Cognitive and bodily selves: how do they interact following brain lesion?

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Dualism has long distinguished between the mental and the body experiences. Probing the structure and organisation of the self traditionally calls for a distinction between these two sides of the self coin. It is far beyond the scope of this chapter to address these philosophical issues, and our starting point will be the simple distinction between reflective processes involved in the elaboration of body image, self awareness and self-recognition (i.e. 'the self') and the sensori-motor dialogues involved in action control, reactions and automatisms (i.e. 'the body' schema). This oversimplification does not take into account the complex interactions taking place between these two levels of description, but our initial aim will be to distinguish between them, before addressing the question of their interactions. Cognitive and sensori-motor processes have frequently been distinguished (review: Rossetti and Revonsuo 2000), and it may be proposed that a similar dissociation can be put forward, a priori, between a central representation of self and a bodily representation corresponding to body schema (Figure 1).

Body schema and body image

Human pathology often reveals dissociated deficits for cognitive and sensori-motor representations. Jacques Paillard, among the firsts of many others (review in Rossetti 1998, Rossetti and Revonsuo 2000), provided a theoretical framework to distinguish between these two processes and reviewed empirical evidence for the distinction (e.g. Paillard 1985, 1987). From his initial sensori-motor area of research practice, which led him to emphasise the role of the moving body in the construction of spatial representations (Paillard 1971), he in turn exported the theoretical distinction into several other fields. His most important contribution to the exploration of the self has been his version of the distinction between body schema and body image (Paillard, 1980, 1982). His first account of the distinction was to translate the "what" and "where" dissociation emphasised in the visual system onto body representations (Paillard 1980), binding the classical psychological distinctions with modern neurophysiological data.

As argued by several authors (e.g., Head and Holmes, 1911; Paillard, 1999, 2005) several aspects of body representation should be distinguished. Obviously one is able to make use of the skin information fed to the primary cortex to construct a "superficial schema". Then a "postural schema" is used to register all changes of posture. This latter representation is now more often referred to as "Body schema" (Schindler, 1935). This level is considered to correspond to a low-level sensori-motor processing of body information prior to its conscious processing. The proper body image ("l'image du corps"; Lhermitte 1942) refers to the actual conscious representation of information related to the body, not only of somatosensory but also of visual and motor origin. Beyond the physiological descriptions, further experiences of the body can be described. As proposed by F. Dolto for example, there are also unconscious levels of body image ("l'image inconsciente du corps"). These images refer to symbolic representations of one's own body that are not directly linked to the low-level sensory inputs. As argued by Dolto, this unconscious body image is purely unconscious whereas the body schema is partly unconscious but also preconscious.

She also delineates a “conscious body schema” which can be taken as an equivalent of the (conscious) body image defined by Lhermitte. Although they have not been investigated systematically by neuropsychological approaches, these unconscious representations inevitably play an important role in the organisation of the patient’s reactions to a deficit. The dominant account of these distinctions in the field of cognitive neuroscience is the distinction between body schema and body image (Paillard 1980, 1999, 2005).

Neurological arguments for the distinction

The key empirical argument used to argue for a double dissociation between body schema and body image comes from the comparison of central and peripheral deafferentation. As early as 1983, Jacques Paillard and colleagues published a paper on a centrally deafferented patient AT (Paillard et al. 1983). Following the discovery of blindsight, they similarly showed that this patient could not feel any tactile stimulus applied to her hand, but could nevertheless point with significant accuracy toward the stimulus. Paillard et al. interpreted their result as a dissociation between “what” (impaired) and “where” (preserved) processing in the somatosensory domain. This tactile equivalent to blindsight was further explored in a patient with a thalamic lesion leading to a complete somatosensory loss on the right side (Rossetti et al. 1995). As the previous case, this patient, JA, could not detect if a touch was applied to his arm, even in a forced-choice manner. And he remained able to point to the location of the stimulus with a well above chance performance. However, the patient could not show where he had been touched on a full-scale drawing of his own arm, demonstrating that the residual pointing ability could only be expressed when pointing where directed at the stimulus (Figure 2). Therefore it was concluded that the residual ability found in this patient did not pertain to ‘where’ processing but rather to ‘how’ processing. The common feature of the two patients was that they remained fully unaware of somatosensory stimuli but could express some residual processing via the sensori-motor representation provided by their body schema.

Paillard contrasted this finding with another patient, GL, who presented with a peripheral loss of somatosensory processing. In this patient, tactile and proprioceptive capacities were lost for long, and she has been extensively studied in to research on proprioceptive deafferentation. However she exhibited a residual thermal stimulus processing, which could be used to investigate her ability to locate stimuli applied to her body surface. Paillard first tested her capacity to locate thermal stimuli by pointing to her own body, a task in which she performed randomly. Paillard then tested her ability to verbalize and to show on a picture of the body where she had been touched. On these tasks she proved to be very accurate in localising the stimulated site (Paillard, 2005). Paillard concluded that GL was able to locate the stimulus on her body, using a conscious body image, without being able to use the same information to drive stimulus oriented movements, i.e. she wasn’t able to incorporate this thermal stimulus in her body schema.

Taken together, these two neurological conditions suggested that there may be a double dissociation between the body schema and the body image (Paillard 2005). However a number of points deserve discussion before this hypothesis can be validated. First, should the inability of GL to point at a cutaneous stimulus be attributed to a sensory or to a motor deficit? A proprioceptive deafferentation makes it difficult to locate the hand in space and hence to guide hand movement in the absence of visual feedback. The apparent failure to locate the stimulus on her body may be explained by a relatively low level motor control deficit rather than by a central representation problem. It would be crucial to know whether GL could show where the location of the stimulus was on her body once she could open her eyes.

Second, one may expect the higher level of body representation to be less prone to deterioration in the presence of a sensory deficit. The sensori-motor levels should be directly and immediately affected by sensory loss, but the higher level should exhibit more inertia. As a matter of fact, JA had a recent stroke causing his deficit while GL presented her deficit for over 10 years. [NOT CLEAR WHAT THIS LAST SENTENCE MEANS OR WHY IT'S IMPORTANT FOR THIS DISTINCTION]

Third, it seems necessary to further define or assess whether localising a stimulus on a body map is representative of the body image. This point is reminiscent of Gordon Holmes' [OTHERWISE IT COULD BE NP HOLMES] classification including a superficial schemata in-between the body schema and the body image levels of processing [G HOLMES DIDN'T TALK ABOUT THE BODY IMAGE DIRECTLY, SO I DON'T UNDERSTAND THIS POINT]. As pointed out by Paillard himself, it is interesting that this superficial representation was defined as a schema, just like the body schema, and not like an image. Can we simply consider that pointing directly to a superficial stimulus activates the body schema whereas pointing to a body map activates the body image? In patients with higher-level body representation problems sych as auto-topoagnosia, the deficit exhibited by the patients does not seem to correspond to a simple body schema deficit, and accordingly their simple actions are not altered (Felician et al. 2003).

Fourth, and more theoretically, several types of interaction have been described between the so called dissociated levels (cf. Rossetti 1998, Rossetti and Pisella 2002).

Self schema and self image

The above questions emphasise the need for clarification before clear conclusions can be drawn about a clear separation of body schema and body image. As a matter of fact, correlates of self perception can be searched for either at the level of body schema or at the level of body image. At the methodological level, it should be stressed that, since the body schema is involved in sensori-motor interactions, it is important to distinguish between its sensory and motor aspects. Interestingly, most of the empirical studies performed to explore the sense of ownership or agency have relied on action paradigms, both in healthy participants and in neurological or psychiatric patients. Most of these studies concluded that there was a bias in favour of self recognition of other's movements or body parts (e.g. Daprati et al. 1997; van der Bos and Jeannerod 2002; Farrer et al. 2003). One crucial methodological question about these approaches is about whether they tested for sensory-motor or inter-sensory difference detection capacities, i.e. a self shema, or for a proper self representation, i.e. a self image? This question calls for using different paradigms, relying on a different question, in order to eliminate this possible bias. A compelling conclusion of these sensorimotor studies is nevertheless that there is a bias for 'self' response in all categories of subjects. However it is known for long that patients with Anton-Babinski syndrome show the opposite trend: they typically deny ownership of their own upper or lower left limb. We have therefore investigated the sense of hand ownership with a simple, but original paradigm (see also Frassinetti et al. 2008).

In the absence of brain damage, recognising your own body, and particularly your own hands, is a trivially simple thing that seems to require very little effort. We are typically always aware of both where our hands are in space, and of the fact that the hands we see and feel in front of us are ours. the ability to recognise and perceive our own body can be lost or impaired following brain damage, resulting in, for example, somatoparaphrenia (e.g., Rode et al., 1992). The fact that this ability (i.e., self-recognition) can be impaired by brain damage suggests that it depends on the operation of a particular brain area which is specialised for self-recognition, and is damaged in those patients with somatoparaphrenia. Alternatively, self-recognition may depend on other brain areas that are not damaged in these patients, but the loss of sensory and motor information related to the hand (e.g., visual, tactile, proprioceptive, efference copy), forces the self-recognition system into a conservative state of 'denial' – the brain reasons that 'if I don't have sufficient sensory information to feel ownership over a particular body part, then it can't be mine'.

We tested this idea in healthy participants. We photographed the left and right hands of participants in both a palm-down and a palm-up posture, then presented the images to them on screen, intermixed with similar photographs of other participants' hands (matched for sex, hand-size, and gross surface features such as skin tone and hairiness). We manipulated the duration that the hand stimuli were displayed on screen, and backward-masked them with an image of scrambled hand-parts (Figure 3). The rationale was to examine how well healthy participants can recognise their own hands (i.e. responding 'mine' or 'not mine') when the available information about the visible hands is decreased to the point that the stimulus is barely visible.

When the visual stimuli were on-screen for 67ms or longer, healthy participants could recognise their own hands better than chance, and displayed no systematic biases in their responding (i.e. they were just as good at saying an image of their own hand was theirs, as saying that an image of another person's hand was *not* theirs. By contrast, when the visual stimuli were presented for 33ms, participants performed significantly above chance levels, but their responses became more conservative – they began to 'disown' the hand images, and typically responded 'not mine'. With only 17ms of stimulus presentation, performance was at chance levels, and participants' strategy became even more conservative. Participants responded about 70% of the time 'not mine', even when they were repeatedly informed that half of the stimuli were photographs of their own hands, and half of other peoples' hands (Figure 4).

How does this relate to somatoparaphrenia and related disorders? It seems that healthy participants are very likely to 'disown' static images of their hands when they do not have sufficient sensory information to make a confident ownership decision: They become more conservative in making explicit ownership judgements. These healthy subjects seem to have an intact mechanism for recognising their own hands, since they performed above chance performance with just 33ms of visual information, but they systematically erred towards denial of ownership when the available sensory information was impoverished. The implications for studying self-recognition in neglect, anosognosia, or somatoparaphrenia are that we need to rule out the possibility that patients are simply adopting a conservative strategy when denying ownership or disease in their affected limbs. The mechanism responsible for self-recognition may be perfectly intact, but when deprived of sensory input from the affected limbs, it assumes a conservative criterion and denies ownership over the limb. Preliminary experiments on patients with unilateral neglect suggest that this conservative criterion may be increased, which is compatible with the classical description of patients with Anton-Babinski syndrome (Rode et al. 1992). However further experiments are needed to assess whether this finding can be generalised across neglect patients with various degrees of severity.

The apparent hierarchy between body image and body schema

When cognitive and sensorimotor levels of processing are distinguished, most emphasis is put on the top-down controls exerted by the higher cognitive level on the more primitive sensorimotor processes (review: Rossetti 1998, Rossetti and Revonsuo 2000). In short, all types of hierarchical control seem be to applied to the sensorimotor level: it can be configured, activated or inhibited by the cognitive supervisor (Rossetti 1998, see figure 5). In the case of body schema and body image, a similar description can be proposed (Rossetti et al. 2005). If one considers the case of numbsense described above, three types of control can be observed. First, as is the case in blindsight, the patients cannot make a spontaneous use of the stimulus. They have to be precisely instructed about what dimension of the stimulus will be varied and what is the expected responses they will have to make. These instruction allow the patient to configure sensorimotor transformations to appropriately process the unfelt stimulus. Second, the patients have to be told when the response is to be made, as they don’t detect the stimulus. This go signal is required to activate the sensorimotor transformation process while the stimulus is available. Third, any attempt to activate a higher level computation of the response will impose its (empty) representation on the sensorimotor process and disrupt its performance. For example, activating a simultaneous cognitive representation of the tactile stimulus inherent to a verbal answer has been shown to disrupt the action-numbsense capacities (Rossetti 1998, Rossetti et al. 2001, Rossetti and Pisella

2002). This phenomenon is depicted in Figure 6. The performance obtained in the sensori-motor pointing task already shown on Figure 2 dropped down to chance level when the simultaneous verbal response was required. In the same way, the introduction of a delay between the application of the stimulus and the pointing response produces a decrease in performance which reached chance level after 2 seconds for tactile stimuli and after 4 seconds for proprioceptive judgements (Rossetti 1998, Rossetti et al 2000, 2001, Rossetti and Pisella 2002, 2003). These results suggest that the higher level cognitive level of stimulus representation interferes negatively with the elementary sensori-motor processing.

It is obvious that, in the case of numbsense, these cognitive and sensori-motor levels of stimulus processing can be connected to the notions of body schema and body image, and this confirms Paillard's view that body image and body schema can be dissociated (Paillard 1999). If one accepts this idea, then one may be tempted to set body image in a position higher than body schema within the hierarchy of body representations, as depicted in Figure 1.

The above results show that is is clearly and logically a top-down influence of cognitive representations on sensori-motor processing of somatosensory stimuli. However a reciprocal influence has been demonstrated as well. A very spectacular effect has been initially revealed by Rubens and by Cappa (1987) in patients with unilateral neglect.

Unilateral neglect and body representation

After having been interpreted as a mere sensory deficit, unilateral neglect is now considered as a deficit of conscious access to information coming from the contra-lesional side of space (e.g. Driver and Mattingley, 2001; Vallar et al., 2003).

Neglect is mostly found following a lesion of the right hemisphere, which causes a deficit for the left side. The deficit observed in unilateral neglect applies both to body space and extra-personal space. Neglect patients typically exhibit inattention to sensory stimuli, and several aspects of their body schema appear to be impaired as well. External neglect is manifested for stimuli delivered in any sensory modality, although it has been mainly studied in the visual domain. Patients just appear to be omitting the items that are presented to their left (Figure 7 & 8). They may present with sustained eye and head deviations to the right or estimate the straight-ahead direction to be shifted to the right. They may produce slower movements to the left and even progressively omit to move the left hand during bimanual tapping. In addition, their body image can be affected as well. They may show anosognosia, i.e. the lack of awareness for a left-sided deficit such as hemiplegia, or even somatoparaphrenia, i.e. a delusion about their own body, especially about their neglected side.

There is no available direct evidence for a dissociation between body schema and body image in unilateral neglect. However several studies have shown that these patients are more impaired for perceptual tasks than for visuo-motor tasks. For example, they may be strongly biased when requested to indicate the middle of a stick with their finger, but they are relatively less impaired when the task is simply to grasp the object (e.g. Robertson et al. 1995). In this latter case, they show a better ability to locate implicitly the centre of the stick for the purpose of grasping. This, among other arguments, suggests that the lower-level visuo-motor functions may be relatively spared in unilateral neglect. Interestingly unilateral neglect patients may exhibit a deficit of both egocentric reference frames used for action and for self body perception. It is classical that patients with severe neglect have difficulties in representing their own body, as their left half is typically strongly neglected. As detailed in the next section of this chapter, personal neglect may include deficits ranging from an impoverishment of the representation of one side of the body to a distortion of the representation of the whole body. These higher-order deficits contrast with the preserved visuo-motor abilities and are compatible with the view that neglect is primarily a deficit of the conscious access and use of information. Higher-order alterations of body-image are exhibited by some neglect patients. Anosognosia and somatoparaphrenia are usually associated with severe neglect. The important point here is that these body-image deficits may not be systematically accompanied by an alteration of the body schema. Therefore the classical conception of a hierarchical domination of cognitive processes upon visuo-motor interactions (e.g. Rossetti, 1998; Pisella & Rossetti, 2000) is not supported by the case of neglect.

Bottom-up effects: Unilateral neglect and vestibular stimulation

Cappa et al. (1987) reported an improvement of anosognosia through vestibular stimulation in two of four right brain-damaged patients who also showed an extrapersonal and personal neglect. One patient (case 3) during the immediate and delayed post-stimulation assessments admitted that his left hand was weaker than the right only after specific inquiry, although he persisted in denying any deficit in the lower limb. By contrast, the second patient only acknowledged the motor deficits (upper and lower limbs) immediately after stimulation when questioned specifically, and spontaneously after 15 minutes said: “I don’t know why, I have always been able to move them, but now they are blocked: it is as if my brain is no longer able to command them.” This behavioural change was still present in the following days. In two patients, improvement of anosognosia was associated with transitory improvement of extrapersonal and personal neglect.

Bisiach et al. (1991) reported the effects of vestibular stimulation on the somatoparaphrenic delusion showed by a patient suffering from a fronto-temporo-parietal infarction in the right hemisphere. Before stimulation, when the examiner pointed to the patient's left arm and asked whose arm is this, she answered: "It's not mine. It's my mother's. I found it in my bed; since the first day. Feel, it's warmer than mine." Under caloric vestibular stimulation, the patient recognized that same arm as her own, but two hours later, the patient had completely relapsed in her full-blown delusion. The same stimulation was repeated twice and the results of vestibular activation were identical to those obtained in the first tests, confirming the possibility of an experimental manipulation of a body image deficit by a peripheral stimulation.

Rode et al. (1992) reported a similar partial remission of anosognosia and somatoparaphrenic delusion in a rare case of long lasting anosognosia consecutive to a large cortico-subcortical stroke of the right cerebral hemisphere including the parieto-temporo-occipital junction. Neurological examination performed 6 months post-onset disclosed a complete left hemiplegia, a left hemianaesthesia and a left apparent total hemianopia on confrontation. Head and gaze were permanently deviated to the right and the patient showed a severe extrapersonal and personal neglect. Anosognosia for hemiplegia and hemianopia was complete. The patient claimed that she was able to walk without any problem and did not understand why she was in hospital. She even accused her husband for having brought her there and asked over and over to go home. When an examiner brought the patient's left arm in her good visual field and asked whose it was, she answered: "It isn't mine. I found it in the bathroom, when I fell. It's not mine because it is too heavy. It must be yours."

When asked where her own arm was, she answered: ‘Behind the door’. Following a left cold ear irrigation, a temporary and complete remission of anosognosia and somatoparaphrenia were observed. The patient was totally aware of her hemiplegia. When asked if she could move her arm, she answered:’No’ and asked why, she said: “Because I have suffered from a hemiplegia. I was in my bathroom and I fell. I called my niece and I was taken to the hospital”. When the examiner brought her left arm in her good field, she recognized it as hers and no longer claimed it was the examiner’s. Surprisingly a temporary remission of the left motor deficit was also observed after vestibular stimulation.

Rode et al. (1998) assessed in the same patients the effects of vestibular stimulation on both anosognosia for hemiplegia and hemiplegia itself. Caloric vestibular stimulation (i.e. the irrigation of the left external ear canal with cold water) temporarily improved left-sided motor deficits in seven out of nine right brain-damaged patients. Neglect for the left side of the body (personal neglect) fully recovered in eight patients, and improved in one patient. All patients had exhibited anosognosia in the acute post-stroke stage, but the deficit was still present at the time of the vestibular stimulation study in six out of nine patients. Anosognosia completely recovered in five out of these six patients. These results were replicated by Vallar et al. (2003) in four right-brain damage patients examined within 24 hours after stroke onset. All patients had a left homonymous hemianopia and hemianaesthesia, and exhibited a severe visuo-spatial neglect, as assessed by bisection and cancellation tasks. All four patients had a severe motor deficit in the upper limb, which was temporarily improved by vestibular stimulation. In all four patients, temporary recovery of the muscle strength deficit paralleled recovery from anosognosia. Personal neglect appears to be unrelated to anosognosia for the left-sided motor deficit, being present in only two out of four patients.

These data showed that vestibular stimulation may temporarily improve both anosognosia for motor deficits and the motor deficits themselves, suggesting that when a deficit become less severe, due to the positive effects of the stimulation, patients become aware of the motor deficit. Recovery from anosognosia for hemiplegia after vestibular stimulation may result from the regression of a motor planning deficit, which itself contributes to the clinical manifestations of hemiparesis or hemiplegia (Vallar et al., 1993). An alternative view may be to consider that vestibular stimulation could act on the body schema[THE 'BODY SCHEMA' IS A REPRESENTATION OF THE BODY, SO A 'BODY SCHEMA REPRESENTATION' IS A REPRESENTATION OF A REPRESENTATION OF THE BODY – NOT VERY USEFUL FOR A BRAIN!], especially on the left part of body space representation.

Among the previous cases several exhibited a restoration of body schema through vestibular stimulation that was only transient. Nevertheless, this was sufficient to permit higher effects on body image consciousness. In the case reported by Bisiach et al. (1991), these effects have even been repeated after successive left cold ear irrigation. The restoration of body schema involved, at each time, a better evocation of explicit knowledge of the left hemibody and deficits located to it. A peripheral stimulation may thus favour “bottom-up” interactions between body schema and body image, between an implicit sensorimotor level and higher explicit level of body space representation, between primary perception and a modular thought-process.

Bottom-up effects: Unilateral neglect and prism adaptation

As the body schema provides the basis for sensori-motor coordination, one may speculate that other techniques known to alter this coordination may affect body schema as well. One interesting aspect of sensorimotor relationships is that they are highly susceptible to adaptive processes. Simple reaching behaviour can be adapted to dramatic changes of the relationship between the body and its environment. For example people can adapt to left-right or up-down reversal of the visual field within a few days (e.g. Sekiyama et al., 2000). A simpler technique, used extensively for about a century to investigate the plasticity of sensorimotor correspondences, consists of simply shifting the visual field to one side of space with prisms (for a review, Redding et al. 2005). This visual shift produces dramatic consequences on the reaching behaviour of the subject exposed to the goggles, but the adaptation to this condition can be obtained much faster than for the more complex visual manipulations mentioned above. Prism adaptation is a simple procedure but its effects are more complex than it seems and the actual development of adaptation is conditioned by a few parameters (Redding et al., 2005). For example, pointing to visual targets without sight of the arm must be controlled following the exposure to the prisms. This parameter is modified in predictable ways depending on the direction of the visual shift and can witness resulting modifications of the body schema. One very interesting connection between prism adaptation and spatial neglect is that prism adaptation can also produce a shift in manual straight-ahead demonstrations in a direction opposite to the visual shift, just like has been described in some patients with spatial neglect (Jeannerod & Rossetti, 1993). If a normal individual is exposed to right deviating prisms, he will exhibit a leftward deviation of his straight-ahead demonstration, and the opposite is true for left-deviating prisms. One may therefore wonder whether the egocentric reference of patients with spatial neglect could be altered by prism adaptation, and whether a hypothetical shift can be accompanied by an improvement of other neglect symptoms. Initially based on the theory stating that neglect was attributed to a shift of the egocentric reference frame that is demonstrable by manual straight-ahead demonstrations, we have investigated the effect of prism adaptation in neglect patients. We have initially demonstrated that the egocentric reference of the neglect patients, when tested through straight-ahead pointing, could be improved following adaptation (Rossetti et al., 1998). Then it was shown that visuo-manual (Rossetti et al., 1998; Pisella et al., 2002; Farnè et al., 2002; McIntosh et al., 2002; Frassinetti et al., 2002), visuo-ocular (Dijkerman et al., 2003), non-visual (imagery: Rode et al., 1999, 2001; touch: Maravita et al., 2003; auditory: Jacquin-Courtois, 2010), non-manual (posture: Tilikete et al., 2001; wheel-chair driving: Jacquin-Courtois, 2009) and even a non explicitly spatial task such as number bisection (Rossetti et al., 2004) could be improved following adaptation to the visuo-manual conflict induced by wedge prisms (reviews: Rossetti & Rode, 2002; Rode et al., 2003; Pisella et al. 2006). It should be emphasised here that awareness of the visual shift is not a necessary ingredient for prism adaptation. On the contrary, conditions preventing the subjects from being aware of the visual shift have been shown to produce stronger adaptation (Michel, 2003). In our experience, neglect patients never exhibited signs of awareness of the visual manipulation, even when specifically asked – whereas healthy controls show an immediate and strong reaction. In addition, the patients show no vegetative reactions (as assessed by skin conductance) to the introduction of prisms during a simple pointing task (Calabria et al., 2004). These arguments converge towards the idea that prism adaptation is acting at the physiological rather than the cognitive level, i.e. directly at the level of sensori-motor coordination that pertains to the body schema. This also shows that higher-level cognition is embodied to such extent that the apparently irrelevant plasticity of visuo-manual coordination is capable of altering at least several aspects of it (Figure 9). The logical consequence of this is that some of the sensori-motor effects of prism adaptation (e.g., postural balance: Tilikete et al., 2001; wheel-chair driving: Jacquin et al., 2009) are interpreted as indirect effects resulting from the top-down control of the corresponding function resulting from the bottom-up influence of visuo-manual adaptation on central representations (Rossetti et al., 1999; Rossetti & Rode 2002; Rode et al., 2003; Pisella et al. 2006).

Conclusions

We have reviewed here the body representation deficits exhibited by patients with intrinsic somatosensory deficits and unilateral neglect. We have tried to apply the concepts of body schema and body image to these conditions and attempted to delineate their behavioural correlates in trying to question their dissociability and interactions. Taken altogether, these clinical cases reveal that it is possible to dissociate between symptoms pertaining to each level of body representation, even if these two concepts [WHICH CONCEPTS? YOU MEAN REPRESENTATIONS?] may not suffice to reflect the inherent complexity of these representation processes [WHICH PROCESSES?]. Then, the issue of the interaction between a higher level body image and an elementary body schema has been addressed in a way that revealed both the expected top-down influences and more surprising bottom-up influences that can be used for rehabilitation purposes. We conclude that, despite an apparent simplicity, the relationship between body schema and body image is rich in reciprocal influences. One can speculate that the existence of these interactions in patients with impairment of at least one of the two levels is indicative of even richer interactions taking place in the healthy brain.

References

Bisiach, E., M.L. Rusconi & G. Vallar (1991). Remission of somatoparaphrenic delusion through vestibular stimulation. *Neuropsychologia 29,* 1029-1031.

Bisiach, E., M.L. Rusconi & G. Vallar (1991). Remission of somatoparaphrenic delusion through vestibular stimulation. *Neuropsychologia 29,* 1029-1031.

Calabria, M., C. Michel, J. Honoré, L. Pisella, G. Rode, D. Boisson & Y. Rossetti (2004). Poster presented at the first European Neuropsychology meeting, Modena, april 2004.

Cappa, S., R. Sterzi, G. Vallar & E. Bisiach (1987). Remission of hemineglect and anosognosia during vestibular stimulation. *Neuropsychologia, 25*, 775-782.

Cappa, S., R. Sterzi, G. Vallar & E. Bisiach (1987). Remission of hemineglect and anosognosia during vestibular stimulation. *Neuropsychologia, 25*, 775-782.

Daprati E, Franck N, Georgieff N, Proust J, Pacherie E, Dalery J, Jeannerod M. (1997) Looking for the agent: an investigation into consciousness of action and self-consciousness in schizophrenic patients. Cognition 65(1):71-86.

Dolto, F. (1984). *L'image inconsciente du corps.* Paris: Seuil.

Driver, J. & J.B. Mattingly (1998). Parietal neglect and visual awareness. Nat. Neurosci. 1(1), 17-22.

Farnè, A., Y. Rossetti, S. Toniolo & E. Làdavas (2002). Ameliorating neglect with prism adaptation: Visuo-manual vs. visuo-verbal measures. *Neuropsychologia, 40/7,* 1069-1080.

Farnè, A., Y. Rossetti, S. Toniolo & E. Làdavas (2002). Ameliorating neglect with prism adaptation: Visuo-manual vs. visuo-verbal measures. *Neuropsychologia, 40/7,* 1069-1080.

Farrer C, Franck N, Paillard J, Jeannerod M. (2003) The role of proprioception in action recognition. Conscious Cogn. 12(4):609-19.

Felician O, Ceccaldi M, Didic M, Thinus-Blanc C, Poncet M. (2003) Pointing to body parts: a double dissociation study. Neuropsychologia;41(10):1307-16.

Frassinetti F, Angeli V, Meneghello F, Avanzi S, Làdavas E. (2002) Long-lasting amelioration of visuospatial neglect by prism adaptation. Brain. 125:608-23.

Frassinetti F, Maini M, Romualdi S, Galante E, Avanzi S. (2008) Is it mine? Hemispheric asymmetries in corporeal self-recognition. J Cogn Neurosci.;20(8):1507-16.

Gallagher, S. (1986). Body image and body schema: a conceptual clarification. *Journal of* Dijkerman, H. C., R.D. McIntosh, Y. Rossetti, C. Tilikete, R.C. Roberts & A.D. Milner (2003). Ocular Scanning and Perceptual Size Distortion in Hemispatial Neglect: Effects of Prism Adaptation and Sequential Stimulus Presentation. *Experimental Brain Research, 153(2)*, 220-30.

Head, H. & G. Holmes (1911). Sensory disturbances from brain lesions. *Brain 34,* 102-154.

Jacquin-Courtois S, Rode G, Pisella L, Boisson D, Rossetti Y. (2008) Wheel-chair driving improvement following visuo-manual prism adaptation. Cortex 44(1):90-6.

Jacquin-Courtois, et al. (2010) Glasses to hear better. Brain, in press.

Jeannerod, M. & Y. Rossetti (1993). Visuomotor coordination as a dissociable function: experimental and clinical evidence. In C. Kennard (Ed.), *Visual perceptual defects. Baillère's Clinical Neurology, International Practise and Research* (439-460). London: Ballière Tindall.

Lhermitte, J. (1942). De l'image corporelle. *Revue Neurologique*, *74*, 20-38.

Maravita A, McNeil J, Malhotra P, Greenwood R, Husain M, Driver J. (2003) Prism adaptation can improve contralesional tactile perception in neglect. Neurology. 10;60(11):1829-31.

McIntosh, R.M., Y. Rossetti & A.D. Milner (2002). Prism adaptation improves chronic visual and haptic neglect. Cortex, 38, 309-320.

McIntosh, R.M., Y. Rossetti & A.D. Milner (2002). Prism adaptation improves chronic visual and haptic neglect. *Cortex, 38,* 309-320.

Michel C. (2006) Simulating unilateral neglect in normals: myth or reality? Restor Neurol Neurosci. 24(4-6):419-30.

Paillard J. (1971) Les déterminants moteurs de l'organisation de l'espace. Cahiers de Psychologie, 14, N° 4, 261-316

Paillard J. (1980) Le corps situé et le corps identifié : Une approche psychophysiologique de la notion de schéma corporel. Rev. Méd. Suisse Romande, 100: 129.141, 1980

Paillard J. (1982) Le corps et ses langages d'espace : Nouvelles contributions psychophysiologiques à l'étude du schéma corporel. In E. Jeddi (ed.). Le corps en Psychiatrie (p. 53-69) Paris. Masson.

Paillard J. (1985) Les niveaux sensori-moteurs et cognitif du contrôle de l'action. In M. Laurent & P.Therme (eds). Recherches en Activités Physiques et Sportives, Publication du Centre de Recherches de l'UEREPS, Université Aix-Marseille II. pp. 147-163.

Paillard J., Michel F, Stelmach G (1983) Localization Without Content. A Tactile Analogue of 'Blind Sight'. Archives of Neurology, 40, 548-551.

Paillard, J. (1999). Body schema and body image – a double dissociation in deafferented patients. In G.N. Gantchev, S. Mori & J. Massion (Eds.), Motor control, today and tomorrow. 197-214.

Paillard, J. (2005) Vectorial versus configural encoding of Body Space A neural basis for a distinction between Body schema and Body image. In : V.Knockaert & H. De Preester (eds) *Body Image and Body Schema: Interdisciplinary perspectives*. (pp. 89-109). John Benjamin, Amsterdam

Pisella, L. & Y. Rossetti (2000). Interaction between conscious identification and non-conscious sensori-motor processing: temporal constraints. In Y. Rossetti & A. Revonsuo (Eds.), *Beyond dissociation: Interaction between dissociated implicit and explicit processing* (129-151). Amsterdam: Benjamins.

Redding GM, Rossetti Y, Wallace B. (2005) Applications of prism adaptation: a tutorial in theory and method. Neurosci Biobehav Rev. 29(3):431-44.

Robertson IH, Nico D, Hood BM. (1995) The intention to act improves unilateral left neglect: two demonstrations. Neuroreport. 29;7(1):246-8.

Rode G, Charles N, Perenin M, Vighetto A, Trillet M, Aimard G (1992) Partial remission of hemiplegia and somatoparaphrenia through vestibular stimulation in a case of unilateral neglect. Cortex, 28(2):203-208.

Rode, G., C. Tilikete, J. Luauté, Y. Rossetti, A. Vighetto & D. Boission (2002). Bilateral vestibular stimulation does not improve hemineglect. Neurospychologia 40, 1104-1106.

Rode, G., C. Tilikete, J. Luauté, Y. Rossetti, A. Vighetto & D. Boission (2002). Bilateral vestibular stimulation does not improve hemineglect. Neurospychologia 40, 1104-1106.

Rode, G., L. Pisella, Y. Rossetti, A. Farnè & D. Boisson (2003). Bottom-up transfer of visuo-motor plasticity. Prism adaptation. Progress in Brain Research series vol.142, (273-287). Elsevier Amsterdam.

Rode, G., M.T. Perenin, J. Honoré, D. Boisson (1998). Improvement of the motor deficit of neglect patients through vestibular stimulation: evidence for a motor neglect component. Cortex, 34, 253-261.

Rode, G., M.T. Perenin, J. Honoré, D. Boisson (1998). Improvement of the motor deficit of neglect patients through vestibular stimulation: evidence for a motor neglect component. *Cortex, 34*, 253-261.

Rode, G., Y. Rossetti & D. Boisson (2001). Prism adaptation improves representational neglect. *Neuropsychologia, 39(11)*, 1250-4.

Rode, G., Y. Rossetti, L. Li & D. Boisson (1998). The effect of prism adaptation on neglect for visual imagery. *Behavioural Neurology, 11,* 251-258.

Rossetti, Y. & G. Rode (2002). Reducing spatial neglect by visual and other sensory manipulations: non-cognitive (physiological) routes to the rehabilitation of a cognitive disorder. In H.O. Karnathh, A.D. Milner, G. Vallar (Eds.), *The cognitive and neural bases of spatial neglect* (375-396). Oxford: Oxford University Press.

Rossetti, Y. & L. Pisella (2002). Tutorial: Several "vision for action" systems: A guide to dissociating and integrating dorsal and ventral functions. In W. Prinz & B. Hommel (Eds.), *Attention and Performance XIX; Common mechanisms in perception and action* (62-119). Oxford: Oxford University Press.

Rossetti, Y. (1998). Implicit short-lived motor representation of space in brain-damaged and healthy subjects. *Consciousness and Cognition, 7,* 520-558.

Rossetti, Y. (2001). Implicit perception in action: short-lived motor representations of space. In P.G. Grossenbacher (Ed), *Finding consciousness in the brain* (131-179). Amsterdam: Benjamins.

Rossetti, Y., G. Rode & D. Boisson (2001). Numbsense : a case study and implications. In B. De Gelder, E. De Haan & C. Heywood (Eds.), *Out of mind: Varieties of unconscious processing* (265-292). Oxford: Oxford University Press.

Rossetti, Y., G. Rode, L. Pisella, A. Farné, L. Li L., D. Boisson & M.-T. Perenin (1998). Prism adaptation to a rightward optical deviation rehabilitates left hemispatial neglect. *Nature, 395,* 166-169.

Rossetti, Y., G. Rode, L. Pisella, A. Farne, L. Ling & D. Boisson (1999). Sensorimotor plasticity and cognition: prism adaptation can affect various levels of space representation. In M. Grealy J.A. Thomson (Eds.), *Studies in Perception and Action*, (265-269). Mahwah, NJ, Lawrence Erlbaum Associates.

Rossetti, Y., S. Jacquin-Courtois, G. Rode, H. Ota, C. Michel, D. Boisson (2004). Is action the link between number and space representation? Visuo-manual adaptation improves number bisection in unilateral neglect. *Psychological Science, 15(6),* 426-30.

Rossetti, Y., S. Jacquin-Courtois, G. Rode, H. Ota, C. Michel, D. Boisson (2004). Is action the link between number and space representation? Visuo-manual adaptation improves number bisection in unilateral neglect. *Psychological Science, 15(6),* 426-30.

Schindler, P. (1935). *The image and the appearance of the human body.* New York: International University Press.

Sekiyama, K., S. Miyauchi, T. Imaruoka, H. Egusa, T. Tashiro T. (2000). Body image as a visuomotor transformation device revealed in adaptation to reversed vision. *Nature, 407 (6802),* 374-7.

Tilikete, C., G. Rode, Y. Rossetti, L. Li, J. Pichon & D. Boisson (2001). Prism adaptation to rightward optical deviation improves postural imbalance in left hemiparetic patients. *Current Biology, 11,* 524-528.

Vallar, G., G. Bottini & R. Sterzi (2003). Anosognosia for left-sided motor and sensory deficits, motor neglect, and sensory hemiinattention: is there a relationship? In C. Prablanc, D. Pelisson & Y. Rossetti (Eds.), *Progress in Brain Research, Vol. 142.* (199-310). Amsterdam, Elsevier Science B.V.

van den Bos E, Jeannerod M. (2002) Sense of body and sense of action both contribute to self-recognition. Cognition.85(2):177-87.

Figure captions

Figure 1 : Distinguishing between two levels of body representation

Schematic depiction of the relationship between central cognitive processes linked to self formation and sensori-motor dialogues operating at the body interface. The level of alteration linked to central and peripheral deafferentation and to unilateral neglect are shown (derived from Rossetti et al. 2005)

Figure 2: Numbsense

Pointing performance of patient JA in response to tactile stimuli (stars) delivered on the forearm. Black dots show the correct responses, which are well above the chance level in the direct pointing condition and just around chance level in the pointing on an arm drawing condition.

Figure 3

Healthy participants were presented with images of their own or of another persons' hands on screen for between 17 and 533ms, followed by a mask of scrambled hands for 200ms. Participants were required to make explicit 'mine' versus 'not mine' responses using two mouse buttons, and were informed that half of the stimuli would be their hands, and half other persons' hands.

Figure 4

Percentage of errors made in an explicit self-recognition task in healthy subjects as a function of stimulus presentation duration for images of the participants own hands ('self' – squares) and of other people's hands ('other' – circles). For stimulus presentation of less than 67ms, participants adopted a conservative response criterion, and consistently responded 'not mine' (i.e., they made many errors for their own hands, but few errors for other peoples' hands).

Figure 5: interactions between body image and body schema

Top-down controls exerted by cognitive levels on sensori-motor processing may include configuration, activation and inhibition (Pisella & Rossetti, 2000). However when longer time scales are considered, such that plasticity can take place, bottom-up influences arising from the basic sensori-motor interactions may structure higher levels. We propose that this also applies to the relationship between body schema and body image. (inspired from Rossetti 1998 & Rossetti et al. 2005)

Figure 6: Cognitive interference on body schema

Action-numbsense in patient JA when a simultaneous verbal representation of the stimulus is activated: the performance dropped to chance level.

Figure 7: unilateral neglect

A: two colouring tests performed by neglect patients.
B: clock drawing by a patient.
C: example of body image disturbance.
D: gardening task: the patient was asked to distribute the yellow flowers over the entire surface of the green grass in a homogeneous way.

Figure 8: unilateral neglect and vestibular stimulation

The mental imagery capacity of a neglect patient is depicted before and immediately after vestibular stimulation.

Figure 9: Unilateral neglect and prism adaptation

Glasses, pointing table, and wheel-chair driving performance of a patient before and after prism adaptation.