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Review article

How do the body schema and the body image interact?

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ABSTRACT

Despite their differences, body schema and the body image representations are not only consistent in everyday life, but also sometimes consistent in pathological disorders, such as in Alice in Wonderland syndrome and anorexia nervosa. The challenge is to understand how they achieve such consistency. Recently, we suggested that these two representations were co-constructed (Pitron & Vignemont, 2017). In his reply, Gadsby (2018) invited us to clarify how this co-construction works and to what extent the body schema and the body image can reshape each other. Here we motivate conceptual grounds for a model on which these two forms of representation modify one another and explore theoretical options for the way(s) in which they might do so. In particular, we highlight the virtues of a serial model in which the body schema has some primacy over the body image, while also acknowledging the special role played by the body image.

1. Introduction

We are thankful to Gadsby for his insightful commentary on our article (Gadsby, 2018; Pitron & de Vignemont, 2017). We welcome the prospect of moving past the mere distinction between the body schema and the body image, towards a better understanding of how the two interact. Whilst our focus was on Alice in Wonderland syndrome, Gadsby offers complementary insights from the study of anorexia nervosa, showing that patients with anorexia act in a manner that is consistent with their false percept of an oversized body (Gadsby, 2017; Keizer et al., 2013; Metral et al., 2014). This further presses the need for an explanation of why these two forms of body representation are not only consistent in everyday life, but also sometimes consistent in pathological disorders. Our aims in this reply are to clarify some of the points raised by Gadsby and explore theoretical options for the ways in which the body schema and the body image might be co-constructed, laying the grounds for further debate and empirical research. We argue that body schema and body image representations are malleable, despite representing long-term properties of the body. We then motivate conceptual grounds for a model on which these two forms of representation might modify one another, which in our previous treatment we labelled a co-construction model. Finally, we outline a range of theoretical options for models of this kind, highlighting the virtues of a serial model in which the body schema has some primacy over the body image, while acknowledging the special role played by the body image.

2. How malleable are long-term representations of the body?

Most of us are born with two arms and two legs. If everything goes well, we still have them when we are eighty-years old. Once we reach adulthood, the size of our limbs also barely changes. Body configuration and body metrics thus qualify as being long-term properties of the body, in so far as they are relatively invariant properties of the body. The question is: what kind of representation

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carries information about bodily properties of this type? O'Shaughnessy (1980) refers to the long-term body image; Carruthers (2008) to off-line representations; de Vignemont (2018) to long-term body maps. But what are the dynamics of these representations? Are they relatively stable, as their name seems to suggest, or do they qualify as long-term only because they represent enduring properties of the body? As noted by Gadsby there is a confusion in the literature, which needs to be addressed.

One may believe that since bodily configuration and metrics do not change much over time, it suffices to represent them once for all. Indeed, it does not seem parsimonious to compute again and again the size of our arm, which *de facto* always stays the same. On this view, while short-term bodily properties, such as bodily posture, require highly malleable representations, representations of long-term bodily properties can be relatively stable. However, although the biological length of our limbs does not change, its functional length can be altered. The size of bodily effectors is crucial to plan one's movements correctly and when one uses a tool, the end point of the effector is modified. Work on the effects of tool-use on motor control demonstrates that the long-term body representation must thus be updated (Cardinali et al., 2009). In Cardinali et al.'s study, participants repeatedly used a long mechanical grabber. When subsequently re-tested while reaching to grasp with their hand alone, the kinematics of their movements were significantly modified, as if their arm were longer than before using the grabber. Moreover, this effect of extension was generalized to other movements, such as pointing to the top of objects, although these movements had never been performed with the grabber.

One may reply that this plasticity is specific to the long-term body schema but does not generalize to the long-term body image. Gadsby, for instance, claims that "it is unwarranted to assume that each time one glances up at tall buildings, [one's] long-term body image changes in size." (2018, p. 165). We do not know whether the long-term body image does change in this particular case, but it is not clear to us why it would be unwarranted to make such a hypothesis. There is indeed evidence that the long-term body image can be altered and that this does not necessarily take much time. Let us return to the case of tool-use. Tools extend our realm of action but they also increase our ability to perceive the world. Take the example of the blind man with his cane. He uses it to get information about its environment and he feels sensations at its tip. Consequently, often when we use a tool, not only do we act as if our arm were longer, but we also perceive it as being such. For instance, after using a long mechanical grabber, participants localize touches delivered on their elbow and middle fingertip as if they were farther apart (Cardinali et al., 2009). It was also found that after tool use participants mislocate the centre of their arms, as if their arms had increased in size (Sposito, Bolognini, Vallar, & Maravita, 2012). Contrary to what Gadsby assumes, tools are thus not only motorically embodied; they are also perceptually embodied. Another way to put it is to say that they are incorporated both in the long-term body schema and the long-term body image.

Further evidence of the plasticity of the long-term body image can be found in bodily illusions, some of which affect perceived bodily size. Consider, for instance, the Pinocchio illusion (Lackner, 1988). If the tendons of your arm muscles are vibrated at a certain frequency, you experience illusory arm movements. For instance, if your bicep's tendon is vibrated, you feel your arm moving away from you, and if you simultaneously grasp your nose, you experience your nose as elongating by as much as 30 cm. One can also visually manipulate the perceived size of the hand. It has been shown that observing the picture of a larger version of the participants' hand alters the representation of the size of their hand, which leads them to overestimate the size of an object touching it (Taylor-Clarke, Jacobsen, & Haggard, 2004). These illusions show that the long-term body image is not off-line, if by that we mean detached from sensory inputs. On the contrary, it can be modified by altering visual and proprioceptive signals. Arguably, it can also be modified during hallucinations, as is the case in Alice in Wonderland syndrome. Here again, body representations quickly recalibrate. Patients do not constantly feel that they are extremely tall. They experience their legs as being longer, but only the time of their hallucinatory episode; afterward, their long-term body representation is recalibrated to represent their normal size.

To summarize, by *long-term* body image and schema we simply mean representations that carry information about enduring properties of the body, such as body configuration and metrics. We argued that these representations are nevertheless sensitive to a range of factors and can thus be swiftly modified. At the core of our interest is whether these representations can be reshaped by one another. That is, our question here (as in our original paper) is this: do modifications of the long-term body image affect the long-term body schema, and vice-versa? We shall first describe the motivation for what we call the co-construction model. We shall then propose different ways it may operate.

3. The co-construction model: why?

In our original paper, we proposed three models to describe the interactions between the body schema and the body image (Pitron & de Vignemont, 2017). The *fusion model* assumes that there is a single, long-term body representation, which is multifunctional. This model seems to be discarded by most authors (de Vignemont, 2010; Gallagher, 1986; Head & Holmes, 1912; Paillard, 1999; Schwoebel & Coslett, 2005). In particular, it cannot easily account for the dissociations between the perceptual and the motor levels found in Alice in Wonderland syndrome. The *independence model* assumes that there are two, functionally distinct, long-term body representations that are constructed separately from one another, one that is action-oriented and the other that is perception-oriented. The difficulty that the independence model faces is in accounting for the fact that most of the time the long-term body image and the long-term body schema have congruent contents. Under normal circumstances, the body we feel does not conflict with the body with which we act. Similarly, both the long-term body schema and the long-term body image can present the same kinds of bodily distortion. This is sometimes the case in Alice in Wonderland syndrome, and Gadsby shows that this is also the case in anorexia nervosa (Gadsby, 2018). Anorexic patients judge their body to be wider, and act as if it were wider (Gadsby, 2017; Keizer et al., 2013; Metral et al., 2014). According to Gadsby, this is a decisive objection against the independence model. He argues that this entails that the priors for both representations are shared, and thus that the body schema and the body image cannot be fully independent. However, we are less optimistic here. To exploit the *same* priors is one thing and to exploit *similar* priors is another. Neither the evidence on anorexia nor on the Alice in Wonderland syndrome can rule out the latter possibility, which is then compatible with the independence model. Hence, complete independence between the two body representations is still possible, even if their final content is fully congruent.

Still, like Gadsby, we want to argue in favour of a third view, the *co-construction model*, according to which the body schema and the body image are functionally distinct, but their construction is partly based on their interactions. Even if it may be difficult to settle the debate at the empirical level, we believe there are conceptual reasons for thinking that body representations are co-constructed, yet separate, rather than fully independent or merged.

The way different kinds of body representations are generated is the result of the pull of two opposing forces. On the one hand, there is the biological fact that we do have a single body, which is roughly similar across time. According to a principle of cognitive economy, there should be a single representation for this unique body (cf. Clark, 1989, p. 64). On the other hand, perception and action require different transformations of sensory signals and make different cognitive demands. One may further suggest that the way the brain uses information determines the way it encodes it. This has been extensively discussed in the case of vision (Goodale & Milner, 1992; Milner & Goodale, 2008) — but it applies just as well for body representations. In particular, action requires fine-grained spatial content while bodily experiences do not. In the specific case of body metrics, it seems a plausible hypothesis that the content of the long-term body schema is detailed and specific (the arm as being 70.5 cm long, for instance), while the content of the long-term body image is more approximate and sketchy (the arm as being between 69 and 71 cm long, for instance). The resolution of the two body representations is then distinct. One may further suggest that the content of the body image is purely descriptive (i.e. it represents how the body is) while the content of the body schema is both descriptive and directive (i.e. it represents how the body is and prescribes the movements it can perform) (de Vignemont, 2018).

The co-construction model emerges from these two opposing forces. If there were only the biological pull, the fusion model would be the most relevant, while if there were only the functional pull, it would be the independence model that would be the most promising. However, since there are both of them, the system needs to find a compromise between the two models, and we believe that the co-construction model is a good candidate for that, by resolving the tension between the pull of the unique biological body and the pull of the distinct functional requirements.

A further motivation for the co-construction model comes from another general cognitive principle, which is that cognitive systems tend to avoid inconsistency as much as possible. This is well illustrated in the case of the Pinocchio illusion. In this illusion, there is a conflict between the tactile information of the fingers in contact with the nose, the proprioceptive information about the arm being stretched and the vestibular and proprioceptive information of the torso being vertical. The illusion is simply the resolution of this conflict. The multisensory literature is also full of examples in which conflicts between two sensory modalities are automatically solved. Consider the case of prism adaptation. Prisms make participants see their hand at a location distinct from where it actually is. After a while, participants wearing prisms cannot help but feel their limbs at their visually perceived position and they can no longer retrieve their “pure” proprioceptive location independently of the influence of the prisms (Stratton, 1899; Welch & Warren, 1980). As described by Stratton (1899), there is then a “harmony of touch and sight”. When it comes more specifically to the relation between perception and action, consistency is also a desirable goal. Although planning and control of bodily movements use information carried by the long-term body schema, one wants to be able to explain why one acts in such a way. To do so, one appeals to the way one perceives one’s body. Consider the case of a child who climbs on a chair to reach for the chocolate bar in the cupboard. If asked why she does so, she would be able to answer that she is not tall enough. She would be unable to answer accurately if her long-term body image did not match with her long-term body schema. In brief, we can make sense of the specific way we achieve our actions thanks to the consistency between our representations.

Now, to require consistency does not entail requiring perfect similarity between the two representations. We should distinguish at least two versions of the co-construction model. According to a strong version, what matters the most is the fact that we have a single body and since there is no numerical identity (not a single representation), the co-constructive process should at least aim at maximizing qualitative identity (two distinct representations with maximally similar content). This version, however, is relatively costly. To reach such a degree of consistency, despite the distinct functional requirements, requires fine-grained comparison between the representations and extensive interactions between them. According to a weaker version of the model, the system aims at reducing discrepancies, but it can be relatively tolerant to some differences. This version appears to us as especially plausible in light of the likely differences in precision between the two representations. As suggested earlier, the body schema is likely more fine-grained than the body image. Still, they match if the former represents the arm as being 70.5 cm long and the latter represents it as being between 69 and 71 cm. The content is not maximally similar, but there is no inconsistency. This version of the co-construction model is in line with the literature on comparator models, which typically shows that it is only after a certain degree of mismatch that an error signal is sent (Franck et al., 2001; Slachevsky et al., 2001).

4. The co-construction model: how?

We just saw that the co-construction model is a promising candidate to account for the typical consistency between the body schema and the body image in normal conditions, as well as in some pathological ones, like anorexia. However, Gadsby’s real challenge to us is not so much to better motivate the co-construction model as to provide more details on how it normally operates and on the reasons why it sometimes does not work. Here we do not have definitive answers to offer. But what we can offer are various plausible theoretical options. We will also raise a number of questions that we believe to be important for future work on the interaction between the body schema and the body image.

A first question concerns the extent of the interactions between the two body representations. In the previous section, we distinguished between a strong and a weak version of the co-construction model. These versions make different predictions. According to the strong version, co-construction should be systematic: there should be no body image that is not influenced by the body schema, and vice-versa. The weak version needs not make such a strong commitment. One may suggest that co-construction occurs only under

some circumstances, when the mismatch is beyond a certain threshold. The threshold itself may vary depending on the context. In some cases, it may not matter much whether the two representations are aligned, whereas in others it may be crucial. A further element to take into consideration is the temporality. It may be that it is only if the discrepancies are persistent across time that they trigger a modification of the representations. The question then becomes: how long can the system tolerate differences?

A second major issue concerns the symmetry between the body schema and the body image. In the original paper, we proposed that two raw sketches of the body are built on the basis of sensory inputs and prior knowledge, and that these raw body sketches are compared and then modified to reduce the differences between them. On this view, no difference is assumed between the way the body schema influences the body image and the way the body image influences the body schema. However, a model of their reciprocal interactions should take into account the apparent primacy of the body schema over the body image from both an evolutionary and a developmental point of view.

Arguably, sensory processing evolved, in the first place, not to provide conscious perceptual experiences, but to provide sensory control of movements. It was only later in evolution with the emergence of more and more complex behaviours that sensory processing evolved to provide internal models of the world, stored in memory and accessible to other cognitive systems. Roughly speaking, bodily information processing primarily evolved to be used for catching one's prey and avoiding one's predator, and only later for admiring one's reflection. If something like this story is true, then the body schema is evolutionarily prior to the body image.

From a developmental perspective too, it is classically assumed that the body schema has a greater influence on the body image than the other way around. When discussing the genesis of the long-term body image, O'Shaughnessy (1980, p. 225), for instance, claims that it is shaped by an individual's sensorimotor interactions with the world: "through assembling the lowest common denominator of all the acts he will undertake with his hand, we might finally manage to assemble a sort of 'practical photograph' of the hand". Young infants engage in repetitive actions on their own body and explore visual-proprioceptive correspondence (Morgan & Rochat, 1997). One can also learn about the exact dimension of one's body on the basis of the sensory feedback that one receives while acting. For example, failing to reach the chocolate on the shelf indicates that one's arm is not long enough. Or hitting the shelf with one's head indicates that one is taller than the height of the shelf.

Arguably, the sensory feedback that one receives when acting is taken into account not only by the body schema, but also by the body image. This plays a key role during childhood and adolescence when the body is still growing in size and the long-term body representations need to adjust. But the contribution of sensorimotor information is not limited to certain periods in life. As argued earlier, each time one actively uses a tool, one adjusts the representation of the body metrics both at the perceptual and the sensorimotor levels. The primacy of the body schema can also be explained by the fact that the body schema has to be more reliable than the body image, which tolerates a larger margin of errors. In brief, to succeed in your movements you must get the size of your arms right, but there are no major consequences in being mistaken in your perceptual judgment about your body.

All these situations seem to indicate a predominance of the body schema over the body image. How might a co-construction model account for this asymmetry? Again, this can take more or less extreme forms. One may more simply propose that the body schema is given a greater weighting in the reshaping of the body image than the body image for the reshaping of the body schema. But we want to explore a more speculative hypothesis. One may indeed be tempted to push the asymmetry further and claim that the body image is built upon the body schema. In our previous treatment, we assumed that the process of co-construction runs in parallel between the body schema and the body image. But one may propose an alternative model, which is serial (see Fig. 1). On this view, the body schema is built first, based on multisensory signals as well as prior knowledge, including motor expertise. Once it is built up, it can work as a prior for the construction of the body image. The body schema is only one prior among others on which the body image is built. Social expectations about how one's body should look, for instance, can also shape the body image. Affective factors also intervene. Even the balance of multisensory signals is different at the level of the body image, giving a greater weight to visual information. The body image is thus not a mere copy of the sensorimotor representation. In the process of its construction, it gains in complexity (by taking into account new inputs on top of the information that fuels the body schema) but loses detail and accuracy. Consequently, the body schema can be preserved while the body image is distorted, the disruption resulting from the other factors that shape the body image. It is also possible that new inputs restore the body image while the body schema is altered. They may also be distorted in different ways. A study showed, for instance, that when *two* rubber hands are stroked synchronously with the participants' own hand, they reported ownership for *two* rubber hands but subsequent pointing movements were influenced by only one rubber hand (Newport, Pearce, & Preston, 2010). Hence, although the body schema influences the construct of the body image, their content can dissociate.

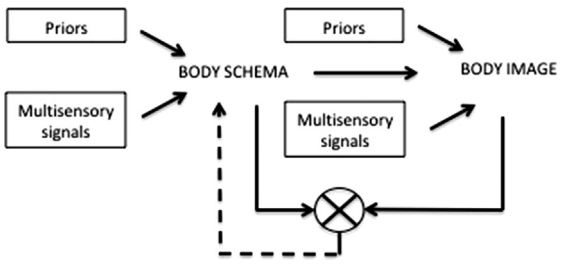

Fig. 1. The serial model of the body schema/body image interactions.

5. Why a body image after all?

At this point, one may wonder whether an organism might be able to avoid developing a body image. Arguably, some animals have only a body schema. One may then legitimately question: why all this extra work for a body image after all? The scope of this question goes far beyond body representations. According to Paillard's (1999) original distinction, the duality between the body schema and the body image corresponds to the functional distinction between sensorimotor and perceptual processing. Asking about the role of the body image is then simply questioning the role of perception in general. We do not intend to answer this latter question, which goes far beyond this paper, but we still want to highlight some assets of the body image.

We claimed earlier that the body schema had a more fine-grained spatial content than the body image. Its precision is important for performing successful movements. However, precision does not mean richness in content. The body schema is functionally restricted: it encodes only information about the bodily properties required for planning and controlling action. The content of the body image may not be as precise as the content of the body schema, but it carries information about more properties. This is true of perception in general: perceptual content is richer and thus more informative than sensorimotor content. For instance, unlike the body schema, it is concerned with the visual appearance of the body. It also provides an important source of information, not only about the body itself, but also about its surrounding environment. By analogy, you might say that the body schema provides a finely traced outline of the body whereas the body image provides the classic Renaissance oil painting in all its glory.

Another respect in which perception is relatively unconstrained is in its spatial content. Action requires that the location of any object upon which one acts must be determined relative to one's own location, *i.e.*, in an egocentric frame of reference. Perception is not restricted to this frame, for it also enables us to judge the locations of objects relative to one another – *i.e.*, in an allocentric frame of reference – and thus not *only* relative to one's own location. The allocentricity of perception then allows for comparative judgments (Jacob & Jeannerod, 2003). For instance, in the Muller-Lyer illusion, one can entertain the erroneous belief that the line above is longer than the line below. Likewise, one may claim that it is only at the level of the body image that comparative judgments between bodies can be made. This is not to say that there is no social dimension at the level of the body schema. Learning by imitation is a key mechanism and this requires the body schema to be partly shared between self and others (de Vignemont, 2014). Interpersonal content allows for correspondence between the body that imitates and the body that is imitated, by abstracting from differences between them. However, it is only the body image that can go beyond what bodies have in common, acknowledge their differences, and allow for comparison. Being able to compare one's body to others may be essential from an evolutionary perspective because only then can one decide whether the other animal is bigger or smaller than oneself.

Perhaps a third distinctive feature of the body image *qua* perceptual representation is that it enables us to represent our bodies as an object in the world we perceive. This bears upon a long-standing philosophical issue, namely that it seems possible to represent something which is in fact oneself – as Oedipus represented his father's murderer – whilst failing to represent oneself *as oneself* (Perry, 1979). Infants are confronted with such a situation before they learn to represent the body that most frequently occupies their visual field (their own body) as the very same body which they use to reach other objects. Hall conveys the infant's predicament vividly: "Sometimes the hand would be stared at steadily, perhaps with growing intensity, until interest reached such a pitch that a grasping movement followed as if the infant tried by an automatic action of the motor hand to grasp the visual hand, and it was switched out of the centre of vision and lost as if it had magically vanished" (Hall, 1898, p. 351 as cited in Bremner, 2017).

A practical grasp of the identities between the contents of a body schema and an (emerging) body image is not only important for solving the mystery of the disappearing hand. It has a range of consequences for development of spatial perception and cognition. It enables one to determine bodily locations as coincident with non-bodily locations, crucial for perception of the world through touch (Begum Ali, Spence, & Bremner, 2015; Martin, 1992). It also enables one to determine the scale and shape of one's body (DeLoache, Uttal, & Rosengren, 2004). This in turn is crucial for accommodating one's body as a space-occupier when performing a task (Brownell, Zerwas, & Ramani, 2007).

To recapitulate, the primacy of the body schema does not entail that the body image has no role. Its content is better suited to place the subject in the physical and social world she perceives. Moreover, it has a much richer content, and this can influence the body schema. We thus posit the existence of a feedback loop that allows the body image to be used as a prior for the body schema. Unlike the influence of the body schema on the body image, we speculate that the influence of the body image on the body schema is not continuous. The body image influences the body schema only under certain circumstances. One may propose, for instance, that the body image is compared to the body schema and if there is too much discrepancy between the two (given a certain threshold) and this discrepancy remains over time, then the body image is used to (re)calibrate the body schema.

This may account for some of the results found in anorexia. Riva (2014, p. 14) suggested that patients with anorexia are "locked to an "objectified body"", that is, a body image determined by how patients believe their body is rather than how it really is. In line with this proposal, a recent longitudinal study suggested that self-objectification (i.e. thinking about and monitoring the body's appearance from an external observer's perspective) is the largest contributor to both the onset and maintenance of the disorder (Dakanalis et al., 2017). The disorder is thus primarily characterized by a deficit in body image that in turn impacts the body schema. The body image is also affected in the first place in those cases of Alice in Wonderland hallucinations in which action is also disturbed. In healthy participants, it has also been shown that if the visual size of a limb is temporarily distorted, the planning of the subsequent movement can be affected (Bernardi et al., 2013; Marino, Stucchi, Nava, Haggard, & Maravita, 2010). Finally, one may suggest interpreting the effect of hypnotic verbal suggestions as modifications on motor performance as the result of the influence of the body image on the body schema (Rahmanovic, Barnier, Cox, Langdon, & Coltheart, 2012).

6. Conclusion

Following up on our previous proposal and Gadsby's commentary, our aim here has been to deepen understanding of interactions

between the body image and the body schema. We focused on two main questions. First, are the interactions systematic or not? Second, are they in both directions? We favour a serial model, according to which body representations are asymmetrically co-constructed and more weight is given to the body schema than to the body image. On this view, the body schema fuels the construction of the body image, which in turn can also influence the body schema when there is too much discrepancy. Co-construction aims at minimizing discrepancies but the content of body representations can dissociate in the end. We believe this proposal is able to account not only for the convergence of body representations most of the time but also for their distinction in some pathological conditions. This model of a co-construction between body representations now needs to be empirically tested. Further questions have also to be answered (see Table 1). For instance, what are the priors specific to each type of body representation? Does the co-construction operate at the level of the representation of the whole body or at the level of the representation of body parts? And in the latter case, is the interaction the same no matter the body part represented? These questions are worth further investigation, especially since a better knowledge of interactions between the body image and the body schema can determine future lines of treatment for patients misperceiving their body.

Table 1
Outstanding questions for empirical research.

1. What is the optimal degree of consistency between the body schema and the body image?	
2. Is the interaction between the two body representations systematic or only in some circumstances?	a. In the latter case, which circumstances? b. How long can the system tolerate differences?
3. Is the relationship between the two symmetrical or is there a priority of one over the other?	a. In the latter case, which one?
4. Does the process of co-construction run in parallel between the body schema and the body image or is it serial?	
5. What do we lack if we do not have a body image?	
6. How does the interaction between the body schema and the body image differ in distinct disorders, such as anorexia and Alice in Wonderland hallucinations?	
7. Can we take advantage of the interplay between body representations to repair distorted body representations?	a. More specifically, when the body schema remains unaffected, can it be used to repair the body image in anorexia or Alice in Wonderland hallucinations?

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