



HAL
open science

The extended body hypothesis

Frédérique de Vignemont

► **To cite this version:**

Frédérique de Vignemont. The extended body hypothesis: Referred Sensations from Tools to Peripersonal Space. Shaun Gallagher; Leon de Bruin; Albert Newen. The Oxford Handbook of 4E Cognition, Oxford University Press, 2018, 10.1093/oxfordhb/9780198735410.013.20 . ijn_03035566

HAL Id: ijn_03035566

https://hal.science/ijn_03035566

Submitted on 16 Nov 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Abstract

According to the extended mind hypothesis, “There is nothing sacred about skull and skin” for our cognitive abilities (Clark and Chalmers 1998). Is this also true for bodily awareness? In this chapter I consider several versions of what we can call the extended body hypothesis. According to a weak version, bodily awareness is not limited by the biological boundaries of our body. In light of tool embodiment, I highlighted the malleability of embodiment but also showed that there are important limitations to the sensations that we can feel in tools. I will then consider a stronger version of the extended body hypothesis, according to which bodily awareness is not even constrained by the *apparent* boundaries of the body. I will describe how we can experience sensations in peripersonal space but argue that even then there seems to be something sacred about our apparent skull and skin.

Keywords

tool, bodily sensation, pain, touch, embodiment, sense of ownership, exosomesthesia, peripersonal space, phantom limb, rubber hand illusion

20

THE EXTENDED BODY HYPOTHESIS

REFERRED SENSATIONS FROM TOOLS TO PERIPERSONAL SPACE

Frédérique de Vignemont, Institut Jean Nicod, Ecole Normale Supérieure, PSL

Stellarc: We can't continue designing technology for the body because that technology begins to usurp and outperform the body. Perhaps it's now time to design the body to match its machines. (Atzori and Woolford 1995)

The possibility of replacing a defective part of one's body is not without raising a number of metaphysical and psychological questions. Is the patient who has received the transplant of another individual's body part still the same person before and after the graft? Does it depend on the type of body part (hand, face, internal organ)? To what degree is she able to appropriate the new body part? These questions seem to reach another level of complexity with the Australian artist Stelarc's redesigning of his own body. Grafts made for medical purposes still follow our genetic blueprint, that is, how evolution designed our body. Grafts made for artistic or technological purposes, on the other hand, no longer respect it. Since the 1960s, Stelarc has tested how far the body can be extended and reshaped. Some of his works might be seen as mere fantasy, like the graft of an ear on the back of his hand. But others might be conceived as improvements of the body, like the addition of a third arm that moved under his control. With technological progress, such bodily improvements risk becoming more and more crucial if one does not want the body to become obsolete, so to speak. It is thus especially important to assess the implications of bodily extension. In this chapter I will leave aside metaphysical and ethical issues in order to focus on phenomenological ones. I will first analyze the case of tool use as a prototypical example of bodily extension and show what effect it has on bodily awareness. I will then consider whether one can extend bodily awareness even though the body itself is not extended.

STRETCHING THE BODY

We do not need Stelarc and his futuristic performances to analyze the consequences of bodily extension. We actually extend our body a hundred times a day by constantly using tools, from toothbrush to knife and pen. By tool, I do not mean any kind of object, but only unattached external objects that one actively manipulates - and not simply holds - for a functional purpose

(Beck 1980). Tools extend our motor, sensory, and spatial abilities. In other words, we can do more and farther away. One may also say that we *feel* farther away. But to what extent are the referred sensations that we feel to be located in tools similar to the sensations that we feel in our own body? We shall see that although more and more findings can be taken as evidence for the embodiment of tools, this embodiment has limits.

TOOL USE

The lower animals keep all their limbs at home in their own bodies, but many of humans' are loose, and lie about detached, now here and now there, in various parts of the world—some being kept always handy for contingent use, and others being occasionally hundreds of miles away. A machine is merely a supplementary limb; this is the be-all and end-all of machinery. We do not use our own limbs other than as machines; and a leg is only a much better wooden leg than any one can manufacture. Observe a man digging with a spade; his right forearm has become artificially lengthened, and his hand has become a joint. Butler (1872, p. 267)

In his utopia *Erewhon*, Samuel Butler denies any significant difference between tools and hands. Over a century later, empirical research seems to confirm his view, showing that tools are processed in many ways as hands. However, one must distinguish among different claims concerning the embodiment of tools. More specifically, one can ask the following two questions:

1. Do tools stretch our space of action or do they also stretch the space of our body?
2. If they stretch the space of our body, are they integrated only at the unconscious level of sensorimotor body representations or do they also modify our bodily awareness?

Let us start with the first question. There is little doubt that tools can enlarge the range of motor opportunities. This is precisely their function. One way to phrase it is to say that they extend what is known as *peripersonal space*, which can be defined as the space “within which it [the body] can act” (Maravita et al. 2003, p. 531).[‡] For example, in a seminal study, Iriki and colleagues (1996) trained monkeys to use a rake to reach food placed outside their peripersonal space and recorded their neural activity. They found that some of the neurons that displayed no visual response to food at this far location before tool use began to display visual responses after tool use. A few minutes after tool use was interrupted, the visual receptive fields shrank back to their original size. Roughly speaking, what was far from the body was perceived as close thanks to tool use.

———~~Does that entail that tools~~ are represented as parts of the body? In other words, does peripersonal space extend farther because of the extension of the body? Not necessarily. One must distinguish within peripersonal space its internal boundaries (where bodily space ends and peripersonal space starts) and its external ones (how far peripersonal space stretches).

Interestingly, the latter can be displaced without the former being modified. For instance, if one uses a remotely controlled device (like in telemedicine), the space surrounding the device is most probably processed as being peripersonal, although it seems highly unlikely that one represents the whole distance between one’s body and the remote device as parts of one’s body (Cardinali et al. 2009a). The situation is different in the case of a tool over which one has direct control: both the internal and the external boundaries are pushed forward because the tool, which is in continuity with the body, is processed as a part of it. This is confirmed by the following study (Cardinali et al. 2009b). Participants repetitively used a long mechanical grabber to grasp various

[‡] I shall come back to the notion of peripersonal space in the last section.

objects. After their training session, they were subsequently re-tested with their hand alone without the grabber. The kinematics of their movements were then significantly modified when reaching to grasp compared to before their training session. More specifically, they planned their movements as if their arm were longer than before using the grabber. The effect of extension was generalized to other movements, such as pointing on top of objects, although they were never performed with the grabber. This clearly shows that the grabber was incorporated in the sensorimotor representation of the body.

This result may not appear as surprising insofar as we already know that amputees can experience phantom limbs, and thus that the perceived boundaries of one's body do not always coincide with its biological boundaries. But can one really compare tools and phantom limbs? There is indeed one difference, which might make the embodiment of tools more difficult. Phantom limbs do not always involve the modification of body representations; it is rather the reverse. It is because body representations have not been correctly updated after amputation that amputees still feel their missing limb. By contrast, to embody tools, one must modify body representations. And one does so all the time, each time one uses a tool, and each time one drops it. Unlike phantom limbs, tool embodiment thus shows extensive plasticity of body representations, at least at the sensorimotor level.²

² One might believe that there is a second major difference between phantom limbs and tools, namely their shape. However, there is no clear-cut distinction at this level. On the one hand, phantom limbs do not always respect the human anatomy. For instance, amputees can feel the presence of a hand attached at the level of their elbow. On the other hand, tools such as a grabber can look like a forefinger and a thumb in pincer grip.

We can now turn to our second question. Since Milner and Goodale (1995) proposed their perception-action model, it is well accepted that what is true at the sensorimotor level may not be true at the conscious level. Perception and action indeed require different transformations of sensory signals and obey different rules. Consequently, the sensorimotor embodiment of tools does not necessarily entail alterations in bodily awareness. Since tools are designed to improve our ability to act, it may well be that they have no effect outside the realm of action. The evidence, however, does not go in that direction: there are perceptual consequences of tool use.

Let us first consider the experience of the limb holding the tool. Butler said: "Observe a man digging with a spade; his right forearm has become artificially lengthened." We have seen that this is true at the motor level but it is also true at the perceptual level (Cardinali et al. 2009b). After using the grabber, participants were asked to localize their elbow, their wrist and their fingertip. The results showed that they mislocalized their body parts, as if their arm were longer (larger distance than before tool use between the fingertip and the elbow). This seems to indicate that the tool has been included in the perceptual representation of one's body too. If this is the case, then one should expect that one could feel sensations in the tool. One way to test this prediction is to consider classic tactile illusions and see whether they can be found when the tactile stimulation is applied on the tool instead of the skin. Consider the following well-known effect: when one closes one's eyes and crosses one's hands, one takes more time and is less accurate in judging which hand was touched first (Yamamoto and Kitazawa 2001a). This difficulty can be explained by the conflict between two distinct spatial frames of reference of tactile experiences: the bodily frame (e.g., on the right hand) and the egocentric frame (e.g., on the left). What happens now when one holds two sticks that are crossed with one's hands uncrossed, and the two sticks are vibrated one after the other? If the vibration were felt in the

hands holding the sticks, there should be no conflict (e.g., the vibration on the right hand is on the right), and one should have no difficulty judging which stick was vibrated first. However, this is not what was found. Participants had the same difficulties with their sticks crossed and their hands uncrossed as with their hands crossed (Yamamoto and Kitazawa 2001b). This indicates that the vibration was experienced as being located at the tip of the sticks (which were crossed), rather than on the hands holding them (which were uncrossed).

Still one may question whether the participants felt the sensations in the sticks *in the same way* as they felt sensations in their hands. For instance, one might claim that they only indirectly felt the vibration at the end of the sticks in virtue of directly feeling the vibration on their palms. It is true that insofar as tactile receptors are on the skin, and not on the tool, referred sensations must involve subpersonal mechanisms of projecting sensations to the tool and recruit different brain processing than non-referred sensations (Limanowski and Blankenburg, 2016). But this is not the same as to say that the participants only indirectly felt sensations in the sticks. According to Dretske (1995), perception is indirect if some of the information about the perceived object or event is not embedded in the information about the more proximal object: I can indirectly hear that the postman is coming on the basis of hearing that the dog is barking and of knowing that the dog barks each time that the postman comes. By contrast, perception is direct if all the information about the perceived object or event is embedded in the information about the more proximal object: I can directly hear that the postman is coming on the basis of hearing his voice. The crucial question thus is whether additional information is required for one to feel sensations in tools. To answer it, let us consider the most famous example of referred sensations, namely, the blind man and his white cane. Arguably, the blind man primarily feels the resistance of the floor rather than the resistance of the cane in his palm, which is less phenomenologically

salient. Furthermore, information about the bumps on the floor is embedded in the information about the pressure on the palm; it just needs to be extracted and conceptually structured. No further knowledge is required: there is no need to first categorize the specific pressure that one feels in one's hand, and then infer on the basis of past associations that there is a bump on the floor. Arguably, the first time that the blind man holds his white cane, he can immediately feel the obstacles on the floor at the end of his cane. He might not be able to correctly categorize what he feels, but this can be the same when using his own fingers to recognize objects. What is important is that the first time he uses his cane, he immediately feels the world in a certain way at the end of his cane (the resistance of the floor, its volume, etc.). By contrast, the first time one hears that the dog is barking, one cannot hear that the postman is coming. Along with many others, I thus want to argue that we *directly* feel touch on tools (Lotze 1888; Martin 1993; O'Shaughnessy 2003; Vignemont, 2018; Vesey 1961).

To summarize, I have argued that tools can extend (1) peripersonal space, (2) sensorimotor body representations, and (3) tactile experiences. Do I then agree with Butler? Is a machine merely a supplementary limb? I will now highlight some major differences between limbs and tools.

PAIN, ITCHES, AND TICKLES

I have just argued that one can feel *tactile* sensations in tools but bodily awareness cannot be simply reduced to these sensations. There is a whole range of other types of bodily experiences, including pains, itches, tickles, and so forth. What is then interesting is that one cannot feel them as being located in tools. You cannot tickle your pen. Nor can you feel the urge to scratch the tip of your fork. As for pain, obviously you wince when your car bumps into another car, but you do not feel pain as being localized in the trunk. More generally, if a tool is damaged, one may feel

annoyed, or even really upset if the tool is important, but one does not feel hurt. The fact is that one uses tools in harmful situations in which one would not use one's own limbs.

What is the origin of this fundamental limit of referred sensations in tools? We need first to rule out a possible explanation: it is not because pain cannot be experienced beyond the biological boundaries of the body. Unfortunately, patients with phantom limbs can feel excruciating pain there. Nor can we appeal to a purely mechanical explanation. It is true that only some specific types of physical stimuli can be transmitted from the body part that holds the tool to the tool itself, such as vibration. However, we know that physical discontinuity does not preclude referred sensations in external objects, as in the rubber hand illusion (Botvinick and Cohen 1998). In this illusion, participants see a rubber hand in front of them, while their own hand is hidden from sight. After synchronous stroking of the biological and the rubber hands, participants report feeling as if they were touched on the rubber hand. Yet the rubber hand is not in physical contact with their body. Hence, the laws of physical transmission cannot be the full story.

One thus needs to analyze what distinguishes touch from pains, tickles, and itches. According to Armstrong (1962), they correspond to two distinct types of bodily sensations, which he calls transitive and intransitive sensations. In transitive sensations, one can easily draw the distinction between the sensation itself and the object of the sensation (the sensation of the pen in my hand, for instance). It has a clear exteroceptive dimension (about the pen) in addition to its bodily dimension (about the skin). By contrast, intransitive sensations have only a bodily component. The feather tickles me, but my tickling sensation is not about it. It is only about my body. Likewise, when my painful experience is caused by an external painful stimulus, it represents the body part in pain, and not the stimulus that caused the pain. This is not to say that

one cannot localize pain in the external world. The localization of intransitive sensations can actually be quite accurate, and this is important to guide appropriate behaviors (like scratching or withdrawing). Still, it is primarily encoded relative to the body in a somatotopic reference frame (Haggard et al. 2013; Mancini et al. 2015). The content of the painful experience is filled in by the body.

Now the function of tools is to act on the external world. That is why we need to experience the external world at their end. This is also why, I argue, we can experience only transitive sensations there. For example, when the blind man uses his white cane, it is to explore his environment. Hence, when he feels the obstacles on the floor at the tip of his cane, he primarily experiences the exteroceptive component of tactile sensations. By contrast, when a noxious or a ticklish stimulus is applied at the end of the tools, it is hard to see what one could experience in tools given the lack of exteroceptive component. In a nutshell, the function of touch is to acquire knowledge about the properties of *external objects*, whereas the function of pain is to prevent the *body* from damage. This difference in focus, I suggest, can account for the absence of referred intransitive sensations in tools.

There is another peculiarity of intransitive sensations. Pains, tickles, and itches have all an intrinsic affective dimension.³ They feel pleasant or unpleasant, but they are not neutral, and they all play a motivational role. One withdraws the hand in pain, scratches the itchy leg, or wiggles and jiggles. Since one does not feel these affectively loaded sensations in tools, one may say that tools are spatially and motorically embodied, but not *affectively embodied*. This is not to say that we cannot have a deep attachment for some tools, or that we do not protect them when we can. I may not care about my fork, which can be easily replaced, but I definitely care about

³ Touch can have an affective dimension too, but stroking a tool hardly makes sense.

my Montblanc pen that was given to me for my PhD. Still, even then do I care about it in the same way and to the same extent as I care about my body? Most probably no, because I do not feel pain in my pen. One may claim that it is actually important for tools *not* to be affectively embodied. If they were, then we would not be able to use them to stoke the hot embers of a fire, or to stir a pot of boiling soup (Povinelli et al. 2010).

THE SENSE OF BODILY OWNERSHIP: THE BODY BY DEFAULT

There is a further reason for which it is important for tools not to be affectively embodied. If they were completely embodied, if they were indeed only supplementary limbs, then we would have no template of our “habitual body,” to borrow Merleau-Ponty’s phrase. It is indeed important to remember that the plasticity of body representations goes both ways. We are able to incorporate tools hundreds of times a day, and a large part of the experimental investigation of body representations has put emphasis on their capacity to stretch. However, one should not forget that each time we drop a tool, we need to go back to our original body representation. We thus automatically recalibrate the correct size of our limbs a couple of minutes after tool use. How do we achieve this recalibration? Given the number of times we drop off tools in everyday life, it does not seem parsimonious to assume that each time we recompute the size of our limbs, as if it had never been computed before. If tools were fully embodied, we would risk losing track of our biological body. On the contrary, the merely partial embodiment of tools, and, more specifically, the lack of affective embodiment, entails that there is a representation of the body that is not altered by tool use, and thus more stable than the others. It is thanks to this representation that one generally experiences what Williams James (1890, p. 242) called the “the same old body always there.” Another way to put it is to say that it represents the body by default. It can then be used to recalibrate the other types of body representations after they have been temporarily

altered. Consequently, the motor system can incorporate the tool for the time of its use with no cost because there is a reference standard of the body that does not vary.

One can then note a last limit to the embodiment of tools. Most of the time, one does not experience a sense of ownership for tools. One does not feel the fork that one uses for lunch as part of one's body. Interestingly, when amputees describe the failure to appropriate their prosthesis, they often explain it by claiming that the prosthesis is just a tool. For example, a patient reported the following:

Using a prosthetic is not a natural thing, because a prosthetic is not a substitute leg, *it is a tool* which may or may not do some of the things that a leg might have done. (Murray 2004, p. 971, my emphasis)

Here we are very far from Butler. Even if tools can be represented to a large extent in the same way as the parts of one's body, one still does not *experience* them as such. It is then tempting to relate the lack of ownership to the lack of affective embodiment. In a nutshell, one cannot feel pain in tools; thus, tools are not affectively embodied; thus, one does not feel ownership for tools. The relationship between pain, affective embodiment, and the sense of bodily ownership needs to be further developed (Vignemont, 2017). Still, one can already contrast the case of tools with the case of the rubber hand illusion. This illusion indeed involves not only referred sensations, but also illusory ownership. Participants report feeling as if the rubber hand were part of their own body. What is then interesting is that participants can feel pain in the rubber hand. In one study, both the rubber hand and the subject's hand were synchronously stroked, as in the classic setup (Valenzuela-Moguillansky et al. 2011). The difference was that immediately after the stroking, they both received a painful stimulation. Subjects were then asked whether they felt pain *in the rubber hand*. The authors found a correlation between the intensity of the pain felt in

the rubber hand and their sense of ownership of the rubber hand. Arguably, unlike tools, the rubber hand can be affectively embodied, and this explains the illusory experience of ownership.

We have just seen the limits of the embodiment of tools. In the absence of intransitive sensations, one does not embody tools at the affective level, although one does so at the sensorimotor and perceptual levels. Consequently, there is a type of body representation, which is affectively loaded, that is immune to the influence of tool use and that can carry information about the body by default, that is, the body to protect.

STRETCHING BODILY AWARENESS

Bodily awareness can be stretched, to some extent at least. So far I have explained that one can feel sensations in tools because tools are embodied at the perceptual and the sensorimotor levels. But is such embodiment necessary? Or is it possible to feel sensations in objects that bear no relationship with the body (i.e. exosomesthesia)? The localization of transitive sensations is not constrained by the biological limits of the body, but is it constrained by the limits of the body as they are mentally represented? I will now consider two series of cases: (1) referred sensations in non-bodily shaped objects that are not tools and (2) sensations in peripersonal space. Although some studies claim to be “explaining away the body” (Hohwy and Paton 2010) or that sensations can be “hopping out of the body” (Miyazaki et al. 2010), I will argue that none of these cases qualifies as exosomesthesia.

BEYOND TOOLS

Could one feel sensations anywhere, maybe as far as the moon, as suggested by Armel and Ramachandran?

If you looked through a telescope at the moon and used an optical trick to stroke and touch it in synchrony with your hand, would you “project” the sensations to the moon? (2003, p. 1500)

There are actually two distinct questions that are raised here. First, can the moon be embodied? Secondly, can you feel sensations in the moon? The first question concerns embodiment and inquires about the constraints that lay upon it: can you incorporate any object, even if it is not bodily shaped and not in continuity with the body and if you have no control over it? However, it might be that one can feel sensations in the moon although the moon is not embodied. What we really want to know is thus the constraints for referred sensations *per se*: does the object need to be embodied for one to feel sensations in it?

Consider the following study by Hohwy and Paton (2010). They used the classic setup of the rubber hand illusion, previously described, but the difference was that the rubber hand was suddenly swapped with a small white cardboard box. This did not preclude participants from reporting sensations on the box. Does that show that one can dispense with embodiment? It is worth noting here that the experimenter could not induce the illusion for the box if no prior classic rubber hand illusion occurred before. Once normally elicited by a rubber hand, visual capture of touch was not disturbed by the intrusion of an object. One possible interpretation of this result is that the transition from the rubber hand to the box was perceived as a visual distortion of the hand (something like “my hand looks like a box”), to which body representations adjusted. This would show the flexibility of body representations, instead of showing that they played no role. Alternatively, as suggested by the authors themselves, it might have been that the box was perceived as hiding the hand (something like “my hand is in the box”). If this is the right interpretation, it is then not even clear that one can talk of referred

sensations. It is rather that participants felt sensations on their hand, which they localized in the box. This hardly qualifies as exosomesthesia.

Let us now consider another bodily illusion, the cutaneous rabbit illusion, that was induced on a non-bodily-shaped object (Miyazaki et al. 2010). We know that repeated rapid tactile stimulation at the wrist, then near the elbow, can create the illusion of touches at intervening locations along the arm, as if a rabbit hopped along it. In Miyazaki and colleagues' (2010) version of the illusion, participants lifted up a stick between their two fingers until it was in contact with the system that delivered mechanical pulses on the fingers via the stick. They received a series of tactile stimulations on their left index finger, then on their right index finger. Participants then reported feeling touches between the two fingers, that is, on the stick that they were holding. The authors concluded that tactile sensations could “hop out of the body.” However, tactile sensations experienced on the stick are not more surprising than sensations experienced on tools. Actually, one may even say that the stick is a kind of tool that the participants manipulated to interact with the stimulating device.

These studies show that embodiment is not constrained by bodily resemblance, but we already knew this thanks to tool embodiment. In this sense, *the body* can be said to be explained away. However, this is not to say that *embodiment* is explained away. The object is still integrated in body representations. A possibly more convincing case can be found in older reports, and in particular in a study by von Békésy:

But if the observer was permitted to see the movements of the loudspeaker in the room and coordinate them with the sensations on his arms, after some training he began to project the skin sensations out into the room. (1959, p. 14)

Von Békésy's report seems to indicate that one can feel tactile sensations in external objects with no spatial contiguity and no resemblance with the body. Can one then explain referred sensations in terms of embodiment of the loudspeaker? This has been tried, but I think with little success (Martin 1993; Smith 2002). The problem is not that this strategy involves assuming puzzling distortions of body representations. The problem is the lack of independent reason to assume that the loudspeaker is incorporated. One cannot appeal to the fact that participants felt sensations in it for risk of circularity. And there seems to be no other plausible justification for the claim that the loudspeaker was incorporated. Participants had never interacted with it. Moreover, it cannot be explained as a kind of rubber hand illusion. The rubber hand illusion indeed involves *fusion* between a visual event and a tactile event (for example, seeing the stroking of the paintbrush). By contrast, what one may perceive here is a relationship of *causality* between the movement of the loudspeaker and the sensation. Causality involves a relationship between two distinct events, not a fusion of them. Finally, one does not even need to argue for the embodiment of the loudspeaker because it is not clear that the observer *directly* felt sensations there. In the previous section, I ruled out the interpretation of referred sensations in tools in terms of indirect perception, but this interpretation seems more plausible in von Békésy's case. As von Békésy described, the observer had to learn to project the sensation. Put another way, he only *indirectly* localized tactile sensations on the loudspeaker. Consequently, this last case shows that indirect referred sensations in external objects do not require the embodiment of the objects, but one is not entitled to draw conclusion about direct referred sensations on this only basis.

PERIPERSONAL SENSATIONS

So far, I have only considered cases in which one feels sensations in *objects*, whether they are tools, boxes, sticks, or loudspeakers. Although these entities bear little resemblance with body

parts, at least they are like body parts in one respect: they are material objects. As such, they could conceivably be represented as parts or extensions of the body. There are, however, other reported cases in which one feels sensations as being located in a specific *empty* region of space. It may then seem that bodily sensations can stretch beyond what is embodied. It is difficult indeed to see how an empty region of space can be embodied. However, we shall see that there are regions of external space that are encoded in a bodily frame of reference, namely, peripersonal space.

Let us first reconsider Hohwy and Paton's (2010) study. In one condition they stroked a discrete volume of empty space five centimeters above the rubber hand in synchrony with the biological hand. Interestingly, participants reported that they still felt sensations on their own skin, and not above it. A subject, for instance, described it as follows: "it's a magnetic field impacting on my arm" (p. 8). The point here is that even when the stimulations are not on the body, the subjects can still experience them on their body. There is, however, another version of the RHI, called the invisible hand illusion (Guterstam et al., 2013). In this study, the experimenter synchronously stroked the hidden participant's hand and a discrete volume of empty space above the table in direct view of the participant. This time, participants localized their sensations of touch at the empty location. Von Békésy (1967) also reports a similar type of referred sensation. By placing two vibrators slightly out of phase with each other on two spread fingers or on the outspread thighs, healthy subjects described feeling the vibration in the region of empty space between the fingers or the legs. Finally, similar reports are also found in patient studies. An amputated patient described feeling a sensation "in space distal to the [phantom]-finger-tips" when his stump was stimulated (Cronholm 1951, p. 190). Another patient

“mislocalized the stimulus to the left hand into space near that hand” (Shapiro et al. 1952, p. 484).

How should we interpret these puzzling cases? Are these referred sensations completely disconnected from the body? Can one feel sensations not on the moon itself, but simply up in the sky? The reply that I want to offer is negative. It is crucial to note that in all these cases, referred sensations are localized *close to the body*, that is, in peripersonal space. The name of peripersonal space finds its origin in a seminal study by Rizzolatti and colleagues (1981), who described bimodal neurons activated both by tactile stimuli and by visual stimuli close to the body. On the basis of this and many other related findings, it has been argued that the zone that surrounds the body (up to 30 cm) is represented differently from far space. We have seen earlier its motor properties, but it also displays specific sensory properties. For instance, in humans, a cross-modal congruency effect is found for stimuli presented in peripersonal space (Spence et al. 2004). Participants are asked to perform a speeded discrimination of the location of a vibro-tactile stimulus presented either on the index finger or the thumb, while trying to ignore visual distractors presented simultaneously at either congruent or incongruent positions. Crucially, incongruent visual distractors interfere with the tactile discrimination (i.e., participants are both slower and less accurate) only when visual stimuli are close to the body. Visuo-tactile interference happens because both visual and tactile experiences share a common spatial frame of reference, which is centered on body parts (Kennett et al. 2002). A similar effect can be found in the neuropsychological syndrome of tactile extinction. After right-hemisphere lesions, some patients have no difficulty in processing an isolated tactile stimulus on the left side of their body. However, when they are simultaneously touched on the right hand, they are no longer aware of the touch on their left hand. Interestingly, the same is true when they see a visual stimulus *near*

their right hand: the visual stimulus on the right side “extinguishes” the tactile stimulus on the left side so that they fail to detect the touch (Di Pellegrino et al. 1997).

One way to interpret the influence of visual experiences on tactile experiences is to say that the perceptual system anticipates the contact of the seen stimulus on one’s body (Hyvärinen and Poranen 1974). Recent theories have highlighted the importance of prediction in cognitive systems (Hohwy 2013). Expectations about upcoming sensory events can be used to prepare sensory systems and allow for enhanced processing of the forthcoming event (Engel et al. 2001). Specifically, the sight of objects moving toward one’s body can generate an expectation of a tactile event. The tactile expectation then influences the experience of the actual tactile stimulus. For example, it was found that merely seeing the experimenter’s hand *approaching* a rubber hand could induce sensations in the rubber hand (Ferri et al. 2013). What is interesting is why such an expectation is generated. One explanation is that the perceptual system expects the body to move. Peripersonal space is then the space where the body could be in a soon future, a gray zone between one’s body and the external world.

Interestingly, it has been repeatedly shown that the rubber hand illusion works only if the rubber hand is placed in peripersonal space (Lloyd 2007; Preston 2013). Roughly speaking, what is in peripersonal space could be part of one’s body. In the invisible hand illusion, the region of space that is stroked is also within the limits of peripersonal space. Actually, participants reported that it seemed as if they had an “invisible hand.” Hence, it was not as if they perceived the empty space as being empty. They perceived it as being occupied by a hand that they could not see. To some extent, referred sensations in this illusion can be compared to sensations in phantom limbs, as suggested by the authors themselves (Guterstam et al. 2013). The other types of peripersonal sensations (i.e., bodily sensations felt in peripersonal space) may be less easily

explained in terms of embodiment. Nonetheless, they can be understood only within a bodily frame of reference.

We can now offer the following explanation of peripersonal sensations (i.e. bodily sensations felt in peripersonal space). When an object or event enters peripersonal space, it is automatically encoded in relation to bodily boundaries as fixed by body representations. Under normal conditions, the perceptual system then generates tactile expectations, which can in turn generate tactile sensations, which are localized on the body. This involves a remapping of what occurs in peripersonal space onto the surface of the body. In illusory or pathological conditions, I suggest that this remapping can be disrupted. In the invisible hand illusion, sensations are still localized within bodily space, but the body is taken to be at a different location from where it is actually. In pathological conditions, the remapping simply fails to occur and sensations remain localized within peripersonal space. Peripersonal sensations are thus only the consequences of the exceptional disruption of the normal process of remapping in tactile expectation.

CONCLUSION

According to the extended mind hypothesis, “There is nothing sacred about skull and skin” for cognitive abilities (Clark and Chalmers 1998). Can we say the same for bodily awareness? Here I have considered several versions of what we can call the extended body hypothesis. According to a weak version, bodily awareness is not limited by the biological boundaries of our body. In light of tool embodiment, I highlighted the malleability of embodiment but also showed that there are important limitations to the sensations that we can feel in tools. Thanks to these limits, we cannot forget who we are and what we must protect in priority. I then considered a stronger version of the extended body hypothesis, according to which bodily awareness is not even constrained by the *apparent* boundaries of the body. In favor of this version, I have described

how one can have peripersonal sensations in which one feels sensations outside apparent bodily boundaries. However, even peripersonal sensations are localized relative to a bodily frame of reference. Thus, there still seems to be something sacred about our apparent skull and skin for bodily awareness.

REFERENCES

- Armel K.C and Ramachandran V.S. (2003). Projecting sensations to external objects: evidence from skin conductance response. *Proceedings of the Royal Society London B: Biological Sciences*, 270(1523), 1499–1506.
- Armstrong, D. (1962). *Bodily sensations*. London: Routledge and Paul.
- Atzori, P. and Woolford, K. (1995). Extended-body: interview with Stelarc. *Ctheory. net*, 9.
- Beck, B.B. (1980). *Animal tool behavior: the use and manufacture of tools*. New York: Garland Press.
- Botvinick, M. and Cohen, J. (1998). Rubber hands “feel” touch that eyes see. *Nature*, 391, 756.
- Butler, S. (1872). *Erewhon*. London: Penguin Classics.
- Cardinali, L., Brozzoli, C., and Farnè, A. (2009a). Peripersonal space and body schema: two labels for the same concept? *Brain Topography*, 21(3–4), 252–60.
- Cardinali, L., Frassinetti, F., Brozzoli, C., Urquizar, C., Roy, A.C., and Farnè, A. (2009b). Tool-use induces morphological updating of the body schema. *Current Biology*, 19(12), R478–9.
- Clark, A., & Chalmers, D. (1998). The extended mind. *Analysis*, 58(1), 7-19.
- Cronholm B. (1951). Phantom limbs in amputees: a study of changes in the integration of centripetal impulses with special reference to referred sensations. *Acta Psychiatrica Neurologica Scandania Supplement*, 72, 1–310.

Di Pellegrino, G., Làdavas, E., and Farnè, A. (1997). Seeing where your hands are. *Nature*, 388, 730.

Dretske, F. (1995). *Naturalizing the mind*. Cambridge, MA: MIT Press.

Engel, A.K., Fries, P., and Singer, W. (2001). Dynamic predictions: oscillations and synchrony in top-down processing. *Nature Reviews Neuroscience*, 2(10), 704–16.

Ferri, F., Chiarelli, A.M., Merla, A., Gallese, V., and Costantini, M. (2013). The body beyond the body: expectation of a sensory event is enough to induce ownership over a fake hand. *Proceedings of the Royal Society B: Biological Sciences*, 280(1765), 20131140.

Guterstam, A., Gentile, G., and Ehrsson, H.H. (2013). The invisible hand illusion: multisensory integration leads to the embodiment of a discrete volume of empty space. *Journal of Cognitive Neuroscience*, 25(7), 1078–99.

Haggard, P., Iannetti, G.D., and Longo, M.R. (2013). Spatial sensory organization and body representation in pain perception. *Current Biology*, 23(4), R164-R176.

Hohwy, J. (2013). *The predictive mind*. Oxford: Oxford University Press.

Hohwy, J. and Paton, B. (2010). Explaining away the body: experiences of supernaturally caused touch and touch on non-hand objects within the rubber hand illusion. *PLoS One*, 5(2):e9416.

Hyvärinen, J. and Poranen, A. (1974). Function of the parietal associative area 7 as revealed from cellular discharges in alert monkeys. *Brain*, 97(4), 673–92.

Iriki, A., Tanaka, M., and Iwamura, Y. (1996). Coding of modified body schema during tool use by macaque postcentral neurones. *Neuroreport*, 7(14), 2325–30.

James, W. (1890), *The principles of psychology*, vol 1. New York: Holt.

Kennett, S., Spence, C., and Driver, J. (2002), Visuo-tactile links in covert exogenous spatial attention remap across changes in unseen hand posture. *Perception and Psychophysics*, 64(7), 1083–94.

Limanowski, J. and Blankenburg, F. (2016). That's not quite me: limb ownership encoding in the brain. *Social Cognitive and Affective Neuroscience*, 11(7): 1130–40.

Lloyd, D.M. (2007). Spatial limits on referred touch to an alien limb may reflect boundaries of visuo-tactile peripersonal space surrounding the hand. *Brain and Cognition*, 64(1),104–9.

Lotze, H. (1888). *Microcosmus: an essay concerning man and his relation to the world*. New York: Scribner &Welford.

Mancini, F., Steinitz, H., Steckelmacher, J., Iannetti, G., and Haggard, G. (2015). Poor judgment of distance between nociceptive stimuli. *Cognition*, 143, 41–7.

Maravita, A., Spence, C., and Driver, J. (2003). Multisensory integration and the body schema: close to hand and within reach. *Current Biology*, 13(13), R531–9.

Martin, M.G.F. (1993). Sense modalities and spatial properties. In: N. Eilan, R. McCarty, and B. Brewer (eds.), *Spatial representations*. Oxford: Oxford University Press.

Merleau-Ponty, M. (1945), *Phénoménologie de la perception*. Paris: Gallimard.

Milner, A.D. and Goodale, M.A. (1995). *The visual brain in action*. Oxford: Oxford University Press.

Miyazaki, M., Hirashima, M., and Nozaki, D. (2010). The “cutaneous rabbit” hopping out of the body. *Journal of Neuroscience*, 305, 1856–60.

Murray, C.D. (2004). An interpretative phenomenological analysis of the embodiment of artificial limbs. *Disability and Rehabilitation*, 26, 963–73.

O’Shaughnessy, B. (2003). *Consciousness and the world*. Oxford: Oxford University Press.

- Povinelli, D.J., Reaux, J.E., and Frey, S.H. (2010). Chimpanzees' context-dependent tool use provides evidence for separable representations of hand and tool even during active use within peripersonal space. *Neuropsychologia*, 48, 243–7.
- Preston, C. (2013). The role of distance from the body and distance from the real hand in ownership and disownership during the rubber hand illusion. *Acta Psychologica* (Amsterdam), 142(2), 177–83.
- Rizzolatti, G., Scandolara, C., Matelli, M., and Gentilucci, M. (1981). Afferent properties of periarculate neurons in macaque monkeys. II. Visual responses. *Behavioural Brain Research*, 2(2), 147–63.
- Shapiro, M.F., Fink, M., and Bender, M.B. (1952). Exosomesthesia or displacement of cutaneous sensation into extrapersonal space. *AMA Archives of Neurology and Psychiatry*, 684, 481–90.
- Smith, A.D. (2002). *The problem of perception*. Cambridge, MA: Harvard University Press.
- Spence, C., Pavani, F., and Driver, J. (2004). Spatial constraints on visual-tactile cross-modal distractor congruency effects. *Cognitive, Affective, and Behavioral Neuroscience*, 4(2), 148–69.
- Valenzuela-Moguillansky, C., Bouhassira, D., and O'Regan, K (2011). Role of body awareness. *Journal of Consciousness Studies*, 18(9-10), 110–42.
- Vesey, G.N.A. (1961). The location of bodily sensations. *Mind*, 70(277), 25–35.
- de Vignemont, F. (2017). Pain and touch. *The Monist*, 100, 4, 465-477.
- de Vignemont, F. (2018). *Mind the body*. Oxford: Oxford University Press.
- Von Békésy, G. (1959). Similarities between hearing and skin sensations. *Psychological Review*, 661, 1–22.

Von Békésy, G. (1967). *Sensory inhibition*. Princeton: Princeton University Press.

Yamamoto, S. and Kitazawa, S. (2001a). Reversal of subjective temporal order due to arm crossing. *Nature Neuroscience*, 4(7), 759–65.

Yamamoto, S. and Kitazawa, S. (2001b). Sensation at the tips of invisible tools. *Nature Neuroscience*, 4(10), 979–80.

]]