenology, in one direction or in the other.

Instead, according to the *Discovery theory* that I defend, disownership feelings do not directly result from the disruption of self-specific embodiment, but from the detection of the disruption (or from the awareness of the abnormal absence of feelings of ownership). As said earlier, the phenomenology of ownership is very weak and elusive. Its absence can thus remain unnoticed. If so, there is no feeling of disownership. One must become aware of the lack of ownership feelings or the disruption of self-specific embodiment to experience disownership.

This theory is close to the Discovery theory of anosognosia (Levine, Calvanio, & Rinn, 1991; Ramachandran, 1995). Patients with anosognosia for hemiplegia are paralyzed, and yet, they deny being paralyzed and claim being able to move, and even being actually moving. According to Levine and coll. (1991), sensorimotor deficits are not phenomenologically salient and need to be discovered by perceiving discordant information. One needs to monitor one's performance to detect anomalies. In other words, one assumes that one's body is healthy, unless one is provided with evidence to the contrary. The default hypothesis is that one's body is not paralyzed. Similarly, when facing what you take for a mirror, you automatically assume that you are seeing the reflection of your own body. This is your default hypothesis, but if you notice discrepancies between what you do and what you see, you then realize that it is not your body that you see.

Like in mirror recognition, we have a default hypothesis about the boundaries of our own body, probably encoded in long-term self-specific body representations. In other words, we do not compute the reliability of the assumption of ownership of our 'default body' all the time. It is only if we detect discrepancies that we question which body is our own. There may be anomalies within the processing of a part of our body (e.g., long-term embodiment of the left hand with lack of short-term embodiment of the left hand). There may be mismatch between information about one body part and information about the contralateral body part (e.g., the left hand feels different from the right hand). What matters is that we detect the presence of

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conflictual information, which leads us to challenge and lower the reliability of the assumption of ownership of this body part. Then we may feel disownership towards the body part.

6. Conclusion

This paper did no deliver the key to the sense of ownership. Rather, it did the spadework to clarify the conceptual landscape of ownership, embodiment and disownership. In particular, I highlighted the conceptual knots that need to be untied before building up any theory of ownership. I addressed issues such as the functional role and the dynamics of embodiment, degrees and measures of ownership, shared body representation between self and others, and disownership delusions. I proposed that an object is embodied if and only if some of its properties are processed in the same way as the properties of one's body. Furthermore, I argued that the feeling of ownership is grounded in self-specific embodiment and that its intensity depends on the reliability of the ownership assumption. Finally, I argued in favor of a metacognitive theory of disownership according to which the lack of ownership does not suffice to induce feelings of disownership.

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