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Since Aristotle, touch has been found especially hard to define. The idea of a privileged relation between touch and the body, however, has remained mostly unchallenged. This has led many physiologists, psychologists and philosophers to subscribe to a bodily view of touch, according to which the mark of touch, by contrast to other senses, is to be related to the body in some specific way. Here we shall consider the relation between touch and bodily awareness from two different perspectives. On the one hand, we shall discuss the *body template theory* of touch according to which touch is defined by the fact that tactile content matches proprioceptive content. We shall contrast the body template theory with other theories of individuation of touch. We shall then expose in details the difficulties and advantages of defining touch by its proper object, and more particularly pressure. On the other hand, we shall discuss the *body map theory* according to which tactile sensations are localized within the frame of reference provided by the mental representation of the space of the body. We shall oppose it to the Local Sign theory and review of series of putative counterexamples to the body map theory.

1. Defining touch

Touch is more elusive than hearing, sight, smell or taste. The problem is not that the biological underpinnings are less known for touch than for other senses. The problem is rather conceptual: what we mean by *touch* is not always sharply delineated. What is the *explanandum* of the various biological, psychological, and psychophysical theories of touch? There is little consensus. Here we shall examine several candidates, including intentional objects, organs, stimuli and the relation to the body.

1.1 The impalpable nature of touch

The problem was first noted by Aristotle (*De Anima*, 422b17-424a16). Sensory modalities, Aristotle argued, are to be individuated by their intentional object. The difficulty, however, is that *prima facie* tactile objects do not constitute a natural class. Let us call the *proper* object of a sensory modality, the entity that we directly perceive through this modality only; and its *primary* object, the entity that we directly perceive through it as a matter of necessity (Sanford, 1976). It is classically assumed that the primary and proper objects of sight, hearing, taste and smell are respectively color, sound, taste and smell. The proper objects of touch, however, are at first sight too heterogeneous to constitute a natural class and to be its primary objects. Hardness, solidity, impenetrability, texture, weight, mass, pressure, tension, contact, temperature, humidity, vibrations, painfulness, ticklishness, wetness and so forth have all been claimed to be perceived by touch exclusively. Yet, it is highly unlikely that they all belong to the same natural class. Furthermore, it is dubious that each instance of tactile perception necessarily involves the perception of some hardness, vibration, temperature, texture, and so forth.

Faced with the heterogeneity of the proper objects of touch, one may renounce defining touch by its intentional objects. Suppose one endorses a biological criterion instead. On this view, sensory modalities are individuated by their proper and primary organ. Touch is then defined by the biological apparatus (including organs, tissues, and receptors) dedicated to touch only and that touch necessarily involves. The skin is often put forward as the proper and primary organ of touch. But it is neither. First, the skin is not only a perceptual organ, it also accomplishes several other functions that we do not want to include in tactile perception (including protection, heat regulation, perspiration and respiration). Second, tactile perception does not essentially involve skin stimulation. Touch on the eyes, on mucous membranes such as the mouth, on internal organs, and on teethes can induce tactile sensations as well. One might even conceive that skinless creatures (such as arthropods) have tactile sensations.

Looking for more specific organs, one faces an impressive anatomical and functional diversity of receptors involved in touch (Johnson, 2001). Some are dedicated to the perception of mechanical properties such as pressure, vibration and texture, some to the perception of tissue damage, some to the perception of temperature. Each sub-group is itself heterogeneous. The mechanoreceptors include the Meissner and Pacini corpuscles, Ruffini organs, Merkel disks and free nerves endings. All are anatomically and functionally heterogeneous: their location in the skin varies (some in the dermis, some in the epidermis, some – the Ruffini organs – are even also found in the joints); their activation threshold and adaptation rates differ (Vallbo and Johansson, 1984; Kandel et al., 2000, p. 438); they are innervated by different kinds of fibers, myelinated or not. They are classified as cutaneous mechanoreceptors only insofar as they allow us to be conscious of mechanical properties and/or they respond to mechanical stimuli.[1] But if we need to appeal to intentional objects or stimuli to individuate organs, then the organ criterion for individuating the senses is not fundamental (Roxbee-Cox, 1970).

Is there then any *sui generis* kind of physical stimuli that is necessarily and exclusively involved in tactile perception? Mechanical properties are sometimes put forward, but they may be also involved in other sensory modalities. Arguably, chemical property involved in olfactory and gustative perception, electromagnetic property involved in sight, and acoustic property involved in hearing are all kinds of mechanical properties. Besides, electromagnetic and chemical properties are also involved in tactile perception. It is actually unclear that physics – be it Newtonian, relativistic or quantum mechanics – provides us with any categorization of physical properties that matches the categorization of our senses.

Whether one relies on intentional objects, organs or stimuli, our ordinary concept of touch appears on closer inspection to be a rag-bag sense that scatters in many sub-senses[2]. Such a multi-sensory view of touch, so to speak, is implicitly assumed in many textbooks, but it is hardly satisfying (Fulkerson, 2011). First, it is hardly a conception *of touch* since it boils down to dissolving its *explandum* into a disjunction of senses. Second, it is a

[1] By contrast to intentional objects, one is not necessarily aware of physical stimuli in perception.

[2] It is not clear that any other criterion (including *qualia*, sensori-motor contingencies, and associated beliefs) or combination of criteria for distinguishing the senses fares better as far as the unity of touch is concerned.

strongly revisionary view, which is committed to dismiss ordinary intuitions about touch like intuitions about the privileged role of touch in our access to external reality or intuitions about the particular relation between touch and bodily awareness. These intuitions, however, may help us to reach some definition of touch that preserves its unity, as illustrated by the bodily theories of touch.

1.2 Bodily theories of touch

Even if sight and hearing are defined by their objects, organs or stimuli, things may go differently for touch. The main proposal of this type relies on the common observation that tactile perception always involves some experience of our own body in combination with the experience of external objects. In other words, touch is bipolar (Katz, 1925). One can then take a second step and argue that the specific nature of touch *consists* in its relation to bodily awareness. This view can be tracked back at least to the Middle Age philosopher P. J. Olivi (see Yrjönsuuri, 2008) and more recent proponents include Armstrong (1962), O'Shaughnessy (1989, 2003) and Martin (1992, 1993). Touch, by contrast to other senses, would enter into specific dependence relation with the awareness of our body.

A difficulty for this approach is to specify the exact relation between touch and bodily awareness. For it has been proposed that proprioception plays a role in every sensory modality (O'Dea, 2011). In order for bodily theories of touch to work, other senses must not depend on bodily awareness in the same way. The most refined proposal to date is that bodily perception functions as a *template* for tactile perception. In a nutshell, our body is geometrically *congruent* with the external objects so that the awareness of our body gives us access to the spatial properties of the external object. For instance, Armstrong (1962, p. 18) argues that we perceive convex objects by feeling concavities of our flesh. The relation to bodily awareness is even more striking for so called haptic touch. According to O'Shaughnessy (2003, pp. 629, 656-680) and Martin (1992, 1993), we perceive the circularity of an object by feeling the circularity of the motion of our hand around it through proprioception. Template theories of touch, however, face three objections.

First, they can account for the perception of spatial properties such as shape, but they fail for the perception of other properties such as weight, pressures and solidity. One way to go, which is endorsed by Armstrong (1962, pp. 21-32), is to claim that all tangible properties are reducible to spatial ones. Such a spatial reduction of tangible properties, however, clashes with the fact that felt weight or pressures might vary independently of any felt spatial variation (a fact later recognized by Armstrong, 1997, pp. 97-8).

Second, it is true that the content of tactile perception can be congruent with the content of bodily awareness. It is also true that this does not generally occur in other sensory modalities. But it can happen (Scott, 2001). For example, in tunnel vision (in which peripheral vision is completely lost, so that vision is restricted to a narrow, tunnel-like, central field), the visual content is congruent with the proprioceptive content: the motion of our eyes matches the shape of the explored object (e.g. Loomis et al., 1991).

Third, even if one grants that tactile content, and only tactile content, is *necessarily* congruent with proprioceptive content, it is still doubtful that such congruence is *essential* to touch. As we shall explain in section 2, we sympathize with the general hypothesis according to which touch exhibits some specific relation with bodily awareness. However, we do not think that this is an *essential* property of touch. Our main worry with the bodily template theories of touch is that they entail that touch is not a sense in the same way as sight, hearing, smell and taste. Touch is distinct from all the other senses because of its privileged relation to proprioception. But sight, hearing, smell and taste are not distinct from each other because of their relation to proprioception. The criterion for distinguishing senses ends up being disjunctive. One version of it could be the following: *x* is a sensory modality if and only if either *x* has a natural class of proper and primary objects or *x* uses proprioception as a template. This threatens the very unity of the concept of sensory modality. Advocates of the template theories of touch save the unity of the concept of touch, but at the price of dismantling the concept of sense.[3] The bullet seems to us hard to bite. A good definition of touch should not only explain the unity of touch; it should also account for its sensory character: touch is one single *sensory*

[3] They indeed declare themselves quite pessimistic about the concept of sensory modality (O'Shaughnessy, 2003, p. 630; Martin, 1992, p. 215).

modality like any others.

To recap, one faces the following dilemma when defining touch: either one gives up the intuition that touch is a single sense by claiming that it is a heterogeneous collection of senses; or one gives up the view that touch is a sensory modality by claiming that its unity-maker – e.g. its relation to the body – is distinct in kind from the unity-makers of other sensory modalities. Either touch is not *a* sense, or touch is not a *sense*. Hopefully, this dilemma is not inescapable.

1.3 The pressure theory of touch

Following the intentionalist approach of the individuation of the senses, which distinguish sensory modalities by their proper and primary objects, we propose to revive the hypothesis that touch is the direct perception of pressure and tension. This view was introduced by Weber in 1846, right from the beginning of experimental psychology:

> [Touch] is essentially a *sense of force*. Our concepts of force would be very much less well developed were we unable to feel pressure, or to sense competing forces in which an equilibrium is established so that no movements are produced, yet in which the forces can still be felt. (Weber, 1846, p. 196)

Pressure, we shall now argue, is the proper and primary object of touch. On the one hand, pressure cannot be directly seen or heard, although its causes and effects can. On the other hand, one can never perceive by touch without feeling some pressure or tension. Touch is by nature the direct perception of pressure and tension. In other words, pressure is the color of touch. Weber's proposal of a pressure sense was confirmed by the discovery of pressure spots on the skin (Blix, 1884; Goldscheider, 1884; Donaldson, 1885), which were soon associated with *sui generis* end-organs by Von Frey (see Boring, 1942, Norrsell et al., 1999, Pearce, 2005). On both phenomenological and physiological grounds, the existence of a pressure sense is hardly controversial.

Such a pressure sense, however, has remained mostly unnoticed by philosophers (at the exception of Armstrong, 1993, pp. 97-9; 1997, p. 213; Sanford, 1976; Perkins, 1983, 242 sqq.; Fales, 1990, p. 16). One reason for this neglect might be the cartesian and humean prejudice against dynamic entities such as force, pressure or tension. If touch is to be the perception of pressure and tension, then there must be such things. Here, we shall assume that macroscopic force and tension are real physical entities, distinct from their kinematic effects, rather than mere theoretical fictions (see Wilson, 2007; Massin, 2009 for arguments in favor of realism about newtonian forces).

In order to know what touch is, one thus needs to venture into the metaphysics of pressure: what are they? Let us first consider forces. Forces are entities of *dynamics*. Dynamics is to be contrasted with kinematics (and *not* with statics). Kinematics describes motion; dynamics causally explains motion. Consequently, dynamics entities, including forces, mass and energy, neither consist in motion, nor cause motion. According to Newton's second law of motion, forces cause accelerations of the bodies they exert on, when not counteracted by other forces. A body submitted to the influence of a single force, such as a body in free fall, is not subject to any pressure. The reason is that nothing prevents that single force from causing the acceleration of the body. Such a solitary force acting on a body is not perceptible by touch. In order for a force to be perceptible, it has to be counteracted by another force, which is often the one exerted by our body, such as when we weight an object. Only then do pressure and tension occur. Pressure, as noted by Weber, only arises when *two* forces act against each other and cancel each other. The same is true for tension. In order to put a stick under pressure, one needs to exert *two* inward forces on each of its extremities. In order to put a rope under tension, one has to exert *two* outward forces on each of its extremities. Pressure and tension are pairs of antagonist forces. *Pace* humeans, the pressure exerted on a body might vary without it moving or undergoing any other spatial change. Likewise, one might feel an object steadily pressing on our body even when it no longer moves relative to the body (Perkins, 1983, p. 248). This remains true even when tactile adaptation occurs. To claim that touch is the sense of pressure and tension amounts to claim that the proper and primary object of touch is a pair of antagonist forces.

If the pressure theory of touch is not to fall under the same criticism as the template theory, then one must assume that other sensory modalities are defined thanks to their proper and primary object as well. This assumption might be found a bit too bold in the context of the contemporary debate about sensory individuation (MacPherson, 2011). Surely more needs to be said in defense of the intentionalist criterion of individuation of the senses (see for example, Brentano, 1979; Roxbee-Cox, 1970; Sanford, 1976; Dretske, 1995; Ross, 2001, 2008). Suffice it to say here that the present pressure theory of touch dismisses one of the main objections raised against the intentionalist criterion since Aristotle, namely the alleged lack of proper object for touch.

It has to be granted, however, that such a proposal entails that touch in the strict sense does not cover all the types of perception traditionally ascribed to it. In particular, the perception of temperatures and of pain needs to be excluded from touch proper. Temperature is indeed not pressure (though it might depend on pressure) and there is no promising way of grounding the perceptual awareness of temperature on the perceptual awareness of pressure. We feel that the temperature in the shade is cold without feeling the shadow or the air pressing on us. Temperature is not felt through pressure. Second, it might be that pain is a sensory quality, on a par with color, sound, pressure and temperature (as first clearly stated by Stumpf, 1928). Here again, pain might be felt independently of pressure. Plausibly, the main reason why the temperature sense, the pain sense, and the pressure sense have been fused into one single sense is that temperature, pain, and pressure are often felt in the same location, namely, in parts of our body (Weber, 1848, p. 69; Mill, 1869, vol. 1, p. 30; Brentano, 1995, p. 83). Despite this felt co-location, they have intentional object of different categories, independent from each other. Touch in the generic sense therefore splits into the sense of pressure (touch in the strict sense), the sense of temperature and, possibly, the sense of pain.

The pressure theory of touch, however, does not amount to a sheer giving up of the unity of touch, for the splitting of touch ends up there. There is no need to introduce further senses of texture, vibration, weight, contact, hardness or solidity. The tactile perception of each of those actually depends on the perception of pressure and tension. There is no *sui generis* sense of texture distinct from the sense of pressure, for we feel the texture of a surface by feeling a spatio-temporal pattern of pressure when stroking it. There is no *sui generis* sense of vibration (*pace* Katz, 1925), for we feel vibration by feeling a temporal pattern of pressure on our body. There is no *sui generis* sense of weight for we perceive the weight of an object by perceiving the various pressure and tension that it exerts on our skin and muscles when wielding it. There is no *sui generis* contact sense for we feel that some object is in contact with our body by feeling that it presses, be it very slightly, on our skin. There is no *sui generis* sense of hardness for we feel that a body is hard by perceiving that pressing or pulling it does not change its shape. There is no *sui generis* sense of solidity or impenetrability for we feel that a body is impenetrable, by perceiving that pressing our body against it does not yield compenetration of our body with it. No texture, no vibration, no weight, no instance of contact, hardness, or impenetrability is ever tactually felt independently of the feeling of a pressure or tension. Such qualities are *indirectly perceived* on the basis of the direct perception of pressure.

One might object that such a claim commits its proponents to some questionable atomistic approach to sensory psychology, according to which felt texture, weight or vibration are either *reducible* to a summation of isolated sensation of pressure or *inferred* on the basis of the prior perception of such isolated pressure. This is not the case. On the one hand, pressures, on the basis of which other qualities are felt, are not necessarily spatially punctual or temporally instantaneous entities. There might be pressure-gestalts that expand over space and time. On the other hand, the notion of indirect perception does not necessarily imply that what is indirectly perceived is reducible to, nor inferred from, what is directly perceived. Our claim is only that texture, vibration, weight and solidity are perceived *in virtue of* the perception of pressure, and not the reverse (Jackson, 1977, pp. 19-20). To say that only pressure and tension are directly perceived in touch is not even to claim that they are the most salient properties in tactile perception. Attention might go directly to the constant and distal properties of the felt bodies. But even if we focus on hardness, weight or texture, these are tactually accessed thanks to the possibly sub-attentional consciousness of pressure and tension. Felt pressure and tension are the tactual *matter* that underlies all tactual perception (Katz, 1935, §5).

1.4 The objectivity of touch

Defining touch as the sense of pressure and tension therefore allows defining touch in the same way as other sensory modalities while saving a substantial part of its unity. This is only one of the advantages of the pressure theory of touch. In addition, the theory can account for two specific features commonly ascribed to touch that cry for explanation. The first might be called the *objectivity* of touch. The second is the aforementioned bipolarity of touch.

As echoed in the use 'tangible', which often means 'real', touch appears to enjoy some priority over the other senses when we wonder about the reality of external bodies. This priority should not be understood in terms of a better reliability of touch with respect to other senses. This priority is rather phenomenological: only tangible objects can be presented to us as real, that is, as existing independently of us. This may seem controversial. For example, Siegel (2006) argues that ordinary visual experiences do represent the independence of their objects from the subject. When seeing an object, one expects that changing one's perspective on it will not change its location.[4] However, Siegel's theory explicitly targets *property*-independence, i.e. the fact that perceptual objects are presented as exemplifying properties (such as location) independently of us. By contrast, the present proposal targets *existential*-independence, i.e. the fact that we are sometimes presented with the fact that the perceived object *exists* independently of us. It is only with respect to existential-independence that touch has some privilege over other senses. The point is not that other sensory modalities present us with their object as existentially dependent on us. Our claim is only that ordinary perception is mute with respect to the mind-independence of the existence of its objects. One reason for this is that independence from the subject is both a self-reflexive and modal (or essential) notion, and that it would be quite a heavy task for ordinary perception to present it on the top of its immediate objects.

Touch, to that extent, plays an essential role in the phenomenology of self-world dualism. The pressure theory of touch paves the way for a neat explanation of tactile

[4] But is it mind-independence or rather perspective-independence (independence from a point of view, which needs not be presented as a subject's point of view) that is presented here? Alternatively, one might challenge Siegel's claim that such expectations are parts of the perceptual content itself, rather than aroused by a simple perceptual content.

objectivity, as follows:

P1 The feeling of physical effort (and of resistance) is the only experience that presents us with the existential independence of the physical world from us.

P2 Touch is the only sensory modality essential to the feeling of physical effort.

C Touch is the only sensory modality essential to the experience of the physical world as existing independently from us.

Following a long tradition, we shall assume the truth of P1.[5] In order to ascertain P2, we need to clarify the nature of physical effort. An agent makes an effort on a body if and only if it exerts a force on that body so as to make it move (or stay at rest) and that this body exerts in return some opposite force on the agent (i.e. resistance). Given that pressure and tension are pairs of antagonist forces, this entails that there is no physical effort without pressure or tension. Likewise, there is no *experience of* physical effort without *experience of* physical pressure or tension. Since experiences of tension and pressure are, on our account, tactile experiences, then tactile experiences, and only them, are essential to the feeling of effort. In other words, in order to feel the resistance of the external world, we have to be aware that that it exerts some force counteracting the force we are intentionally exerting on it. Such pairs of counteracting forces are the proper and primary objects of touch. If so, no being completely deprived of touch could ever experience the existential independence of physical bodies.

This is not say that tactile perception *per se* presents us with the mind-independence of its objects. It does not. Experience of effort does, which is essentially tactile, but which is not essential to tactile perception. This is neither to claim that ordinary perception, including tactile perception, does not present us with mind-independent objects. It does. But ordinary perception does not present us with their mind-independence *per se*. Our point is only that touch is the only sense required for the experience of the mind-

[5] See e.g. Maine de Biran (1820); Brown (1846, p. 151); Müller (1842, p. 1080); Mill (1869); Bain (1868, p. 82); Dilthey (2010); Scheler (1973b; 1973a, pp. 135-8); Baldwin (1906); Katz (1935, p. 8; 1989, 51); Stout (1931, Bk IV, chap. 1 & 6); Hampshire (1982); Garnett (1965); Hamlyn (1990); Baldwin (1995); Russell (1995); Bermudez (1998, p. 164); Smith (2002); Williams (2002, p. 136); Cassam (1999); Matthen (2005, p. 8).

independence of physical bodies. There lies its greater objectivity.

On the present proposal, the objectivity of touch results from the nature of touch together with the nature of physical effort. As it stands, such an account of tactile objectivity is still a rough sketch. Though we are confident that more can be said in support of this approach, our present point is quite modest. Any good theory touch should either account for tactile objectivity or explain it away. The pressure theory of touch, contrary to its rivals, suggests some fairly promising explanation of tactile objectivity.

A second feature of tactile perception that needs to be accounted for by any theory of touch is its aforementioned bipolarity, that is, the fact that every instance of tactile perception presents us not only with external objects, but also with our body. Here again, the pressure theory of touch provides some natural explanation. On the pressure theory of touch, the bipolarity of touch follows from the nature of touch together with a likely hypothesis: pressure felt in touch is generally pressure between (parts of) our body and some external object. Pressure is a symmetrical relation: we feel something pressing on this part of our body (or that this part of our body is pressing on something). The reason why touch is bipolar is that its proper and primary objects are relations, whose *relata* are generally parts of our body and external objects. This is not so with sound or color: though their location might be perceived as relation to our own location, their very sound- or color-quality is not presented in terms of a relation between something and part of our body. The bipolarity of touch results from the relational character of its proper and primary object.

This explanation of tactile bipolarity relies on the hypothesis that pressure felt in touch consists in relation between (parts of) our body and some object, and consequently, that felt pressure is always located on our body. This may come as a surprise: if pressure is to touch what sound is to hearing, how is it that contrary to sound, pressure is always felt to be located on our body?

2 Localizing tactile sensations

When we have tactile sensations, we normally experience pressure to be applied on a specific part of our body. We localize tactile sensations on our body, so to speak.[6] We can then form a belief about the felt location of the sensations and report it (e.g., "I feel pressure on the shoulder"), attend to it (e.g. by looking at the shoulder), indicate it (e.g., by pointing to the shoulder), and act accordingly (e.g., by removing the object that is touching the shoulder). Furthermore, tactile sensations are *bodily* sensations. One way to interpret this claim is in spatial terms. At first sight, it seems indeed that the localization of tactile sensations is always within the boundaries of our body. However, like for other types of bodily sensations, the localization of tactile sensations displays puzzling features, which do not seem to be captured by typical treatments of spatiality. Most discussions in the literature have focused on the use of "in" when one localizes pain. For instance, the pain that I feel *in* my leg is not felt in the refrigerator when my leg is in the refrigerator (Coburn, 1966). Nor is the pain that I feel in my thumb felt in my mouth when my thumb is in my mouth (Block, 1983). But one can raise similar questions if one considers the use of "on" when one reports "I feel pressure on my hand". For instance, I feel a light pressure on my hand; my hand is on my head; yet, I do not feel pressure on my head. The rule of spatial transitivity is not preserved. The peculiarities of the localization of tactile sensations might cast doubt on their intrinsic spatiality. But if tactile sensations are not essentially spatial, then their privileged relation to the body might disappear. They may be localized on the body most of the time, but there would be no necessity to it. The relation would be only contingent. Here, we shall determine whether tactile sensations are essentially localized and what constraints, if any, lay upon the localization of tactile sensations.

2.1 Are tactile sensations essentially spatial?

How are tactile sensations individuated? Are they individuated exclusively by the type and intensity of the pressure exerted on the body? Or are they also individuated by

[6] This is not to say that we localize the mental event of the tactile sensation in our body. Rather, we localize what we tactually feel, that is, the physical event of pressure.

their felt location? Let us consider for example that pressure of the same intensity is applied on two distinct parts of the body inducing two tactile sensations. Are the two sensations strictly similar or not? In other words, is the spatial component a constitutive part of tactile sensations or is it independently acquired and then associated to tactile sensations? The latter view has been defended by the Local Sign theory in the 19th century (Lotze, 1888; Wundt, 1897; Titchener, 1908; James, 1890), which can be summarized as follows:

> the theory which denies that there can be in a sensation any element of actual locality, any tone as it were which cries to us immediately and without further ado, 'I am here', or 'I am there'. (James, 1890, p. 798)

On this view, the localization of tactile sensations is not grounded on spatial information carried by tactile signals. Rather, it is grounded on the sensation of a "peculiar qualitative coloring" associated to each sensible nerve (Wundt, 1897) or of an "auxiliary impression" of the specificity of the flesh that is touched (Lotze, 1888).

However, this view has been widely criticized because of the lack of such local signs (Vesey, 1961; Coburn, 1966; Martin, 1995; O'Shaughnessy, 1980). It is true that the density of tactile receptors is not the same over the surface of the body. At the phenomenological level, there can be differences between specific parts of the body (such as the bony forehead and the plump cheek). But there is no difference between two sites that are slightly apart on the same body part or between two similar sites on both sides of the body (left and right hands, for example). Furthermore, it is one thing to notice a difference – if there is any – between a sensation on the back of the hand and a sensation on the palm. It is another thing to localize this sensation on the palm. Specific qualitative coloring may be the *natural sign* of the body site of the sensation: its experience cannot but betray the location of the sensation in the same way that smoke cannot but betray the presence of a fire. Nonetheless, the presence of smoke needs to be interpreted on the basis of prior knowledge about the systematic association between smoke and fire. Likewise, the experience of a specific qualitative coloring needs to be interpreted on the basis of prior knowledge about the systematic association between the local sign and a specific body site. In particular, proponents of any theory that denies that tactile sensations are spatially individuated are committed to posit a purely contingent relation between tactile sensations and their spatial ascription, which seems unlikely (Brentano, 1979; Coburn, 1966; Holly, 1986). In addition, they are committed to accept the possibility of *floating tactile sensations*, that is, tactile sensations with no apparent location. But can one feel tactile sensations without at least roughly ascribing the sensations to particular parts of the body?

This might be possible in the case of bodily feelings, like thirst or hunger (Armstrong, 1962). However, in the case of touch, it seems difficult, if not impossible, to conceive feeling pressure nowhere in particular. [7] As argued in section 1, pressure is a dynamical relation between bodies, and bodies necessarily occupy regions of space. Consequently, experiencing pressure is experiencing pressure in a region of space. This seems to be confirmed by some recent empirical results that show that there is a systematic relationship between tactile sensations and localization. On the one hand, the more spatially determinate the sensation is, the less it takes time to experience pressure. For instance, it was found that we are faster to detect pressure when viewing the body part that is touched (Tipper et al., 2001). One possible explanation is that viewing the touched body part facilitates the localization of pressure, thus allowing pressure to be experienced more quickly. On the other hand, the less spatially determinate the sensation is, the more it takes time to experience pressure. For instance, it was shown that when we are uncertain about the location of pressure (because of a conflict between visual information and proprioceptive information, for instance), we take longer to detect pressure (Folegatti

[7] Even young infants, who cannot *communicate* the localization of their sensation, can orient their attention toward the location of pressure, as shown by a range of neonatal reflexes (such as automatically grasping unseen objects in contact with the hand) and voluntary behaviors (such as looking toward the bodily site that is touched, cf. Bremner et al., 2008). Furthermore, as far as we know, there has been no report of patients who experience sensations that are not at least approximately localized. Head and Holmes (1911, p. 139) describe the case of a patient who claims: “I feel you touch me, but I can’t tell where it is”. But the patient further reports: “The touch oozes all through my hand”. This indicates that tactile localization can be more or less indeterminate. It can also be more or less accurate. But this is not to be confused with tactile sensation with no localization whatsoever.

et al., 2009; Moseley et al., 2008). Roughly speaking, one has no sensation as long as one cannot localize where the pressure is applied. Taken all together, these results suggest that to be aware of pressure is to be aware of a location of pressure, though not necessarily correctly. The location of pressure is part of the individuation conditions of tactile sensations (Margolis, 1966, Brentano 1979).

To conclude, the spatiality of tactile sensations may be peculiar compared to the spatiality of visual experiences for instance, but this does not suffice to show that tactile sensations are not essentially spatial. Rather, it invites us to deepen our understanding of tactile spatiality.

2.2 The body map theory

Contrary to the Local sign theory as described by James, tactile sensations immediately cries to us 'I am here'. However, to be aware that one is touched here is one thing, and to locate where 'here' is another thing. A cross indicating "you are here" is of little interest if there is no reference point on the map. Likewise, tactile localization requires a spatial frame of reference, which is classically defined as "a locus or set of loci with respect to which spatial position is defined' (Pick & Lockman, 1981, p. 40). In the case of tactile sensations, the set of loci is not provided by tactile signals themselves. If I am touched on the right index finger, the peripheral neural signal originating from the right index finger carries information about the location of the stimulation only. It does not carry the information that this is an index finger, or that it is located on the right hand. Thus, it does not suffice to fully account for the spatiality of tactile sensations. For tactile sensations to get a relatively rich and accurate spatial content, raw spatial tactile signals need to be interpreted with the help of a topological and geometric mental map of the body (hereafter *body map*).

The notion of body map can be tracked back to Bonnier (1905), who first introduced the notion of schema to refer to the spatial organization of bodily sensations. Head and Holmes (1911) also posit the existence of what they call a superficial schema, which is the model of the skin surface of the body used for localizing bodily sensations. More recently, Schwoebel and Coslett (2005) argue in favor of what they call a body structural description, which is impaired in patients suffering from autotopagnosia. These patients are not able to correctly localize where they are touched and identify the parts of their body. But it is O'Shaughnessy (1980, 1995) who best develops the body map theory. He postulates the existence of a long-term body image in order to compensate for the intrinsic insufficiency of the body senses. The long-term body image explains how all bodily experiences share the same spatial content of the structural shape of the body over an extended period. It is thanks to the body map that tactile sensations are experienced as being at more than at an isolated body point. The body map plays a structural role in spatially shaping tactile sensations. In other words, it plays the role of a somatosensory field (Martin, 1992). In visual experiences, visual properties are localized relatively to the visual field. In tactile experiences, pressure is localized relatively to the body map.

Although the body map represents long-term properties of the body such as the size of the limbs, it is flexible and can quickly adjust to changes. The body boundaries that we experience can actually stretch beyond the biological body boundaries to include either non-physical extension like phantom limbs or physical extensions like tools (Vesey, 1961; O'Shaughnessy, 1980; Martin, 1995). For example, the felt size of our limbs can be temporarily altered for the time of acting with a tool (Cardinali et al., 2009). Once the action achieved and the tool dropped off, the body map readjusts to the normal size of the body. We may think of it in terms of plastic band: we can stretch it as much as we want but it always comes back to its default size. It is worth noting here that the body map does not necessarily represent the *agentive body* (space of the body used in action). Phantom limbs can be paralyzed. Furthermore, the body map can be altered by the mere distorted vision of one's static limbs (Taylor-Clarke et al., 2004).[8] The body map is neither necessarily the representation of the *affective body* (space of the body where one can feel pleasure and pain). We indeed use a spoon to stir the pot of boiling soup, rightly unafraid to feel pain in the spoon. Nor does the body map necessarily include a self-referential component (space of one's body *qua one's own*). Indeed, unlike phantom limbs, we do *not* feel tools as our own body parts. As Botvinick (2004, p. 783) noted, "the feeling of

[8] For a multimodal view of the body map (and of bodily expériences), see Vignemont (under revision).

ownership that we have for our bodies clearly does not extend to, for example, the fork we use at dinner".

If tactile localization were constrained by the felt boundaries of the body, as represented by the body map, rather than by the biological limits of the body, then one should be able to feel sensations in phantom limbs, in tools or in any other object represented within the body map. And indeed amputees can experience sensations in their phantom limb: "A draught of air on the stump produces the feeling of a draught on the [phantom] foot." (James, 1887, p. 258). Likewise, they can experience sensations in their prosthesis: "That may sound strange, but to me, my prosthesis is an extension of my body. I can actually 'feel' some things that come into contact with it, without having to see them" (in Murray, 2004, p. 970). It has been even found that even individuals with a healthy and complete body can feel sensations in a prosthetic rubber hand (Botvinick and Cohen, 1998). In the Rubber Hand Illusion, healthy subjects sit with their left arm resting on a table, hidden behind a screen. They are asked to fixate on a rubber hand in front of them, and the experimenter simultaneously strokes the participant's hand and the fake hand with two paintbrushes. After a short while, the majority of participants report that they feel the touch of the paintbrush at the location where they see the rubber hand being touched: "It seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand touched" (item 3 in the questionnaire in Botvinick and Cohen, 1998, p. 756).

Finally, one can experience sensations at the tip of a tool like Descartes' blind man with his cane, if the body map has incorporated the cane. Sensations in tools are not a mere way of speaking (Katz, 1925; Lotze, 1888; Gibson, 1966; Martin, 1993; O'Shaughnessy, 2003). First, localization in tools appears as direct. One does not need any training before feelings sensations in tools. The first time blind people use their cane, they immediately feel the solidity of the floor in the cane. Moreover, one could not have a fine-grained control over the tool if one was aware only inferentially that the pressure and the forces were located in the tool: "Pen and brush would be clumsy instruments in the hand of the clerk or the painter, if we did not directly feel their contact with the paper" (Lotze, 1888, Bk V, p. 588-9). Finally, it has been found that the localization of touch in tools follows the same principle as the localization of touch in hands (Yamamoto and Kitazawa, 2001b; for more details, see section 2.3).

We have argued that the localization of tactile sensations uses the body map as spatial reference frame. However, the body map theory can be true only if exosomesthesia is impossible, that is, if there is no case of extrapersonal sensations localized independently from the body. As argued, pressure is necessarily experienced as of being located. But is it necessarily located as of being located *on the body*? Only cases of exosomesthesia can show that there is no bodily constraint that lays upon tactile localization. We shall now analyze three series of cases that may cast doubt on the body map theory. Interestingly, these cases are almost the only cases of exosomesthesia reported in the literature in more than a century of research on the localization of bodily sensations. If there were no bodily constraint on tactile localization, then one might have expected more cases.

2.3 Is there no limit to where we can feel tactile sensations?

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

Von Bekesy's report seems to indicate that one can feel tactile sensations in external objects with no spatial contiguity and no spatial resemblance with the body. If this were true, then one should be able to feel sensations anywhere, maybe as far as the moon, as suggested by Armel and Ramachandran (2003, p. 1500):

> If you looked through a telescope at the moon and used an optical trick to stroke and touch it in synchrony with your hand, would you 'project' the sensations to the moon?

Martin (1995) disqualifies von Bekesy's report because, he claims, the loudspeaker is felt within the extension of the body. But why would it be so? Martin cannot appeal to the fact that participants feel sensations in it for risk of circularity. And there seems to be no other plausible explanation for the embodiment of the loudspeaker. In particular, it cannot be explained as a kind of Rubber Hand Illusion. It was indeed found that multisensory correlation could result in the embodiment of an external object if the object was bodily shaped such as a rubber hand, but not if it did not look like a body part, like a wooden spoon (Tsakiris and Haggard, 2005), or a loudspeaker.

A different strategy to disqualify von Bekesy's results consists in denying that subjects localize sensations in the loudspeaker. More precisely, they localize sensations there, but only indirectly. For example, when talking on the phone, I directly localize your voice close to my ear, and indirectly localize it in your office from which you are calling. Indirect localization is grounded on direct localization: with no knowledge on the functioning of the phone, I would localize your voice only close to my ear. Likewise, bodily sensations can be directly and indirectly localized.[9] Following von Bekesy's own description, we suggest that participants do not immediately experience sensations in the loudspeaker, but rather learn to "project" their sensations there. In our terminology, they *indirectly* localize tactile sensations in the loudspeaker. The rules that govern indirect localization are not necessarily the same as the rules that govern direct localization. Consequently, this result is not relevant for the study of the constraints that lay upon direct localization of tactile sensations, which is our primary concern here.

If Martin's strategy fails to account for von Bekesy's results, it is more successful in the case of a recent study that uses a well-known tactile illusion, namely, the cutaneous rabbit illusion: repeated rapid tactile stimulation at the wrist, then near the elbow, can create the illusion of touches at intervening locations along the arm, as if a rabbit hopped along it. In Miyazaki and coll. (2010)'s version of the study, participants lifted up a stick between their two fingers until it was in contact with the system that delivered mechanical pulses on the fingers via the stick. They received a series of tactile stimulations on their left index finger, then on their right index finger. Participants then reported feeling touches between the two fingers, that is, on the stick that they were holding. The authors concluded that tactile sensations could "hop out of the body". Out of

[9] For instance, when having a heart attack, I experience the pain primarily in my left arm, but I can also experience the pain derivatively in my heart if I am aware that the pain in my left arm indicates a heart attack.

the biological body, yes, but do they hop out of the body map? This is less certain. Unlike von Bekesy's loudspeaker, one can suggest a plausible account of the embodiment of the stick within the body map, which does not fall into circularity. The stick can actually be easily conceived as a tool manipulated by the participants to interact with the stimulating device. As such, it can be experienced as an extension of the body. Tactile sensations experienced on the stick are then not more surprising than sensations in tools.

The final series of putative cases of exosomesthesia comes from patient studies. An amputated patient reported feeling a sensation "in space distal to the [phantom]-finger-tips" when his stump was stimulated (Cronholm, 1951, p. 190). Another patient "mislocalized the stimulus to the left hand into space near that hand" (Shapiro and coll., 1952, p. 484). Unfortunately, we have little information on these patients.[10] Still, it is interesting to note that these reports are congruent with further results from von Bekesy (1967). He reports having used vibrotactile stimulation to induce in healthy subjects sensations located in the region of empty space between two spread fingers and between the outspread thighs. In all those cases, sensations are localized in the space *close to the body*. It is now well known that space immediately surrounding the body, which is known as peripersonal space, is represented in a special way (Ladavas and Farne, 2004). For instance, when a threatening object enters a spatial margin of safety around their body, animals engage in a range of protective behaviors (Dosey & Meisels, 1969; Cooke and Graziano, 2003). In humans, it was found that viewing a light close to a part of one's body interfered with simultaneous tactile sensations, if the location of the light was incongruent with the location of the tactile stimuli (Spence et al., 2004). The special significance of peripersonal space can be explained in various ways. It may correspond to a spatial overestimation of the boundaries of the body. Arguably, the brain computes the boundaries of the body, but taking into account some margin of spatial errors. From an evolutionary perspective, it is actually safer to overestimate the body boundaries than to

[10] For instance, does the amputated patient normally wear a prosthetic arm, which may be longer than his phantom arm? What other disorders does Shapiro's patient suffer from? Both patients report feeling sensations beyond the end of their body part phantom or physical, but would they agree if asked whether they feel sensations outside their body?

underestimate them. Alternatively, the representation of peripersonal space may play an anticipatory role. Objects immediately surrounding the body are likely to be in contact with the body in a very close future. On both interpretations, peripersonal space is perceived as potentially the space of the body. Its spatial frame of reference is centered on body parts (if the body part moves, then peripersonal space follows, cf. Kennett et al., 2002). Consequently, tactile sensations that are localized in peripersonal space are not localized independently from the body. They are localized relative to a bodily frame of reference.

To recap, the burden of proof is on the side of those who defend the view that tactile sensations can be felt in the outside world. We have analyzed a series of apparent cases of exosomesthesia, but for each case, there is always an alternative interpretation, which respects our basic intuitions about the spatial relation between tactile sensations and the body. The body map theory then explains the constraints that lay upon the spatiality of tactile sensations. Tactile sensations are necessarily localized relatively to the boundaries of the felt body because the frame of reference exploited by tactile sensations consists in the body map. Hence, when I feel a tactile sensation on my hand, I do not feel it on my hand as opposed to another hand. In contrast, when I see a red spot on my hand, I see it on my hand as opposed to many other hands. This is a fundamental difference between tactile experiences and visual experiences (Martin, 1995).

A last precision needs to be added. The body map is not the only frame of reference of tactile sensations. If it were the only reference frame, then the posture of the body should not affect tactile sensations: within the bodily frame, a sensation on the right hand remains on the right hand and a sensation on the left hand remains on the left hand even when the hands are crossed. However, crossing hands matters. If you cross your hands over your body midline with your eyes closed and if your left hand is briefly touched, and then your right hand, you take more time and you are less accurate in judging where the first touch occurred (Yamamoto and Kitazawa, 2001a). Furthermore, you experience the same difficulties if you cross two sticks with your hands uncrossed (Yamamoto and Kitazawa, 2001b). Your difficulties could not be explained if tactile sensations were mapped only relatively to the body map. Rather, they result from the localization of tactile sensations in the external world (e.g., on the left), which comes into conflict with their localization on the body (e.g., on the right hand). Pressure is therefore encoded at being at two distinct locations, what Bermudez (2005) calls A-location (i.e. within the bodily frame independent of the posture of the body) and B-location (i.e. within an external frame relative to the posture of the body). In O'Shaughnessy's terms, we experience sensations "at-a-part-of-body-at-a-point-in-body-relative-space".

This is not to say, however, that we localize sensations "relative to the fixed stars" independently of bodily localization (O'Shaughnessy, 1980, vol. I, p. 184). This is neither to say that we experience pressure first in external space, and only secondarily on the body part that happens to be at this specific region in space. If it were the case, then one should be able to localize tactile sensations independently from the body. It is rather the reverse. The body map is the primary frame of reference. Tactile sensations are localized within the external frame only insofar they are localized within the body map. More precisely, B-location derives from the combined experience of A-location (which body part is touched) and of bodily posture (where the touched body part is in space).

To conclude, the localization of tactile sensations requires a dual specification, both in terms of tactile signals and in terms of body map, which is used as spatial reference frame. Tactile sensations have therefore a privileged relation to bodily awareness. This is not to say, however, that this relation is the 'mark' of tactile sensations. It is actually shared with other bodily sensations, including pain, thermal perception, tickles and kinesthetic sensations. As argued, the mark of touch is that it is the only perceptual process that carries information about *pressure*. The body map theory is fully compatible with our earlier rejection of the body template theory. The body map theory and the body template theory must indeed be distinguished, although O'Shaughnessy (and to some extent Martin[11]) defend them both. They differ both in their explanandum and in their explanans. The body template theory aims to explain the spatial *properties* felt in tactile

[11] Martin's account is exclusively at the phenomenological level. He does not appeal to the notion of a mental representation of the body, unlike O'Shaughnessy.

perception (e.g., I feel *a circular shape*) whereas the body map theory aims to explain the spatial *location* of tactile objects (e.g., I feel pressure *at the tip of my finger*). To this end, the body template theory appeals to proprioception (dynamic sense of bodily posture) whereas the body map theory appeals to the body map (relatively stable mental representation of the structural bodily shape). One can therefore defend the body map theory without necessarily defending the body template theory. Tactile sensations consist in sensations of pressure localized within the reference frame of our body map.

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