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Abstract

What are the epistemic bases of the knowledge of the reality of our own body? Proprioception plays a primordial role in body representation and more particularly at the level of body schema. Without proprioception people can feel amputated and the mislocalization of proprioceptive information through the remapping of the Penfield Homonculus induces illusions of phantom limbs, illusions that contradictory visual feedback cannot erase. However, it turns out that it is not as simple as that and that vision also intervenes in body knowledge: vision of one's own body allows deafferented patients to move and phantom limbs to disappear. Finally, the existence of phantom limbs in aplasic patients as well as studies on neonates provide evidence of an innate component of body representation.

Descartes applied his systematic doubt on the reality of his own body: nothing assured him that he had a body, that he was not dreaming or hallucinating its existence. More recently, Putnam (1981) has suggested that we could be disembodied brains in a vat and that the experience of our own body could be the result of electric impulses from a large computer. At the end of their reflections, Descartes and Putnam refuted skepticism and assumed that people do have bodies. I do not want to study how they reached this conclusion here, nor to address the metaphysical question of the reality of the body. Rather, the focus of this paper will be the epistemological question of the knowledge of body existence: how do I know that I have a hand rather than that I am amputated? The answer seems to be obvious, I can see my hand and I can feel it. But it is not always so

[1] I would like to thank Shaun Gallagher for his helpful comments.

obvious, and I'd like to start from certain borderline phenomena in order to study the respective roles of proprioception and vision in the knowledge of body existence.

A Questionable Reality of the Body

According to Merleau-Ponty (1962), one of the main features of the body is its permanency: the body is not an object among others that could leave me or disappear. He proposes that this permanency is even a metaphysical necessity in the sense that the permanent body appears as a point of reference in the dynamic world. It doesn't mean that the body is always at the core of our attention and that we are constantly aware of the state of each body part. It only means that we can hardly deny or forget our own body. But could we say that the knowledge of body existence is transparent: if I believe that my body exists, does it necessarily exist and conversely, if my body exists, do I necessarily believe it?

The Disappearance of the Body

In some psychiatric cases, the body is felt as if it is absent: in depersonalization disorder, patients report that they feel as if they are detached from their body, whereas in Cotard syndrome, they believe that their body is dead and rotting away. In addition, following an injury of the right parietal cortex, a part of the body literally disappears from body representation. In hemisomatognosia or in personal neglect, patients explicitly deny the existence of one side of their body or forget it (for instance, patients suffering from personal neglect shave or make up only the right side of their face). Such phenomena could be explained by a disruption of body representation or by a deficit of attention.

The body can also disappear because of the absence of peripheral information relative to it. When people are paralytic (lesion of motor and sensory nerves) or deafferented (lesion of sensory nerves following neuropathy that can extend to almost the entire body), they receive no proprioceptive and tactile information about the state of their body and they report that their body appears "as a hole" as soon as they close their eyes (Berger and Gerstenbrand, 1981). For instance, G.L., one of these deafferented patients, has no information about her body below the mouth, except visual information. Consequently, she has to learn to control her movements only by means of vision, which requires her to always observe what she is doing. But if she is in the dark, she loses her body: she is no longer able to move appropriately, and even worse, she feels as if her body has disappeared. This illusion of an amputation is not so surprising given that, in the dark, she doesn't see her body, she doesn't feel it, she doesn't even move it (or at least, control her movements). But what is more surprising is that some people can still feel the presence of their limb after it has been amputated, as is the case in the phenomenon of phantom limb.

The Phantom Body[2]

> "[I was] suddenly aware of a sharp cramp in my left leg. I tried to get at it with my single arm, but, finding myself too weak, hailed an attendant. 'Just rub my left calf,… if you please.' 'Calf ?… You ain't got none, pardner. It's took off'" (Melzack, 1992, p. 90).

At the beginning, the notion of a phantom limb was only the topic of a short story written by the neurologist Mitchell. However, beyond fiction, people feel the presence of absent body parts like their arm, their leg, their breast, their tooth or even their internal viscera. This sensation is frequent (around 90% of patients experience a vivid phantom immediately after the loss), can be very painful and persists from a few days to 60 years. If people were paralyzed before the operation, they will be unable to move their phantom limb; otherwise, they can feel phantom movements, voluntary or not. The content of the illusion is realistic and specific: John felt so vividly that he had grasped a cup with his phantom arm that he began to scream when the examiner had moved the cup away from him (Ramachandran and Blakeslee, 1998). People also continue to feel their wedding ring or can suffer from arthritis in the phantom limb when the weather is damp and cold, as they suffered before the amputation. Indeed, although the phantom sensation is related to the memories previous to the amputation, we should not reduce the phenomenon of phantom limb to the persistency of past representations of the body. Phantom limbs also appear in people who suffer from the congenital absence of limbs (aplasia).[3] The representation of the phantom body in aplasic people cannot be based on the representation of their past body: if A.Z., who is born with no arms and legs, experiences her body as normal and can learn to count on her phantom fingers, it is not because one day her body had been normal (Brugger et al, 2000). Similarly, we need another explanation to understand how a woman can experience the feeling of having four phantom legs, in addition to her two actual paralyzed legs (Vuilleumier et al, 1997), and more generally how people can feel the presence of supernumerary limbs.

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[2] For a complete review, see Ramachandran and Hirstein (1998).

[3] 20% of aplasic people have phantom limbs according to Melzack et al (1997)

The body and its representation are two different things. In the phenomenon of phantom limb, the body disappears but not its representation, whereas in the phenomenon of deafferentation, the body representation is disturbed while the body still exists. Even if we have the intuition that the existence of our own body is a transparent fact, sometimes we have to discover that we are amputated, or that we are not amputated, or even that we get a new body part, as in transplants. These kinds of knowledge are different. Indeed, it doesn't seem plausible that we need to constantly rediscover that our body is intact. Unlike the continuity of the body presence, the loss of a body part, as well as transplantation of new parts, appear as a rupture. We'll focus here on the knowledge of the modification of the body, rather than on the knowledge of the continuous presence of the body. However, we should keep in mind that these two kinds of knowledge are intrinsically related.

The Proprioceptive Phantom

Deafferented patients – if they don't see their body – as well as amputated ones do not receive any tactile, proprioceptive, and visual information about a part of their body. However, this sensory loss doesn't have the same consequences in both cases: deafferented patients feel as if they are amputated while real amputated patients feel as if their limb is still there. In 1911–1912, Head and Holmes postulated the existence of a "body schema," a dynamic internal model of body posture generated by a constant flow of sensory inputs. If such a body representation exists, the deprivation of any sensory information relative to a certain part of the body should result in a modification of the body schema. But the illusion of phantom limb shows that it is not as simple as that. It seems that the representation of the body does not reflect the extinction of proprioception and vision of the amputated limb and that the representation of the phantom limb is not based on this information.

More exactly, people with phantom limb do not pretend to see their absent limb. What they report is that they internally feel the limb, its position, its temperature, its pain. Consequently, the phantom limb seems to have its source from interoception, that is, the inner perception of one's own body. But how is it possible if there is no more interoceptive information relative to the absent limb?

Reflexive and Instrumental Proprioception

Interoception (proprioception, nociception, sense of temperature, sense of balance, etc.) allows me to permanently know the position and the state of my own body, even if my eyes are closed. O'Shaughnessy (1995) makes a distinction between reflexive (or introspective) proprioception and instrumental proprioception. When I voluntarily pay attention to a body part, I use proprioceptive information reflexively: I become conscious that my legs are crossed by a deliberate act of reflection about the sate of my body. But I am not permanently conscious or attentive to the state of my own body. Most of the time, I use proprioceptive information in an instrumental mode, that is, for the purpose of execution of action: attention is focused on the goal of action rather than on body position. Indeed, I constantly receive a flow of proprioceptive information about my body, which allows me to plan, to execute and to control my actions: when I move, I need to know second by second where my limbs are, whether my muscles are stretched, whether I risk falling, and so on. In the absence of proprioception, people are no longer able to control their movements. I.W., one of the deafferented patients, reported that at the beginning of his deafferentation, he was not even able to sit by himself and to remain seated. Even after 20 years, if there is no light, he cannot turn in bed during the night. G.L., another patient, is still unable to walk even if she is not paralyzed, because movements of her legs are far too complex for her to control in the absence of proprioception. In summary, we constantly receive proprioceptive information, which is necessary for action and for body perception, and when we no longer receive it, we loose the control of our body. Given that, how can we understand that the loss of proprioception seems to have no effect on people with phantom limbs who experience the position of their phantom and who are even sometimes able to move it?

Penfield Homonculus

We have to be careful not to consider the amputated limb by itself isolated from the other parts of the body. The phantom limb can only be understood on the background of the whole body: even if there is no proprioceptive information from the absent limb, we still receive proprioceptive inputs from other parts of the body, inputs that could explain phantom feelings. A first hypothesis is that the source of the phantom limb is the irritation of the remaining nerve endings in the stump, and indeed the stimulation of the stump can produce or increase phantom sensations. However, phantom sensations do not disappear when the stump is anaesthetized or amputated. Thus, we need to add to this peripheral cause a more central cause, at the level of the representation of the body.

At the cortical level, there is a somatotopic map of the body, which associates each part of the cortex to a part of the body resulting in the picture of an "Homonculus" (Penfield, 1950). Two features of the Penfield Homonculus constitute the basis of phantom limbs: the organization of the Homonculus (for instance, the cortical representation of the hand is contiguous to the cortical representation of the face) and the plasticity of the body representation. Monkeys show (i) a reduction of the cortical area dedicated to the body part when sensory nerves of a certain part of the body are cut; (ii) an extension of the corresponding cortical area when monkeys excessively use one finger (Merzenick et al, 1984). The change is not only local, but it also influences the whole representation, the face area extending on the hand area when the hand is amputated or deafferented. That is what happens in the phenomenon of phantom limb in humans, which we should define as a " remapping " of the Penfield Homonculus.

When your hand itches, you know where to scratch. But when it is your phantom hand that itches, where do you scratch? Ramachandran and Hirstein (1998) show that when the face is touched, the patient feels as if his face and his phantom hand are simultaneously touched: the sensory nerves from the face (and also the stump) have invaded the cortical area dedicated to the hand. In the same way, there is a remapping at the level of the primary motor area, which is also somatotopic (but to a lesser extent). Studies in functional MRI also provide evidence of the activation of the neighbouring face area in sensorimotor cortex when the subject imagines that he is moving his phantom hand (Lotze et al, 2001). The activation is correlated with the fact that the phantom is painful and according to these authors, this reorganizational change may be the neural correlate of phantom limb pain. In short, scratch your face when your phantom hand is itching.

Sensory Mislocalization

Therefore, the phenomenon of phantom limb should be defined as a mislocalization of proprioceptive information: patients receive proprioceptive information from other parts of the body and represent them as if their source is the amputated limb. Bermudez (1998) explains that the content of proprioceptive representation is dual: it is descriptive (description of the state of the body) and spatial (representation of the state as a state of a certain body part). Similarly, bodily sensations like pain are always localized in the body space: it is not only a pain, it is a pain in my right hand. The body space should not be confounded with the space of other objects. As Merleau-Ponty (1962, p. 114) puts it: "The border of my body is a frontier that usual spatial relations do not cross." We should distinguish different body spaces, as we should distinguish different body representations. However, for our actual purpose, all we need is the basic conception that a sensation is located in a body part and that the body part can move without the pain moving. That's what Block (1983) notices when he says that the following inference is not valid:

I have a pain in my thumb.
My thumb is in my mouth.
Thus, I have a pain in my mouth.

He concludes that the term "in" cannot be understood here as a spatial transitive relative and that phenomenal localization shows certain specific characteristics. However, what this invalid inference really shows is rather that the localization of bodily sensation is intentional (Tye, 1995). Indeed, in the context of phenomenal localization, one cannot substitute one constituant (my thumb in my mouth) by another co-referential constituent (my mouth) *salva veritate*. Similarly, propositional attitudes are referentially opaque: I cannot conclude from the fact that I want to be in the Town Hall and that the Town Hall is in a ghetto, that I want to be in a ghetto. According to Tye, the intentional nature of bodily sensation explains why phenomena such as phantom limbs exist. In the case of a phantom hand, even if I feel it as a pain in my right hand, it is not true that my right hand is painful given that it has been amputated. What is false here is not the descriptive content, it is the spatial content. There is a pain, but this pain is mislocalized.

However, could we really be mistaken about our bodily sensations? It seems to be in contradiction to the thesis of privileged access to one's own mental states, and more particularly to one's own bodily sensations. According to a strong version of this thesis, my knowledge of my pain is such that I cannot believe that I am in pain when I am not in pain (infallibility) and I cannot be in pain without believing that I am in pain (omniscience). I do not have time here to treat the classical debate about the infallibility of self-knowledge. Moreover, the phenomenon of phantom pain does not inscribe itself in the very same problematic. As I've already said, the problem is not the existence of the sensation, the problem is its localization.

Nevertheless, the possibility of mislocalization depends on the intentional status of bodily sensations. In other words, if one sustains that pain sensations are pure phenomenal states that do not represent bodily states, then they cannot misrepresent them. Conversely, if one sustains that bodily sensations have the function to represent the state of the body, bodily sensations can be true or false. For instance, according to PANIC theory (*Poised Abstract Non- conceptual Intentional Content*) endorsed by Tye (1995), pain sensations are non-conceptual sensory representations of body disorders that are based on information delivered by nociceptors about the state of the body. In the same way, Bermudez (1998) sustains a representational view of bodily sensations. Proprioceptive content can be true or false, depending on the fact that the body is actually in the state represented and on the fact that the state of the body is well localized. Moreover, Bermudez also provides a functional account of proprioceptive content. The proprioceptive content is intimately related to action and more particularly, the spatial content: it doesn't help to take care of the hand that is not painful. Actions are appropriate to the body part that hurts and if pain is mislocalized, the same actions are no longer relevant. If we come back to the phenomenon of phantom limb, we have seen that if the phantom hand itches, the appropriate action is to scratch the face. Consequently, the representation of a phantom limb is a misrepresentation of the body state, not at the level of the descriptive content, but at the level of the spatial one.

According to the traditional view, phantom limbs are a kind of bodily hallucination. There is no more limb in phantom sensations than there is a pink elephant in visual hallucinations. However, the illusion of pink elephants has no external component while phantom sensations are partly caused by physical events in the external world: I experience my phantom hand being touched because my face is touched. Therefore, rather than a pure hallucination, we should interpret phantom limbs as a case of sensory mislocalization. Nevertheless, the hypothesis of remapping of the Penfield Homonculus cannot account for all phantom sensations and the phenomenon of phantom limb depends on various factors, such as the reactivation of body representation stored in long-term memory. We have seen what would be the basis of phantom sensations and we are going to see now what would be able to chase them out.

The Visible Phantom: Visuo-proprioceptive Conflict

The illusion of amputation in deafferented patients does not resist the vision of their own body. However, the illusion of phantom limb in amputated patients does resist the vision of the absence of their limb. We have seen the importance of proprioceptive information, but now the question is to understand the role of vision in the knowledge of body existence.

Despite the fact that all the sensory modalities do not always provide the same representation of the body, we tend to maintain consistency by the resolution of sensory conflicts. For instance, Lackner (1988) produced illusory configurations of the body by manipulating such conflicts. He showed that muscle vibrations induced illusory movements: the vibration seemed to move the arm and if the motion was resisted, the subject still felt as if he was moving. In addition, if the subject was asked to grasp his nose while his arm seemed to move, he would experience his nose as elongating, by much as 30 cm. This illusory configuration was the solution of a sensori-motor conflict: the vibration gave to the subject the illusion of a movement of extension, but the fact that the hand maintained contact with the nose meant that the nose was also moving, and as the head was stationary, it meant that the nose was elongating. There was no more conflict. But this solution was effective only if the subject did not see that his arm was not moving because in this latter case, the conflict found another solution: despite what he felt, the subject didn't believe that his arm was moving and thus, he didn't feel as if his nose was elongating. In this example, we see that in the case of mismatch between vision and proprioception, vision prevails. We believe more what we see than what we feel.

Other experiments find the same result. Fourneret and Jeannerod (1998) asked subjects to trace sagittal lines on a graphic tablet while they were given a visual feedback projected from a computer screen on a mirror. In normal trials, the line seen in the mirror exactly matched the traced lines. In perturbed trials, a bias was introduced and subjects consistently displaced their hand in order to compensate the bias. After each trial, they were asked in which direction they thought their hand had moved. They showed poor consciousness of the signals generated by their own movements and they tended to adhere to visual information rather than to kinesthetic information. With another experimental device, Sirigu et al (1999) asked apraxic patients to execute hand movements, while the visual feedback they received about the movement was systematically manipulated. They were required to decide whether the movement shown on the screen was their own or not. They showed severe difficulties in recognizing their own movements and they tended to believe what they saw rather than anything else. Two patients overtly expressed their own surprise at how well they had executed the movement, while in fact they failed to perform it. In other words, visual feedback given on the screen became predominant constituting the unique information available for conscious decision.

More generally, it is well established that we trust vision and give it priority, and if there is any conflict with other sensory modalities, what we see prevails. It is thus all the more surprising that illusions of phantom limb are not erased by the fact that patients see that the limb does not exist. Another neuropsychological phenomenon is also resistent to vision, that is, anosognosia. In the case of anosognosia, patients feel as if they can move their arm while they are paralyzed, whereas in the case of phantom limb, patients feel as if they have an arm while they don't have it any more. More generally, anosognosic patients suffer from a certain deficit[4] without any consciousness of this deficit. They can deny the importance of their deficit (anosodiaphora) or deny that they have any problem. In the latter case, if you ask the patient to move while he is paralyzed, he will confabulate and explain that he doesn't want to move. He can also pretend that he has accomplished the desired movement while he can obviously see that his

[4] The deficit can be visual, motor, verbal… but we are interested here only by anosognosia for hemiplegia.

arm has not moved at all. As in the phenomenon of phantom limb, they have the illusion of movements despite the fact that they don't see any movement.

We could try to extend theoretical explanations of anosognosia to the phenomenon of phantom limb. One hypothesis about anosognosia suggests that the loss of sensory information is not phenomenologically salient and has to be discovered by observation and inference (Levine et al, 1991). However, this theory of "discovery" cannot be applied to the phenomenon of phantom limb for two reasons. First, we have seen that the phenomenon of phantom limb cannot be defined as a sensory loss, it is rather a problem of sensory mislocalization. Second, while anosognosic patients really believe that they move, patients with phantom limbs only feel "as if" they move, but do not believe that they actually move nor do they believe that their phantom limb is real. Their problem is that their theoretical knowledge does not suffice to erase the illusion.

At this level, we should make a distinction between two levels of perception: object perception (the child sees a cat) and fact perception (the child sees that there is *a* cat) (Dretske, 1995). When I see a cat, there is a primary level where I just see the cat without recognizing or naming what I see. At this low level, there is something it is like to see the cat but I do not identify the cat as a cat. That's what Dretske calls the level of object perception (or non-epistemic perception). Object perception constitutes the basis of fact perception (or epistemic perception). Fact perception is the perception that the object O has a certain property P. At this level, I recognize what I see and I can also misrecognize it.

In this conceptual framework, we can provide two interpretations of the resistance of the proprioceptive illusion of phantom limb to vision. First, we can understand it as the consequence of the encapsulation of object perception. The persistency of illusion despite contradictory beliefs is a well-known phenomenon in visual illusions. In the illusion of Muller-Lyer, even if one knows perfectly that both lines have the same size, one cannot help feeling as if one line is longer than the other. Indeed, the visual illusion results from encapsulated visual processing that cannot be influenced by higher order beliefs. Similarly, the illusion of phantom limb should be understood as the output of early stages of proprioceptive and tactile processing. The level of non-epistemic proprioception (the "what it is like" to have a phantom limb) and the level of epistemic vision (the visual belief that one is amputated) cannot communicate.

However, we have also to describe the relation between non-epistemic vision and non- epistemic proprioception. At this low level, there should be a conflict between what patients see and what they feel, and unlike what usually happens, patients do not seem to take into account what they see. Maybe we could say that there is no plurimodal integration. In order to understand why, we are going to see what happens when patients are confronted with the vision of their phantom limb.

Chasing the Phantom

Paralytic patients before amputation have learnt that their intentions to move are not followed by actual movements. Consequently, even after amputation, the brain still thinks that the phantom limb is frozen in the prior position. For suppressing the paralysis, Ramachandran and Rogers-Ramachandran (1996) have invented a virtual reality box that provides to patients the missing visual feedback of the phantom hand in movement. A mirror is placed vertically so that the mirror reflection of the intact hand is "superimposed" on the felt position of the phantom hand; when the intact hand moves, the mirror reflects a moving contralateral hand. This experimental device induced the illusion of phantom movements in six of ten patients, even if the phantom hand had been paralyzed for ten years. It allowed certain patients to unclench their painful hand. Moreover, for three patients, the tactile stimulation of the intact hand induced a sensation of touch at the level of the phantom hand. Interestingly, the tactile sensation increased when patients saw their phantom hand being touched. It also influenced the presence of the phantom limb itself. Indeed, a patient whose phantom finger disappeared 28 years ago felt again his phantom finger with the mirror box. Conversely, a repeated practice of simple movements in the box during three weeks suddenly induced the complete dissolution of D.S.'s phantom arm.

We should notice here that these phenomena occur even if the normal hand put into the box belongs to the experimenter. It means that patients do not just transpose proprioceptive information from the intact limb to the contralateral absent limb. Pure visual feedback plays an important role and allows (1) phantom movements, (2) phantom tactile sensations, (3) reappearance and disappearance of phantom limb.

Ramachandran's mirror box reveals the following paradox: what chases out the phantom is not the vision of the absence of the limb, but rather the vision of the phantom limb. With the mirror box, as visual inputs become consistent with proprioceptive inputs (there is a hand in such position), we could expect that this consistency reinforces the illusion and indeed it induces phantom movements, tactile sensations and even the reappearance of a phantom finger. However, it has also the opposite effect, the extinction of the representation of D.S.'s phantom arm. How can we explain this result?

Before trying to formulate some hypotheses, I'd like to focus on another case of dissolution of phantom limbs occurring after hand transplant. Giraux et al. (2001) describe the case of D.C. who underwent amputation of both hands in

1996 and who felt painless phantom hands.[5] Four years later, he was given two new hands. Progressively, he has regained his sensitivity and his motricity. At the level of the somatosensory representation, Giraux et al. show a shifting of the representation of the hand, the hand winning back lost ground suffered during amputation. This shift proves the late reversibility of the reorganization of the Penfield Homonculus following amputation: the new hands restore what was lost in body representation. The new flesh and blood hands have quickly replaced the phantom hands and D.C. began to recognize his new hands as his own before he regained his complete sensitivity and motricity. Different factors can explain this fast integration of the new hands: (i) cortical plasticity, (ii) micro-movements made very quickly after the operation, (iii) vision of the hands. Relative to this latter point, D.C. is in the same situation as if he has put his hands in the mirror box, but in his case what he sees is reality. Another difference is that in the case of the graft, the phantom disappears, but not the representation of the hand, while in the case of the mirror box, the phantom and the hand representation disappear.

Knowledge with Observation of One's Own Body

Ramachandran and Blakeslee (1998) assert that D.S. was "the first amputation of a phantom limb," an amputation allowed by the vision of the phantom limb in movement. However, we should be more cautious. Indeed, D.S. still had phantom fingers that he felt near the shoulder. In addition, Ramachandran describes only one case and nothing guarantees that the disappearance of the phantom actually depended on the utilization of the mirror box. Thus, we can wonder about the effective role of vision in this amputation. Nevertheless, keeping in mind these limits, it seems to me interesting to try to analyze the effect of vision on phantom limbs.

One hypothesis could be that the mirror box and the graft allow visual feedback to play again a role in body representation. The idea is that most of the time, amputated patients do not confront proprioceptive and visual information together. Even if vision is processing the same portion of objective space as proprioception,[6] visual and proprioceptive inputs are not "about" the same object. Indeed, vision does not carry information about a body part, but only about what is visible at the place where the hand no longer exists. Conversely, proprioception

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[5] More particularly, D.C. reported the feeling of putting on gloves when putting on his prothesis, and he was able to count his phantom fingers and to move them.

[6] For instance, the area beyond the elbow in the extension of the arm.

concerns only the body. Therefore, there is no reason why what we see should be compared with what we feel. As there is no conflict, there is no attempt to resolve the conflict. In other words, when the messages from vision and proprioception are too different, there cannot be any communication between them. Therefore, there are only conflicts and resolutions of conflicts when sensory representations have the same intentional object – when they are about the same thing, that is, about the body. It does not suffice to occupy the same place in objective space, it has also to be localized in body space.

On the other hand, cases in which both proprioceptive and visual information concern the body initiate a new dialogue between them. That's what the phenomenon of brachial plexus shows. People who have sustained a brachial plexus avulsion are partly paralyzed, but they also experience the feeling of having a phantom arm fixed in a different position than the real arm. What is interesting is that they are confronted with a conflict between the seen position of the real arm and the felt position of the phantom arm, a conflict that they try to solve by putting their real paralyzed arm in the same position as the phantom arm.

Conversely, with the mirror box and the graft, visual inputs match proprioceptive inputs. With the repeated utilization of the mirror box, we may speculate that the consistency creates expectancies about the presence of a visual hand: the subject gets used to comparing what he feels with what he sees and this comparison leads to a visuo-proprioceptive conflict outside the mirror box. The solution of the conflict is to give supremacy to visual information and to inhibit proprioceptive information so that the phantom limb disappears:

> However, if the device is used for a long time, the resulting flood of conflicting sensory information (e.g. from vision versus proprioception), may cause the signals from the limb to be "gated" so that the arm disappears. (Ramachandran and Rogers-Ramachandran, 1996, p. 382).

In the case of the graft, the consistency between visual and proprioceptive information reinforces the representation of the hand. We should notice that the persistency of hand representation through the presence of phantom hands allows D.C. to integrate more easily the new hands. Otherwise without phantom hands, it would have taken more time for the patient to adopt his new hands and to generate a new hand representation.

This is pure speculation. However, it seems clear that we have to be careful for our understanding of body knowledge to take into account vision as well as proprioception. It seems that the knowledge of one's own body is far from being a "knowledge without observation" (Anscombe, 1959). According to Anscombe, we directly know the position of our body without any observation, in the same way that we know our own intentions: I do not need to observe my hand raising in order to know that I intend to raise my arm; similarly, I do not need to observe my legs crossed in order to know that they are crossed. Indeed, I can know the position of my legs without looking at them. What distinguishes the knowledge of my own body from the knowledge of another's body is internal perception (I have a proprioceptive access only to my own body). Nevertheless, internal perception does not exhaust the characterization of the knowledge of one's own body and we should not forget that most of the time, it depends on the integration of proprioceptive and visual information.[7]

The question now is to determine at which level vision intervenes. Till now I have talked about body representations without mentioning the different kinds of such representations. Gallagher (1995) makes a distinction between body image and body schema. A simplified version of this distinction would characterize the body image as a conceptual conscious representation of the body and the body schema as a non-conceptual sensory-motor representation of the body. On this interpretation, vision might be said to play a role mostly at the conscious level of body image whereas instrumental proprioception is considered as part of the basis of body schema. For instance, vision allows me to recognize myself in the mirror and proprioception allows me to grasp the glass in front of me. According to Gallagher and Cole (1995), the loss of proprioception would even result in the loss of the body schema in deafferented patients. However, we should not assimilate the distinction between body image and body schema to the distinction between vision and proprioception. Reflexive proprioception influences the body image and vision plays an important role in the body schema. In Fourneret and Jeannerod's experiment, subjects compensated to the visual bias even if they were not conscious of doing so. This sensori-motor adjustment resulted from the comparison between the efferent copy of the motor command and visual feedback. There would have been no adjustment if they had compared the efferent copy with the proprioceptive feedback because there would have been no discrepancy between both signals.

But do we want to say that this sensori-motor use of visual information is identical to the use that is involved in mirror recognition? We have seen that O'Shaughnessy distinguishes instrumental and reflexive proprioception. I suggest that we could also apply this distinction to vision. Instrumental vision would be the unconscious flow of visual feedback about the position of one's own body in movement, while reflexive vision would be the conscious use of visual information that provides semantic information about one's own body. In other words, in Milner and Goodale's terminology (1995), there is a vision for action and a vision for recognition. This latter distinction is usually applied to external

[7] Graziano (1999) finds in the monkey some neurons in the premotor cortex that are activated by both kinds of information.

objects but we can extend it for body perception. Indeed, by definition vision for action encodes the relation between the agent and the goal. Therefore, it encodes both the goal and the body of the agent.

We should not confound instrumental vision with Gibson's notion of visual kinesthesis. Through visual kinesthesis, visual experiences about the external world generated by motion are decoded so that subjects perceive that they are moving:

> Vision is kinesthetic in that it registers movements of the body just as much as does the muscle joint skin system and the inner ear system. Vision picks up both movements of the whole body relative to the ground and movement of a member of the body relative to the whole." (Gibson, 1979, p. 183).

So, visual kinesthesis is primarily about the external world and it makes available information about the movement of the perceiver by computations made on the basis of the optic flow, whereas instrumental vision directly concerns the movement of one's own body.

In summary, I agree with Anscombe if she means that we do rarely use vision for identification. But I do not agree with her if she means that we do not appeal to instrumental visual information about our own body and visual kinesthesis that both belong to the body schema.[8] However, one can say that instrumental vision is not a case of observational knowledge, but rather a case of pragmatic knowledge, a "know how." Vision intervenes in the detection of body position but also in the knowledge of body existence. However, in order to be able to influence body representation, visual inputs need to be about the body and not about the place where the body was.

Finally, I'd like to point out the importance of action in the dissolution of phantom limbs. Indeed, D.S. ceased to feel his phantom arm because he was moving his phantom in the mirror box. Monitoring of action allows comparisons between visual feedback and efferent copy, which leads to the disappearance of the phantom limb. Thus, action makes it possible for visual information to play its role in the knowledge of body existence.

The aplasic phantom

We have seen how somatosensory remapping induces the feeling of phantom limbs. However, we may wonder how this hypothesis could account for the

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[8] We can even suggest that in the absence of proprioception, deafferented patients can rely on this kind of instrumental vision for guiding their actions.

existence of phantom limbs in aplasic patients, given that they have never received any tactile or proprioceptive information about the absent body part. There are three alternatives[9]. According to Merleau-Ponty (1962), the body schema is the product of development and in the absence of any sensory information, the representation of the absent limb has never been able to develop. In other words, as the absence of the limb is congenital, the Penfield Homonculus reflects this absence since the beginning: there has never been any somatosensory representation of the limb and aplasic people cannot have phantom limbs. However, it has been shown now that aplasic people do experience phantom limbs (Melzack 1990, 1992). Therefore, we need to provide another explanation. The second alternative consists in appealing to another source of sensory information. If phantom limbs cannot exist without sensory information and if phantom limbs do exist while there is no sensory information about one's own body, then phantom limbs are based on the observation of the bodies of other people. However, we can also suggest a third possible reply: it is not necessary to receive sensory inputs for constructing the body schema. Knowledge of the body is not only empirical, it is also innate.

Shared representations of the body

One explanation is to appeal once again to vision, not the vision of one's own body but the vision of the body of other people. Even if aplasic patients have never seen their limb, still they have been able to observe the body of other people around them. We have seen that the vision of the experimenter's hand in the mirror box sufficed to induce illusory movements of the phantom hand. Moreover, there is a network of human brain activation common to simulation, execution and observation of actions.[10] Rizzolatti et al (1996) have also found that the same mirror neurons in the area 6 fire whether a monkey is observing a specific movement or executing it. Thus, it means that doing an action and observing it activate the same internal representation of action. Appealing to this theory, Brugger et al (2000) emphasize the importance of the observation of actions performed by others for the existence of phantom movements in aplasic people: the representation of someone moving would allow the representation of oneself moving. We can extend this idea of action representations shared between

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[9] For a review of the debate about the existence of innate body schema, see Gallagher and Meltzoff (1996).

[10] The inferior parietal lobule (area 40), part of the supplementary motor area and the ventral premotor area (Decety et al 1997).

oneself and the others to body representations. For instance, in the phenomenon of facial imitation, one needs to map from visual information of the body of someone else to proprioceptive information about one's own body. Thus, in order to do so, one needs to have a common undifferentiated representation that describes one's own body and the body of others. In aplasic people, the absence of somatosensory information about the absent limb would be compensated by visual information about the body of other people.

However, I'd like to point out two difficulties in this hypothesis. First, this kind of explanation doesn't account for the precise content of the illusion. If the phantom limb reflects the limb of other people, it should be normal and this is not the case: the phantom limb could be too short or the arm could be "telescoped."[11] Second, maybe observation of other people can compensate the loss of sensory information about one's own body, but can it compensate the complete absence of sensory information? In other words, the representation of other people is not necessarily sufficient to construct the representation of oneself. Consequently, aplasic patients need to already have a representation of their own body in order to be able to use visual information about the body of other people; as they have never received any sensory input about their own body, this representation has to be innate.

An innate representation of the body

Neonates show various abilities that tend to confirm the existence of an innate body representation. It has been shown that very young infants are able to imitate some simple movements like protrusion of tongue. According to Meltzoff and Moore (1999), an innate system of active intermodal mapping (AIM) makes facial imitation possible in neonates. Indeed, facial imitation requires one to map visual information to a motor schema based on an innate representation of the face in order to reproduce on one's own face the movement that is seen on the other's face. In addition, it has been shown that the infant's mouth "anticipates" the arrival of the hand in hand-to-mouth movements. According to Gallagher et al. (1998), this hand-mouth coordination, which can be found in utero and in early infancy, provides evidence of an innate motor schema. The same innate motor schema would also partly explain the existence of phantom limbs in aplasic patients: the hand is represented in the innate schema of the mouth-hand coordination despite the lack of the hand.

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[11] When the fingers are next to the elbow for instance.

Based on the study of phantom limbs in aplasic people, Melzack (1990, 1992, and 1997) also proposes that there is an innate structure of body representation, the "neuromatrix." The idea is that sensory inputs are not sufficient in themselves to construct body representations, they can only become integrated into a pre-existing neuromatrix. Roughly, the innate body representation could be compared to a form such as "right arm, left arm, right leg, left leg, etc.," and sensory information would give a content to each box. In the absence of any sensory information, the innate body representation would still endure. According to Melzack, the neuromatrix is a neural network that includes the sensory pathways (from thalamus to somatosensory cortex), the limbic system associated with emotion and motivation, and the parietal lobe, which is necessary for the sense of ownership of the body. The neuromatrix replies to the sensory inputs and continuously generates a "neurosignature," that is, a specific pattern that indicates that (1) the body is intact, and (2) the body belongs to the subject. The information is shared between the three systems and converted into an integrated output. If the neuromatrix is only associated with the neurosignature without any peripheral information, the subject would feel the presence of a phantom limb.

We should notice that Gallagher and Melzack slightly differ in their conceptions of innate body representations and aplasic phantoms. Indeed, Gallagher sustains the existence of an innate body schema[12] while Melzack tends to describe an innate body image, which is both perceptual and emotional. Moreover, unlike Melzack, Gallagher enphasizes the importance of the reorganization of the neuromatrix, a reorganization similar to the remapping of the Penfield Homonculus. This reorganization in prenatal development can be more or less dramatic and it is only in the case where it is partial that aplasic phantoms appear.[13] For my part, I think that both body schema and body image can be partly innate. Relative to the question of reorganization, it would be interesting to know whether aplasic people scratch their face when their phantom hand itches.

The illusion of phantom limb would remain a mystery if we describe the brain as a passive receptor of sensory information. What we need to understand is that body representation is not the simple reflection of peripheral inputs, it is rather the result of an active process of integration of afferent information (vision, proprioception, touch, etc.) and efferent signals such as efferent copies of motor commands. Such integration can require resolving conflicts between the different kinds of inputs and what we see prevails on what we feel as long as the intentional

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[12] Gallagher and Meltzoff (1996) also admit the possibility of an innate body image.

[13] Otherwise, it results in the absence of aplasic phantom as it is the case in 80% of aplasic people (Melzack, 1990).

object of visual information is the body itself. More than a body representation, we should talk of a construction of the body, a construction based on an innate structure. Thus, the knowledge of body existence is both innate and empirical, visual and proprioceptive, fallible and easily influenced. Maybe this paper offers more questions than replies but it shows that we need to give up the idea of the knowledge of the existence of our own body as a primitive fact immediately given.

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