Tony Cheng and
Patrick Haggard

The Recurrent Model of Bodily Spatial Phenomenology

Abstract: *In this paper, we introduce and defend the recurrent model for understanding bodily spatial phenomenology. While Longo, Azañón and Haggard (2010) propose a bottom-up model, Bermúdez (2017) emphasizes the top-down aspect of the information processing loop. We argue that both are only half of the story. Section 1 introduces what the issues are. Section 2 starts by explaining why the top-down, descending direction is necessary with the illustration from the 'body-based tactile rescaling' paradigm (de Vignemont, Ehrsson and Haggard, 2005). It then argues that the bottom-up, ascending direction is also necessary, and substantiates this view with recent research on skin space and tactile field (Haggard et al., 2017). Section 3 discusses the model's application to body ownership and bodily self-representation. Implications also extend to topics such as sense modality individuation (Macpherson, 2011), the constancy-based view of perception (Burge, 2010), and the perception/cognition divide (Firestone and Scholl, 2016).*

Keywords: bodily spatial phenomenology; recurrent model; skin space; tactile field; bodily self-representation.

1. State of Play

One crucial aspect of bodily phenomenology is its spatiality: bodily experiences include bodily sensations, thermal sensations, nociception

Correspondence:
Email: h.cheng.12@ucl.ac.uk

such as pains, and they all exhibit distinct spatial characters. How should bodily phenomenology in general be modelled? In Longo, Azañón and Haggard (2010), a purely bottom-up approach has been proposed. In this paper we explore its strengths and limits, and seek to provide a more plausible model. To anticipate, this new model acknowledges the bottom-up direction identified by Longo and colleagues, while supplementing it with a distinct account of the somatosensation level based on *skin space* and *tactile field*. Also, the new model adds the top-down direction based on the 'body-based tactile rescaling' paradigm. This new model is therefore a *recurrent* one, constituted by two distinct mechanisms.

Matthew Longo and his colleagues (Longo, Azañón and Haggard, 2010) have proposed this following way of conceptualizing the hierarchy of the somatosensory system:

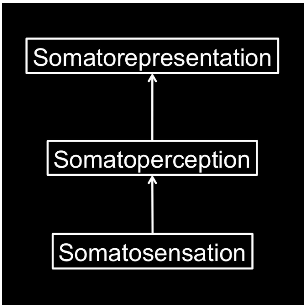

Figure 1. A hierarchical model of three levels of somatosensory content. Adapted from Longo, Azañón and Haggard (2010).

Somatosensation refers to sensory experiences generated by stimulation of bodily receptors; they are what philosophers call 'sensations', such as tickles and pains. In this paper we focus on neutral sensations, i.e. not painful, and not too hot or cold. Cases such as pains have different spatial characteristics that we do not aim to cover here. Somatoperception refers to using somatosensory inputs to perceive specific objects — in the case of touch, the acknowledged interoceptive/exteroceptive duality of touch (Katz, 1925/1989), which means that the content of somatoperception is both a stimulus object and the body itself. In philosophers' terms, they are sensory experiences that are *purported* to be about external objects. Somatorepresentation refers to the representation of one's own body specifically, both as a volumetric physical object and as the site or *owner* of lower-level somatosensory experience. In Longo *et al.*'s original model, these levels are perceived as hierarchically *ascending* only (note the arrow directions in Figure 1; the arrows indicate the direction of information processing. The idea is that we receive pieces of information from the external world, which generate sensations first, and with further processing we then perceive both the external world and our own bodies. But we want to suggest that there should be a recurrent, *descending* arrow from the somatorepresentational to *either* the somatoperceptual *or* somatosensory level, depending on which kind of spatial experience is being discussed. This means that *both* sensation and perception in touch can exemplify cognitive penetration from the top down. In Section 2, we first explain how the descending arrow can be tested empirically, and then substantiate the ascending arrow by introducing a crucial notion of 'skin space' (defined in Figure 4). A recurrent model with both the ascending and the descending arrows is thus proposed. In Section 3, we explain how this model can help understand body ownership and bodily self-representation.

A few remarks on our methodology: we believe that the issues tackled here are at the same time empirical in nature and with profound philosophical implications. In order to be focused, however, we put the discussions of the latter in the second half and also in various footnotes to make sure the gist of the main text is easy to grasp. But this style does not imply that those rather philosophical discussions are unimportant. We believe that the boundary between science and philosophy in this context is blurry anyway, but for practical purposes we have decided to emphasize the empirical thread in the first half of the main text.

Why are materials in this paper specifically about skin space as a mosaic of sensitive receptors, relevant to bodily spatial phenomenology? Bodily experiences typically exemplify spatial characteristics: tactile sensations tend to have some rough locations, and one can feel one sensation as beside another one, for example. These examples of bodily spatial phenomenology are normally explained by notions of body images and schemas (Gallagher, 2005). Apart from the difficulties of reaching the consensus about the definitions of those notions (de Vignemont, 2016), it is striking that the role of skin is largely ignored; it is not covered by body images or schemas at all. In what follows, one half of the recurrent model — the ascending side — will crucially rely on the spatial properties of the skin.[1]

2. The Recurrent Model Vindicated

Here we first explain why the descending arrow has to be postulated. In the 'body-based tactile rescaling' paradigm (e.g. de Vignemont, Ehrsson and Haggard, 2005), a participant is asked to hold their left index finger tip, while tendon vibration is applied to the right biceps tendon. The tendon vibration causes the somatosensation that the right arm is extending. This in turn produces a change in the representation of the left index finger, as longer than it really is. When participants are then asked to judge the distance between two touches on the index finger (which we consider a somatoperceptual task), they perceive this tactile distance as longer than in a control condition where the tendon is not vibrated. This finding deserves several comments. Firstly, somatosensory inputs drive representations of the body as a physical object, confirming the ascending hierarchy of Figure 1. Secondly, and crucially, the representation thus generated influences the percept caused by other somatosensory stimulations, such as the distance between the two touches, and exemplifies the descending arrow. These data show that the representational level can influence bodily spatial experience. Notice that the extension of the right forearm causes a representation of the left index finger as lengthening only because the left and right fingertips are moved to the same external spatial location, and are in contact. Figure 2 shows how the experiment works, and Figure 3 shows how we should think about this experiment through the two-mechanism recurrent model.

Now, in the literature the ascending arrow is in general accepted, but exactly how it works behaviourally and how it is realized physiologically are still open questions. In what follows we propose a specific way of understanding this ascending direction and the inputs for it.

1 A recent work by Clare Mac Cumhaill (2017) argues that the figure–ground structure can also realize in touch. While illuminating and congenial to our proposal below on skin space and tactile field, that work also does not discuss the relevant contributions of skin (though the term does appear in various places).

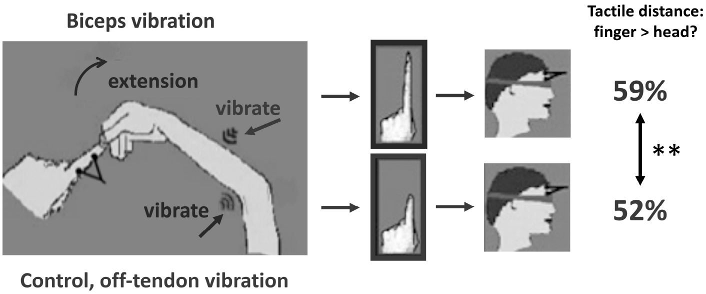

Figure 2. A proprioceptive illusion of right arm extension, generated by vibrating the bicep tendon, leads to the perception of the left finger being lengthened, but only if the right hand grasps the left finger. This in turn leads to two touches on the left finger being judged as more distant from each other, relative to two touches on the forehead, than in a condition where no tendon vibration is applied. Adapted from de Vignemont, Ehrsson and Haggard (2005).

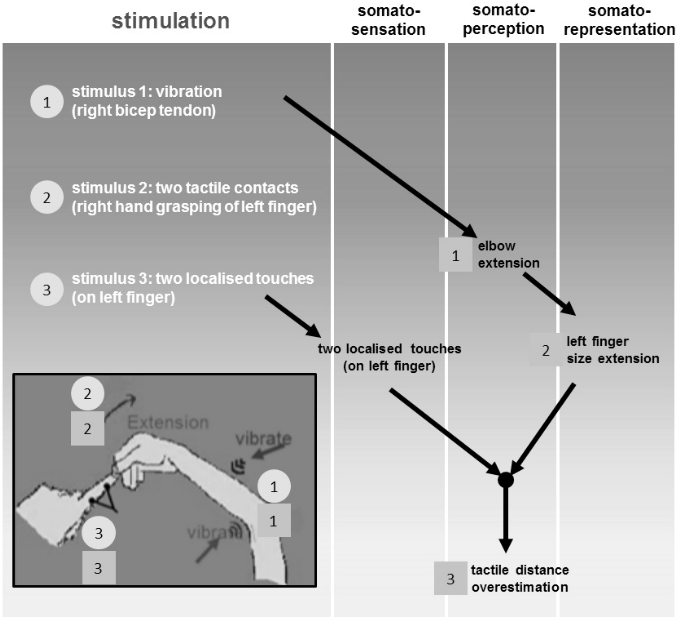

Figure 3. ‘Left finger size extension’ (somatorepresentation) and ‘two localised touches’ (somatosensation) jointly induce ‘tactile distance over-estimation’ (somatoperception). We thank Lynn Chiu for making this figure.

There is no physiological receptor that tells us how big our body parts are. Somatosensory inputs by themselves say nothing *directly* about it (Roberts, 2002, especially chapter 18 and 19). Size information is not something that can be directly read out from afferent inputs. What we have are indirect feedbacks from sight, haptic exploration of our own bodies, and so on. What this means is that one has to ask this question: where is this kind of geometric-morphological information and where does it come from? How do you know the parameters at the somato-representational level? This is where the ascending arrow comes in: what is distinctive about *bodily* awareness is that it is at least partially relying on *bodily* signals at the somatosensation level.

An interesting follow-up question is this: do the receptors in the skin itself provide enough spatial organization to account for bodily spatial phenomenology, as introduced in Section 1? Our answer is positive. The skin contains several classes of receptor cells that respond to different forms of touch, such as vibration, light-touch, and sustained pressure (Gallace and Spence, 2014, chapter 2). Importantly, these receptors are systematically, though disproportionately, distributed across the body surface, rather like a receptor mosaic. This distribution explains both the familiar Penfield homunculus (Penfield and Rasmussen, 1950) and the columnar organization of the somatosensory cortex (V.B. Mountcastle, 1997). The somatotopic maps in the brain show that receptors responsive to adjacent regions of skin project to adjacent sites in the cortex. Thus, the cortex respects the receptive field organization of the skin. In typical everyday activities, skin receptors with a particular spatial arrangement will show reliable patterns of activation. For example, a leaf brushing against my face as I walk under a tree will trace a path across a succession of receptive fields on my face (see Figure 4). The natural statistics of such stimuli means that *skin space* alone could be sufficient for spatial adjacency relations. For example, in the figure below, the same leaf might trace the paths A1 to A4 on one occasion, and A4 to D4 on another, depending on the direction that I am walking. In contrast, a sequence of stimulation A1–B3–C2–C3 might be less likely. The regularity of the A1–A4 and A4–D4 paths allows an implicit, non-conceptual spatial representation of S-space, based only on a relation of adjacency between receptive fields. A similar proposal for the sensory origin of logical structure of space was made by Jean Nicod (1930).[2] Importantly, this kind of spatial organization is sufficient for the kind of spatial behaviour known as path integration.

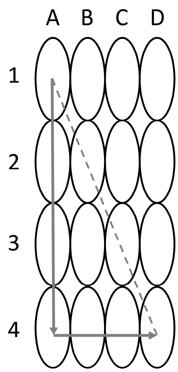

Figure 4. A simple model of skin space (S-space): the skin is covered by a mosaic of sensitive receptors, whose receptive fields are arranged like the cells of a spreadsheet, or the pixels of a screen. When an object touches the skin in the corresponding receptive field, a signal from the receptor is sent to the brain. When an object moves relative to the body, it traces a continuous path across adjacent receptive fields (solid grey arrows). The natural statistics of such paths allows the organism to build up, from many repeated experiences, a map of the organization of S-space, based only on relations of spatial adjacency. This map can in turn support an advanced level of geometric processing, such as the most direct path between two points via a novel route (dashed grey arrow). The idea of this diagram is from Fardo *et al.* (in preparation).

Suppose that the leaf has brushed first A1–A4, and then A4–D4. Suppose that I wish, for some reason, to move the leaf, or move my body, so that the leaf returns to its original A1 location on the skin of my face. If the system has stored the adjacency relations between all the receptive fields, I do not need to retrace the leaf's original paths. I can instead move so that the leaf goes directly back towards the A1

---

2 Nicod there invokes an interesting thought experiment that involves a creature moving back and forth on a keyboard that can make sounds. His main contention is that succession and resemblance are sufficient to construct spatial representation. It is interesting to compare this with Strawson's sound-world (1959), with which space's special status is revealed. Strawson (1959) argues that the sound-world cannot support the type of objective thought for which he thinks a conception of space is required. Evans (1985) suggests that this can be overcome by postulating a 'travel-based conception of space' (p. 255). For more on this, see Haggard *et al.* (2017).

home position, via C3 and B2. Exactly the same process of movement tracking and path integration is thought to underlie the construction of an allocentric map of the environment by the place and grid cells of the rat hippocampus and entorhinal cortex (Bush, Barry and Burgess, 2014; O'Keefe, 1994). We suggest that a similar 2D map of *skin space*, or S-space, could underlie the experienced spatiality of the body. Importantly, this process does not require a hierarchical progression from non-conceptual sensory to conceptual content, such as Figure 1. Rather, the spatial processing is a consequence of the *field organization* at the somatosensory level.[3] Now, some might still wonder how somatosensation can play a key role in deriving geometrical and morphological information about the body, given what we just said above. The answer is this: path integration has been taken as one hallmark of spatial representation, because the bias indicates that the system takes into account the spatial connections between the previous paths (Etienne and Jeffery, 2004). Now, it has been shown that path integration happens at the level of human skin too (Haggard *et al.*, 2017). This is the key evidence for the ascending aspect of the recurrent model. Notice that we do not claim that the hypothesis here is necessitated by the finding; rather, it is proposed that this hypothesis has the strength of being explanatorily effective and simple. Neighbour relations are sufficient for topological space, which is in turn sufficient for distance estimation.

One natural way to understand S-space is to think of it as a *tactile field*, which is analogous to a visual field. The basic idea is that 'the tactile field *supports computation of spatial relations* between individual stimulus locations, and thus *underlies tactile pattern perception*… Perception of spatial patterns across the field is linked to a structural representation of one's own body' (Haggard and Giovagnoli, 2011, pp. 65–6, our emphasis; for detailed description of how the tactile field underlies tactile pattern perception, see Haggard *et al.*, 2017). 'Tactile pattern judgements depend on secondary factors over and above local tactile perceptual ability at the stimulated locations' (Haggard and Giovagnoli, 2011, p. 73).[4] Tactile field in a

3 The discussion concerning the conceptual/non-conceptual divide is a thorny one that we wish to avoid on this occasion (Gunther, 2003). What we say here about skin space and tactile field are presumably non-conceptual.

4 The discussion here is based on Haggard and Giovagnoli (2011). That paper involves a stronger assumption concerning the analogy with visual field as understood by Smythies (1996). The notion of visual field there is a *sensationalist* one, which postulates a 2D

significant sense sustains tactile object perception. Compare the nociceptive sense, the thermal sense, and the tactile sense: while the nociceptive sense is neither capable of being exteroceptive nor object-directed, the thermal sense is capable of being exteroceptive but not object-directed, and the tactile sense is capable of being both exteroceptive and object-directed (Mancini *et al.*, 2015; Marotta, Ferrè and Haggard, 2015). This is because estimating distances between stimuli on the skin requires computing the position of one stimulus *relative to another*. Both the nociceptive sense and the thermal sense represent relative position poorly, and notably worse than they represent absolute position of a single stimulus. In contrast, the tactile sense supports representation of relative position fairly well, which justifies the postulation of a tactile field.

Previous work on tactile fields and tactile distance perception did not clearly distinguish between two very different forms of bodily modulation of touch (e.g. Gallace and Spence, 2008). The first would be a descending modulation of somatoperception by somatorepresentation. The tendon vibration effects on tactile distance, and the structural, joint-based modulations of tactile distance, strongly support this route. The second form of bodily modulation occurs at the level of S-space alone, based on acquisition of spatial-adjacency information from experience, and simple processes of path integration. This form of spatial organization could be sufficient to explain the experienced spatiality of the body. On this view, the tactile field itself may house some key features of bodily experience, as opposed to merely reflecting features of bodily experience generated at other levels of representation. To repeat, there may be two distinct mechanisms of body representation underlying the spatiality of bodily experience. One is the use of cognitive representations to modulate somatoperceptions generated in S-space. The second is the capacity of S-space to house non-cognitive representations of the body, at least in the 2D sense of the tactile field, and sometimes to contribute to somatoperception and somatorepresentation. Clearly, and importantly, this latter mechanism lacks the third dimension of space, but it does involve an important and powerful form of spatial processing. An important point for future research will be to investigate the respective

sensational mosaic for vision. This idea can be traced back to Bishop Berkeley's works, and one famous contemporary version is Peacocke (1983). This additional view is *not* assumed on this occasion. Perhaps the materials provided above can be resources to argue for sensationalism for touch, but here we do not pursue this line.

contributions of these two mechanisms for the spatiality of bodily experience.

Here are more details about S-space and the tactile field. The tactile field has axes, and it is capable of misrepresentation, for example the estimation of distances between multiple stimuli can be biased for all sorts of reasons (e.g. Fardo *et al.*, in preparation, on the path integration bias similar to animal navigation). Its organization is based on receptors, as opposed to joints. It is organized as a continuous sheet, as opposed to structured and segmented. Again more studies need to be done concerning this level of bodily spatial phenomenology, but we believe to have shown that skin space is crucial in capturing some aspects of it. It provides information for further processing at the somatoperceptual and somatorepresentational levels, but we have also seen that the other direction exists as well, as shown by the body-based tactile rescaling paradigm. Both the ascending and the descending directions are crucial in understanding bodily spatial phenomenology, and thus the most plausible model should be a recurrent one. Neither purely a bottom-up nor purely top-down level alone is able to fully capture bodily spatial phenomenology.

This tactile field theory has profound implications for many current issues in philosophy of perception and psychology. Here we discuss only three. First of all, it might provide a potential partial answer to sense modality individuation (Macpherson, 2011): if one sense is interoceptive only while the other is capable of being exteroceptive, then perhaps it is sensible to hold that they are distinct modalities. Similarly, if one sense is capable of being object-directed due to the tactile field while the other is not, then perhaps it is sensible to hold that they are also distinct modalities (Cheng, 2015). This view might compete with two other views: one argues that touch is a unified sense (Fulkerson, 2014), while the other argues that there will be no satisfying answer forthcoming (Ratcliffe, 2012). Secondly, this field-based view of tactile spatial perception might be an interesting contrast with, or perhaps a supplement to, the constancy-based view of object and objective perception (Smith, 2002; Burge, 2010): on varieties of that view, perceptual constancy is the basis of object perception. The field-based view might help explain perceptual constancy in touch through S-space and the tactile field. Last but not least, the tactile field idea might also contribute to the debate concerning the division between perception and cognition. Traditionally, it has been thought that Fodorian modularity (Fodor, 1983) can secure such a division, but it has been challenged by recent works on cognitive penetration (for a recent discussion, see Firestone and Scholl, 2016). Since the tactile field can host spatial perception in its own right without downstream cognition, it might offer further grounds for insisting on the perception/cognition divide in the case of touch. Notice that the existence of cognitive, top-down penetration does not by itself challenge the idea that there is a distinctive perceptual level: actually it might even presuppose that there should be a perception/cognition divide, since A can penetrate B only if A and B are distinct in some significant sense.

3. Body Ownership and Bodily Self-Representation

Above we have attempted to model bodily spatial phenomenology, focusing on neutral touch. In this final section we discuss some implications of the model concerning body ownership and bodily self-representation. First, what is body ownership? In the literature it roughly means that we have a sense of ownership over individual body parts and the body as a whole. This is to be contrasted with *mental* ownership, which concerns *who* the subject is (Lane, 2012). Why does the recurrent model have anything to do with body ownership? In his chapter in *The Subject's Matter: Self-Consciousness and the Body*, José Luis Bermúdez (2017) provides an explanation of body ownership. The hypothesis he defends is that judgments of body ownership are based on the experienced spatiality of the body. He then uses A-location (the location of a bodily event in a specific body part relative to an abstract map of the body, without taking into account the current position of the body) and B-location (the location of a bodily event in a specific body part relative to the current position of relevant body parts) to cash out the account.[5] We are sympathetic to his view, but his model seems to cover the descending arrow only, as shown in his adaptation of the Marr and Nishihara's (1978) model of object recognition. Our discussion of S-space can be seen as supplementing his model by providing the ascending model, and thereby has a fuller account of body ownership.

What about bodily self-representation? In this context we mean by it one's representation of one's own body as a physical object. We argue that one form of *exteroceptive* perception — tactile perception — is crucial in understanding not only body ownership but also bodily self-

5 See also Bermúdez (1998; 2005; 2011; 2015).

representation. ‘Perception of a tactile pattern based on the spatial relations between stimuli therefore involves at least a basic element of self-representation… Tactile pattern perception involves an important yet overlooked aspect of [bodily] self-representation’ (Haggard and Giovagnoli, 2011, p. 66, p. 73). The role of body representation in mediating tactile pattern perception offers a new insight into the classic problem of the relation between perception and bodily self-representation (*cf.* Bermúdez, 1998; Campbell, 2012; Peacocke, 2015):

> A substantive representation of one’s own body as a volumetric object mediates spatial judgements on the body surface covered by skin. Tactile pattern perception involves representing oneself both as a source of sensory experience, but also as a physical object with a characteristic body structure, and therefore having spatial attributes analogous to other objects. In touch, then, the linkage between primary experience and [bodily] self-consciousness seems stronger than in vision. The linkage shows that the body is a physical as well as a psychological object. In this sense, tactile pattern perception presupposes a self that is an object embedded in the world, rather than simply a viewpoint on the world. (Haggard and Giovagnoli, 2011, p. 74)[6]

In the example of tendon vibrations given above, one invokes representations of one’s own body to *measure* external objects, in order to make distance judgments. In this paper we have shown that the tactile field defined in S-space may also play a similar role, without any need of cognitive body representation. But, tactile signals in S-space could also contribute to body ownership and bodily self-representation, in much the same way as Bermúdez argues that body representations do. Without this supplement from S-space and the tactile field, Bermúdez’s picture risks overemphasizing the role of somatorepresentation, and underemphasizing the role of somatosensory signals. Somatosensation may be a simpler, more grounded place to look for

6 In the Haggard-Giovagnoli paper, M.G.F. Martin’s view (1992; see also O’Shaughnessy, 1989) is one of the critical targets, but the disagreement might actually be elsewhere. In particular, it might be due to Martin’s (perhaps correct) insistence that the visual field should not be understood in sensationalist terms. Both Martin’s view and O’Shaughnessy’s view can be traced back to Strawson: ‘The case of touch is less obvious; it is not, e.g., clear what one would mean by a “tactual field”’ (1959, p. 65). The view presented here can be seen as an answer to Strawson’s question. This view on self-representation can find further support in Merleau-Ponty (1962/2013), McDowell (1996), Cassam (1997), and Gallace and Spence (2014), though the ways they argue for this kind of view are crucially different from the current discussion.

'from-the-inside-ness', since both body ownership and bodily self-representation in the relevant sense are distinctively *bodily* in character. To be sure, we do not venture to propose that the tactile field is necessary or together with other elements jointly sufficient for body ownership and bodily self-representation. For example, patients with somatoparaphrenia still have the tactile field, but this does not guarantee the veridicality of the relevant bodily self-representation.[7] More generally, Bermúdez's conditions might be met while body ownership can still be missing, i.e. his conditions can bring about the judgment '*this* body', but perhaps not '*my* body'. Adding an additional condition of S-space might be helpful in this regard, but whether it is necessary or sufficient is another matter. We do not pretend that we have met the challenge of explaining body ownership and bodily self-representation on this occasion. However, while many authors agree that body ownership and bodily self-representation are somehow related to body spatial phenomenology, very few authors consider the role of tactile spatial perception in this regard. Since this aspect of the body has so far been ignored by the literature, we believe it is beneficial to have it in view even if it does not ultimately answer the difficult questions of body ownership and bodily self-representation just by itself.[8]

Acknowledgments

We are grateful to Frederique de Vignemont, Adrian Alsmith, and two anonymous referees for this journal for their helpful comments on an earlier draft of this paper.

References

Bermúdez, J.L. (1998) *The Paradox of Self-Consciousness*, Cambridge, MA: MIT Press.

Bermúdez, J.L. (2005) The phenomenology of bodily awareness, in Smith, D.W. & Thomasson, A.L. (eds.) *Phenomenology and Philosophy of Mind*, pp. 295–316, New York: Oxford University Press.

7 See Vallar and Ronchi (2009) for a nice review.

8 These points are inspired by questions from Hong Yu Wong and Christopher Peacocke at the workshop 'The Body and the Self Revisited', held in Copenhagen, 2015; they urged Bermúdez and us to be more explicit about how our conditions can answer the above challenge.

Bermúdez, J.L. (2011) Bodily awareness and self-consciousness, in Gallagher, S. (ed.) *Oxford Handbook of the Self*, pp. 157–179, Oxford: Oxford University Press.

Bermúdez, J.L. (2015) Bodily ownership, bodily awareness and knowledge without observation, *Analysis*, **75**, pp. 37–45.

Bermúdez, J.L. (2017) Ownership and the space of the body, in de Vignemont, F. & Alsmith, A. (eds.) *The Subject's Matter: Self-Consciousness and the Body*, Cambridge, MA: MIT Press.

Burge, T. (2010) *Origins of Objectivity*, Oxford: Oxford University Press.

Bush, D., Barry, C. & Burgess, N. (2014) What do grid cells contribute to place cell firing?, *Trends in Neurosciences*, **37**, pp. 136–145.

Campbell, J. (2012) Does perception do any work in an understanding of the first person?, in Coliva, A. (ed.) *The Self and Self-Knowledge*, pp. 102–119, Oxford: Oxford University Press.

Cassam, Q. (1997) *Self and World*, Oxford: Oxford University Press.

Cheng, T. (2015) Book review: *The first sense*, *Frontiers in Psychology*, **6**, art. 1196.

de Vignemont, F. (2016) Bodily awareness, *The Stanford Encyclopedia of Philosophy*, [Online], https://plato.stanford.edu/entries/bodily-awareness/.

de Vignemont, F., Erhsson, H. & Haggard, P. (2005) Bodily illusions modulate tactile perception, *Current Biology*, **15**, pp. 1286–1290.

Etienne, A.S. & Jeffrey, K.J. (2004) Path integration in mammals, *Hippocampus*, **14**, pp. 180–192.

Evans, G. (1985) Things without the mind, in *Collected papers*, New York: Oxford University Press.

Fardo, F., Beck, B, Cheng, T. & Haggard, P. (in preparation) Mechanisms of spatial perception on the human skin.

Firestone, C. & Scholl, B.J. (2016) Cognition does not affect perception: Evaluating the evidence for 'top-down' effects, *Behavioral and Brain Sciences*, **39**, pp. 1–77.

Fodor, J.A. (1983) *The Modularity of Mind: An Essay on Faculty Psychology*, Cambridge, MA: MIT Press.

Fulkerson, M. (2014) *The First Sense: A Philosophical Study of Human Touch*, Cambridge, MA: MIT Press.

Gallace, A. & Spence, C. (2008) The cognitive and neural correlates of 'tactile consciousness': A multisensory perspective, *Consciousness and Cognition*, **17**, pp. 370–407.

Gallace, A. & Spence, C. (2014) *In Touch with the Future: The Sense of Touch from Cognitive Neuroscience to Virtual Reality*, Oxford: Oxford University Press.

Gallagher, S. (2005) *How the Body Shapes the Mind*, Oxford: Clarendon Press.

Gunther, Y.H. (ed.) (2003) *Essays on Nonconceptual Content*, Cambridge, MA: MIT Press.

Haggard, P. & Giovagnoli, G. (2011) Spatial patterns in tactile perception: Is there a tactile field?, *Acta Psychologica*, **137**, pp. 65–75.

Haggard, P., Cheng, T., Beck, B. & Fardo, F. (2017) Spatial perception and the sense of touch, in de Vignemont, F. & Alsmith, A. (eds.) *The Subject's Matter: Self-Consciousness and the Body*, Cambridge, MA: MIT Press.

Katz, D. (1925/1989) *The World of Touch*, Mahwah, NJ: L. Erlbaum.

Lane, T. (2012) Toward an explanatory framework for mental ownership, *Phenomenology and Cognitive Science*, **11**, pp. 251–286.

Longo, M.R., Azañón, E. & Haggard, P. (2010) More than skin deep: Body representation beyond primary somatosensory cortex, *Neuropsychologia*, **48**, pp. 655–668.

Mac Cumhaill, C. (2017) The tactile ground, immersion, and the 'space between', *Southern Journal of Philosophy*, **55**, pp. 5–31.

Macpherson, F. (ed.) (2011) *The Senses: Classic and Contemporary Philosophical Perspectives*, Oxford: Oxford University Press.

Mancini, F., Stainitz, H., Steckelmacher, J., Iannetti, G.D. & Haggard, P. (2015) Poor judgment of distance between nociceptive stimuli, *Cognition*, **143**, pp. 41–47.

Marotta, A., Ferrè, E.R. & Haggard, P. (2015) Transforming the thermal grill effect by crossing the fingers, *Current Biology*, **25**, pp. 1069–1073.

Marr, D. & Nishihara, H.K. (1978) Representation and recognition of the spatial organization of three-dimensional shapes, *Proceedings of the Royal Society of London*, **200**, pp. 269–294.

Martin, M.G.F. (1992) Sight and touch, in Crane, T. (ed.) *The Contents of Experience*, pp. 196–215, Cambridge: Cambridge University Press.

McDowell, J. (1996) *Mind and World*, Cambridge, MA: Harvard University Press.

Merleau-Ponty, M. (1962/2013) *Phenomenology of Perception*, Landes, D. (trans.), London: Routledge.

Mountcastle, V.B. (1997) The columnar organization of the neocortex, *Brain*, **120**, pp. 701–722.

Nicod, J. (1930) The foundations of geometry and induction, *Journal of Philosophical Studies*, **5**, pp. 455–460.

O'Keefe, J. (1994) Cognitive maps, time and causality, in Peacocke, C. (ed.) *Objectivity, Simulation and the Unity of Consciousness*, Oxford: Oxford University Press.

O'Shaughnessy, B. (1989) The sense of touch, *Australasian Journal of Philosophy*, **67**, pp. 37–58.

Peacocke, C. (1983) *Sense and Content: Experience, Thought and Their Relations*, Oxford: Oxford University Press.

Peacocke, C. (2015) Perception and the first person, in Matthen, M. (ed.) *Oxford Handbook of the Philosophy of Perception*, pp. 169–180, Oxford: Oxford University Press.

Penfield, W. & Rasmussen, T. (1950) The cerebral cortex of man: A clinical study of localization of function, *Journal of the American Medical Association*, **144**, p. 1412.

Ratcliffe, M. (2012) What is touch?, *Australasian Journal of Philosophy*, **90**, pp. 413–432.

Roberts, D. (ed.) (2002) *Signals and Perception: The Fundamentals of Human Sensation*, New York: Palgrave Macmillan.

Smith, A.D. (2002) *The Problem of Perception*, Cambridge, MA: Harvard University Press.

Smythies, J. (1996) A note on the concept of the visual field in neurology, psychology, and visual neuroscience, *Perception*, **25**, pp. 369–371.

Strawson, P.F. (1959) *Individuals: An Essay in Descriptive Metaphysics*, London: Methuen.

Vallar, G. & Ronchi, R. (2009) Somatoparaphrenia: A body delusion. A review of the neuropsychological literature, *Experimental Brain Research*, **192**, pp. 533–551.

Paper received May 2017; revised July 2017.