Phenom Cogn Sci
DOI 10.1007/s11097-013-9301-7

Skillful action in peripersonal space

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Abstract In this article, I link the empirical hypothesis that neural representations of sensory stimulation near the body involve a unique motor component to the idea that the perceptual field is structured by skillful bodily activity. The neurophenomenological view that emerges is illuminating in its own right, though it may also have practical consequences. I argue that recent experiments attempting to alter the scope of these near space sensorimotor representations are actually equivocal in what they show. I propose resolving this ambiguity by treating these representations as responsive to the development or degeneration of know-how—which can be isolated as an appropriate object for scientific investigation.

Keywords Peripersonal space · Spatial perception · Skillful action · Motor intentionality · Neurophenomenology · Rizzolatti · Merleau-Ponty

Introduction

I aim to make the relationship between neuroscience and phenomenology somewhat richer by developing aspects of the relation between the perception of space and skillful bodily activity. In more precise terms, I link the empirical hypothesis that neural representations of sensory stimulation near the body involve a unique motor component to the idea that the perceptual field is structured by skillful bodily activity. The neurophenomenological view that emerges is illuminating in its own right, though it also may have practical consequences. I claim that recent experiments attempting to alter the scope of these near space sensorimotor representations are actually equivocal in what they allege to show. I propose resolving this ambiguity by treating these representations as responsive to the development or degeneration of

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Published online: 13 March 2013

know-how—which can be isolated as an appropriate object for scientific investigation.

The argument proceeds as follows. I present some well-documented empirical work concerning neural representations of sensory stimulation in the space near the body ("peripersonal space"). I then offer an interpretation of Maurice Merleau-Ponty's idea that spatial perception is modulated by skillful bodily activity ("bodily space"). I return to the present day, where researchers have begun to test whether the boundaries of peripersonal space are plastic. I identify a possible problem with the existing experimental protocol—namely, that changes in peripersonal space could be the inadvertent by-product of incorporating tools into what counts as the body ("personal space"). I then suggest modeling peripersonal space on bodily space. Thus, a new experimental protocol emerges in which skillful bodily activity (*sans* tools) is the variable against which body size is held constant, allowing researchers to test whether perceptual space can be structured solely by the perceiver's bodily activity, instead of (or in addition to) being structured by the perceiver's body size.

The space around us

When neuroscientists Giacomo Rizzolatti, Luciano Fadiga, Leonardo Fogassi, and Vittorio Gallese published "*The Space Around Us*" in 1997, some prevailing assumptions about how the brain represents the spatial structure of the perceptual field ("perceptual space") were called into question.[1] Their data, compiled over nearly two decades, remain intriguing.

Rizzolatti et al. reported that there are many neurologically distinct locations that participate in the representation of sensory stimulation in perceptual space. In addition to sensory areas, sensorimotor pathways and motor areas are crucial for these representations. This seems to have been a significant departure from the standard account—that after sensory stimulation from different sense modalities was processed, the various streams fed into a single area of the brain, where the whole of perceptual space was represented, before being routed to areas involved in motor control. According to Rizzolatti et al., stimuli in perceptual space are *not* represented in a single area of the brain and have a distinctly motor aspect.

Also, and relatedly, Rizzolatti et al. reported that sensory stimulation emanating from the space near the body (particularly, near the head, hands, and trunk) activates areas in the brain involved in the production of bodily movement—for instance, they

[1] Rizzolatti et al.'s "*The Space Around Us*" summarized major findings from 1979 to 1997 on the existence, boundaries, and characteristics of peripersonal space (Leinonen et al. 1979; Rizzolatti et al. 1981; Gentilucci et al. 1983; Rizzolatti et al. 1983; Petrides and Pandya 1984; Matelli et al. 1986; Gentilucci et al. 1988; Rizzolatti et al. 1988; Colby et al. 1993; He et al. 1993; Graziano and Gross 1994; Matelli et al. 1994; Rizzolatti et al. 1994; Graziano et al. 1994; Jeannerod et al. 1995; Colby et al. 1996; Fogassi et al. 1996a; Fogassi et al. 1996b; Gross and Graziano 1995; Graziano et al. 1997a; Graziano et al. 1997b; Murrata et al. 1997). What I call here the "prevailing assumptions" (and later the "standard account" and the "mainstream view") that were called into question by Rizzolatti et al.'s article are claims culled from various texts (Brewer 1993; Martin 1993; Pinker 1997; Hershenson 1999; Snowden et al. 2006; Mitchell 2010).

documented activation of neurons in specific areas of the putamen, parietal cortex, and premotor cortex. The same sensory stimulation, but originating in space slightly further from the body, produced no such neurological response. This too seems to have been a real departure from the mainstream view—where representations of stimuli, if movement is involved at all, were assumed either to trigger reflexive reactions or to become available for guidance of intentional actions. According to Rizzolatti et al., representations of stimuli originating near the body present the perceiver with "a potential action, a motor schema, directed toward a particular spatial location" (Rizzolatti et al. 1997, p. 190).

Even today this research program still strikes a radical note. If Rizzolatti et al. are right, then a doorknob within arm's reach is *not* represented in the brain as (*located at egocentric coordinates* <*x, y, z*>); instead, it is (or is also) represented in the brain as (*graspable by doing* <*A*>). That is, the brain does not represent stimuli near the body merely in virtue of their location per se; rather (or in addition), the brain indexes nearby stimuli in virtue of the skillful bodily activities required to engage with them.[2]

There is an obvious affinity between Rizzolatti et al.'s research and certain ideas in the phenomenological tradition—an affinity that they themselves acknowledge. Rizzolatti et al. wrote, "it is interesting to note the closeness of this view, emerging from single neuron recordings, and the philosophical stance of phenomenological philosophers on space perception" (Rizzolatti et al. 1997, p. 191). In fact, Rizzolatti et al. give the last word in their article to Merleau-Ponty, quoting him as stating that "space is 'not a sort of ether in which all things float…The points in space mark, in our vicinity, the varying range of our aims and our gestures'" (Rizzolatti et al. 1997, p. 191).

This quotation is actually a hybrid, combining two different passages from Merleau-Ponty's *Phenomenology of Perception*. To better understand this hybrid, it is worth reviewing the two original quotations, both in context and in their entirety. First, in Chapter 3, "Spatiality of One's Own Body and Motility," Merleau-Ponty begins by describing a blind man using a cane to make his way around in the world. Merleau-Ponty then describes exploring his environment, having become used to poking around with a stick of his own:

> I can see what things are 'within reach' or out of reach of my stick. There is no question here of any quick estimate or any comparison between the objective length of the stick and the objective distance away of the goal to be reached. The points in space do not stand out as objective positions in relation to the objective position occupied by our body; they mark, in our vicinity, the varying range of our aims and our gestures. (Merleau-Ponty 2002, p. 166)

And then, in Chapter 6, "Space," Merleau-Ponty describes the difference between experiencing an object in its "the pure *position*" and "the *situation* of the object in its concrete context":

> Space is not the setting (real or logical) in which things are arranged, but the means whereby the position of things becomes possible. This means that instead of

[2] In the neuroscientific literature, the language of neural *representation* is prevalent, so I prefer to use that terminology when discussing empirical data. In the phenomenological literature, the language of object *presentation* is prevalent, so I prefer to use that terminology when discussing perception. I am not committed to representationalism or anti-representationalism at either level of explanation.

> imagining it as a sort of ether in which all things float, or conceiving it abstractly as a characteristic that they have in common, we must think of it as the universal power enabling them to be connected. (Merleau-Ponty 2002, p. 284)

While I cannot do justice to the full import of each quotation, the unifying principle is clear. Both posit that perceptual space can be presented to the perceiver *either* as a system of objective coordinates in which things are located *or* as a situation in which things are positioned for potential actions. But even with a quick perusal, it is clear enough that Merleau-Ponty favored the latter, alternative conception of the spatial structure of the perceptual field—one in which objective determinations about perceptual space are abstractions from a more fundamental bodily acquaintance with the world.

We cannot know how far Rizzolatti et al. were willing to take the comparison between their research and Merleau-Ponty's idea. Nevertheless, they shared the same belief that spatial perception is structured—perhaps even constituted—by bodily activity. It seems, however, that subsequent *un*familiarity with this phenomenological heritage may have led to a problem in recent neuroscience. In order to voice this concern, I will first revisit a particularly relevant idea that Merleau-Ponty articulates in his work—the idea being alluded to in the quotations above, that is, *bodily space*.

Merleau-Ponty's idea of bodily space

According to Merleau-Ponty, to say, "I perceive the spatial location of [X]" is actually to say something quite vague, as there are multiple ways to conceive of perceptual space. There is evidence of many such conceptions in the text. He dubbed two of them: 1) "external space" ("positional spatiality") and 2) "bodily space" ("situational spatiality") (Merleau-Ponty 2012, pp. 102–103).

External space is an idea of space similar to what is taught in geometry class: $<x, y, z>$ coordinate system, measurable heights, calculable distances, determinate volumes. It sometimes also goes by the names "Cartesian" or "Euclidean" or "Newtonian" space.[3] On this conception, perceptual space is neutral with regard to the perceiver's bodily activity. In Merleau-Ponty's words, objects simply occupy "a determinate position in relation to other positions or in relation to external coordinates" (Merleau-Ponty 2012, pp. 102–103).[4]

Now compare this to the idea *bodily space*. On this conception, in Merleau-Ponty's words, "the position of objects is given immediately by the scope of the gesture that

[3] The conception of external space is not unique to Merleau-Ponty. Other terms that may have a similar sense are: Absolute Space, Allocentric Space, Cartesian Space, Euclidean Space, Physical Space, Objective Space, and Ideal Space (Smith 2002; Morris 2004; Hatfield 2009).

[4] Poincaré argued that we are able to conceptualize external space by first having a practical understanding of egocentric space (Poincaré 1905). And Husserl argued that the perceiver occupies the center around which perceptual space unfolds (Husserl 1997, 1998; Zahavi 2003). Others since have pursued this line of thought, comparing and contrasting external space and egocentric space (Gibson 1979; Evans 1982; Peacocke 1992; Campbell 1994; Briscoe 2009). For Merleau-Ponty, however, the difference between external space and bodily space did *not* hinge on egocentricity. This is an important point as both external space and bodily space can be understood in egocentric terms. The difference between these two conceptions instead hinged on the role of the perceiver's bodily activity in structuring perceptual space.

reaches them…the radius of action" (Merleau-Ponty 1945b, p. 144). In other words, objects occupy space in virtue of the perceiver's actual and potential bodily activity. In addition, it appears that objects in bodily space have differential spatiality in virtue of the perceiver's bodily activity—that is, in terms of the perceiver's practical engagement with them, what Merleau-Ponty referred to as the perceiver's "situation" (Merleau-Ponty 2012, p. 102). Consequently, the more an object is part of the perceiver's bodily activity, the more perceptual space it takes up (and the opposite). For example, Merleau-Ponty wrote, "if I stand in front of my desk and lean on it with both hands, only my hands are accentuated and my whole body trails behind them like a comet's tail" (Merleau-Ponty 2012, p. 102). Here, the perceptual field is structured by Merleau-Ponty's skillful bodily activity—his leaning on the desk.[5] In this situation, his hands took up more space in the perceptual field than his feet—which taper off "like a comet's tail." But because Merleau-Ponty could walk away at any moment, his feet never fully gave up their spatial real estate—they "trail behind" but they do not cease to exist. In bodily space, skillful bodily activity forms and deforms perceptual space by expanding out those objects that are part (or potentially part) of one's engaged activity and contracting to a point those objects that are no longer part (or potentially part) of one's situation.[6]

A particularly relevant feature of Merleau-Ponty's view is that *the space near the body* is always imbued with (supper)added significance for the perceiver in bodily space, but not necessarily so in external space. Describing a case in which a perceiver sees two objects of the same size—one viewed (straight on) from far away and the other viewed (at an angle) from close up—Merleau-Ponty claimed that, in external space, these two identical objects occupy the same perceptual space.[7] And this seems an acceptable thing to say. They are, after all, the same actual size (and the same apparent size). However, Merleau-Ponty observed that, in bodily space, "for me who is perceiving, the object at a hundred paces is not *present and real* in the sense that the object at ten paces is" (Merleau-Ponty 2012, p. 315; *emphasis added*). Similarly, we can imagine Merleau-Ponty observing that an object at ten paces is not present and real as when it is within arm's reach; an object within arm's reach is not present and

[5] I am treating "skillful bodily activity" as synonymous with "motor intentionality." In Merleau-Ponty's work, motor intentions are never bodily movements *simpliciter*. That is, motor intentions—and thus skillful bodily activities—are not to be confused with incidental or unorganized bodily movements. Nor are they to be confused with reflective actions, of which the agent is completely aware. Rather, motor intentions are characterized in terms of the goal, purpose, or intention of bodily movements, regardless of whether the agent is aware of the intention of those movements (perhaps even because there is no such awareness) (Dreyfus 2002, 2007; Gallagher 2005; Carman 2008). Motor intentions also can be thought of as bodily habits.

[6] Husserl claimed that because the body occupies space (and moves through it), the body is the condition of *possibility* of the spatiality of objects in the perceptual field (Husserl 1997, 1998; Zahavi 2003). Though Merleau-Ponty agreed, he also seemed to have been making a different point—that skillful bodily activity *conditions* the spatiality of objects in the perceptual field. Whether Merleau-Ponty also wished to make the Husserlian point is not an issue I address here.

[7] Because the two objects are the same actual and apparent size in external space, according to Merleau-Ponty, any perceived differences must be inferred or judged. "For science and for objective thought, an object seen a hundred paces away with a very small apparent size is indiscernible from the same object seen ten paces away and at a greater angle" (Merleau-Ponty 2012, p. 315).

real as when it is in the palm of your hand; and so on.[8] So why might bodily space imbue objects in space nearer to the perceiver with greater presence and reality? Perhaps because, in bodily space, if perceptual space is structured by your skillful bodily activity, and skillful bodily activity tends to be oriented toward near space, then *eo ipso* objects in near perceptual space are more present and real than objects in far perceptual space.[9]

To sum up, external space and bodily space are certainly different, perhaps even incompatible, ways of understanding perceptual space. But the dichotomy is revealing. On the one hand, in external space, the spatial structure of the perceptual field is (in an important sense) independent of the perceiver and her actions, such that objects and the space between them occupy a determinate spatial profile (*viz*. volume, depth, size, shape, etc.), regardless of what the perceiver is doing. On the other hand, in bodily space, the spatial structure of the perceptual field is (in an important sense) wholly dependent on the perceiver and her actions, warping objects and the space between them in the perceptual field—with particular significance given to the space near the body.

Peripersonal space

Scientific research stemming from Rizzolatti and his colleagues' early work continues to accumulate into the present day. A consensus seems to have formed around the view that representations of perceptual space in the brain are carved up into at least three main sectors: *personal space representation* (delimited by the surface of the body); *peripersonal space representation* (near space corresponding to >0 to 24–36 in. from the body); and *extrapersonal space representation* (the space far from the body).[10]

One branch of this contemporary research concerns whether the *boundaries* of these sectors space are *moveable*—and, in particular, whether this applies to peripersonal space. Indeed, there is gathering empirical data supporting the hypothesis that the boundaries are moveable.[11]

While reviewing these experiments, however, I identified a possible flaw in their common experimental design—specifically, they always involve *tool use*. The empirical data purportedly tracking the plasticity of peripersonal space may in fact be equivocal between (at least) two interpretations:

[8] This may be why Merleau-Ponty put "within reach" in scare quotes when he wrote, "I see which objects are 'within reach' or out of reach of my cane"—that is, to stress that near objects in bodily space have added significance because they are in immediate striking distance of the perceiver (Merleau-Ponty 2012, p. 144).

[9] There are other accounts of Merleau-Ponty's notion of bodily space and, more generally, the role of the body in structuring perceptual space (Morris 2004; Barbaras 2006; Gutting 2010). There are also accounts of the relation of spatial perception to phenomenology, but not of the moving body per se (Heelan 1983; Stöker 1987; Plomer 1991; Cataldi 1993).

[10] The technical use of "personal space" here is different than the term's more familiar use. In ordinary language, "personal space" refers to a kind of socially constructed zone surrounding one's body whose encroachment may feel uncomfortable or threatening.

[11] A well-wrought summary of the research conducted on this topic can be found in "Action-Dependent Plasticity in Peripersonal Space Representations" (Làdavas and Serino 2008).

1. *The Preferred Interpretation* is that tool use changes the range of the perceiver's bodily activity, and therefore expands the boundaries of peripersonal space;
2. *The Unconsidered Interpretation* is that tool use expands the size of the perceiver's body, and therefore expands the boundaries of personal space.[12]

Although my investigation was not (nor could be) exhaustive, I feel comfortable claiming that the empirical data I reviewed are consistent with both interpretations. Yet nearly all the researchers fail to acknowledge this ambivalence, and treat their data as indicative only of the preferred interpretation.[13] And while it is common enough in scientific discourse to offer alternatives to preferred interpretations of empirical data, I think this particular equivocation may be problematic. The reason is that, according to the unconsidered interpretation, changes to peripersonal space are merely *derivative* of changes to personal space. And if what makes peripersonal space representation unique is its connection to the "'varying range of our aims and our gestures'" and not merely to the size of our bodies, then a demonstration of the plasticity of peripersonal space must be a function of variations in bodily activity and not a function of variations in body size (Rizzolatti et al., *op. cit.*). I do not believe that the experiments achieve this.

To argue this point, I will present a small subset of experiments that I think are representative of the research being conducted in this area.[14] The experiments on humans fall under two general categories: tests with neuropathological patients and tests with normal subjects.[15] I will offer two experiments characteristic of each of the two general categories. After each presentation, I will explain why the empirical data are consistent with the two interpretations (preferred and unconsidered) introduced above.

[12] There are other unconsidered interpretations of the data that, though intriguing, I do not discuss. One reason, which I discuss later, is that there already are well-established empirical data supporting the unconsidered interpretation.

[13] There seems to have been (at least) one notable *exception*. In an experiment conducted in 1996, Atsushi Iriki, Michio Tanaka, and Yoshiaki Iwamura found neural activation in monkeys' intraparietal sulcus when presented with a raisin that was within arm's reach, but not so when presented with a raisin that was out of reach. The monkeys were then given a rake. And the results adapted accordingly. Iriki et al. found neural activation in the monkeys' intraparietal sulcus when presented with a raisin that was out of arm's reach but still within rake's reach. A careful reading reveals Iriki et al. were aware that their data are consistent with *two* interpretations: an expansion of peripersonal space ("this phenomenon implies that the structure of peripersonal space has been modified") or an expansion of personal space ("alternatively…by using a tool as an extension of the hand, the image of the hand was expanded to include the tip of the tool, resulting in the extension of the visual receptive field") (Iriki et al. 1996, p. 2329). Nevertheless, Iriki et al.'s 1996 experiment is often cited in articles as evidence *supporting* peripersonal space plasticity.

[14] There are many experiments that share this protocol (Farnè and Làdavas 2000; Maravita et al. 2001; Pegna et al. 2001; Ackroyd et al. 2002; Holmes et al. 2004; Farnè et al. 2005; Gamberini et al. 2008).

[15] Many early studies on peripersonal space and tool use were conducted on monkeys, using PET and fMRI scans (Rizzolatti et al. 1981; Rizzolatti et al. 1983; Iriki et al. 1996). Recently, similar studies have been conducted on human subjects using PET and fMRI scans (Weiss et al. 2003; Makin et al. 2007). In both monkey and human studies, however, *normal movement is severely restricted*: either because the monkeys are strapped to chairs and partially anesthetized (unable to move their heads, necks, or trunks) or because human subjects are instructed to remain motionless in the narrow PET and fMRI scanners in order to get clean films. If peripersonal space is indeed delimited by the range of skillful bodily activity, when action is limited in these ways, it is hard to know how to interpret the results. For this reason, I do not discuss them here.

Visual neglect in neuropathological human patients

One of the earlier human studies designed to test the plasticity of peripersonal space was conducted by Anna Berti and Francesca Frassinetti (2000). Berti and Frassinetti worked with a patient suffering from *visual neglect*. This is a neuropathology in which patients with damage to one side of the brain *can* detect stimuli when presented in the same ("ipsolesional") side of the visual field but *cannot* detect stimuli when presented in the opposite ("contralesional") side of the visual field. This results in "neglecting" some portion of the contralesional visual field, thereby shifting the apparent "center" of the visual field to either the left or the right, depending on which side of the brain is damaged.

Berti and Frassinetti worked with P.P., a 77-year-old, right-handed woman who suffered a stroke, resulting in severe damage to the right hemisphere of her brain.[16] While her cognitive abilities amazingly remained intact, P.P. neglected stimuli on the left side of her personal space and peripersonal space, but not extrapersonal space.

Berti and Frassinetti asked P.P. to bisect lines on a page (*viz*., mark the center or middle point) in peripersonal space (50 cm) and extrapersonal space (100 cm), either by using her index finger, a stick, or a laser pointer. The assumption was that, if P.P. bisected the lines close to the true center, then there was no visual neglect. However, if P.P. bisected the lines to the right of true center (if the bisection was "displaced right"), then there was visual neglect. See Fig. 1.

After training with the stick and laser pointer, Berti and Frassinetti found that there was significant displacement when P.P. bisected lines in peripersonal space by any means (28 % with finger, 29 % with stick, 24 % with laser pointer). Berti and Frassinetti also found that, in extrapersonal space, there was significant displacement with the stick (27 %) but little displacement with the laser pointer (9 %). Thus, according to Berti and Frassinetti, "a far object can become near if we can reach it, no matter what means we use, the hand or a tool" (Berti and Frassinetti 2000, p. 418). In other words, using a tool to perform action at a distance transforms extrapersonal space into peripersonal space.

This is not, however, the only interpretation of the data. The stick may have been incorporated into P.P.'s personal space after training. If so, then this would explain why the range of displacement remained approximately constant (24–28 %), regardless of whether she used her hand to bisect the line at 50 cm, the tool to bisect the line at 50 cm, or the tool to bisect the line at 100 cm. On this unconsidered interpretation of the data, the boundaries of personal space had expanded.

But suppose we concede to Berti and Frassinetti that the boundaries of P.P.'s peripersonal space had expanded. The deeper issue then becomes, "why?" Reconsider their assertion that "a far object can become near if we can reach it, *no matter what means we use*, the hand or a tool" (Berti and Frassinetti 2000, p. 418*; emphasis added*). I think that it does matter what means we use, as that would inform us whether the remapping of perceptual space is due to *either* an expansion of the functional range of bodily activity by using the tool *or* an expansion of body size to

[16] The areas affected were her right frontal, temporal and occipital lobes, the inferior and superior parietal lobes, the right basal ganglia, and the insula (Berti and Frassinetti 2000).

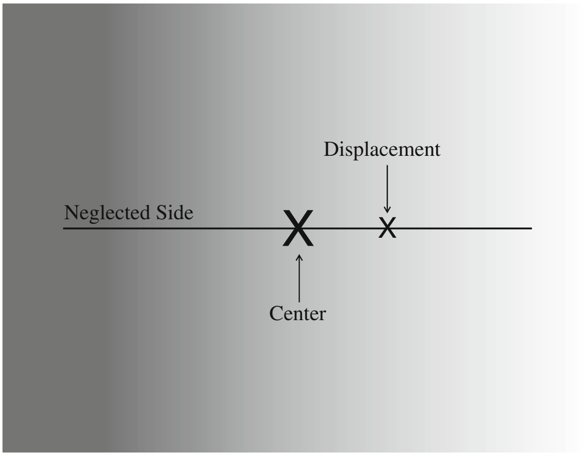

Fig. 1 Line bisection testing visual neglect. P.P. was asked to mark the middle of the line. True center is depicted here by the large "*X*." If P.P. neglected the left side of perceptual space, then she would bisect the line to the right of center (depicted here by the small "*x*")

include the tool.[17] Only the former would be a genuine expansion of peripersonal space that was not derivative of some other process. Yet Berti and Frassinetti do not seem to recognize this important difference in the interpretation of their data.

Sensory extinction in neuropathological human patients

Sensory extinction is a neuropathology that can affect patients who have damage to one side of the brain—usually the right parietal. These patients *can* recognize stimuli when applied to personal space on one side of the body or the other, but they *cannot* recognize stimuli when applied simultaneously to personal space on both sides of the body. In the latter case, when stimuli are applied simultaneously, patients recognize only the stimulus on their ipsolesional side (*viz.* the same side as the damage), while the stimulus is "extinguished" on their contralesional side (*viz.* the opposite side of the damage). For example, a patient with damage to the right side of the brain could report feeling a tap on her left shoulder followed by a tap on her right shoulder. But if both shoulders were tapped at the same time, the patient would report only feeling a tap on her right shoulder.

Early on there was good evidence that extinction also occurs in peripersonal space (but, notably, *not* in extrapersonal space). For instance, extinction might occur when

[17] Berti and Frassinetti write, "the remarkable result of the present experiment is that the use of a stick, by extending the body schema to include the space accessible by the stick, influenced the patient's computation of space" (Berti and Frassinetti 2000, p. 418). A close reading does not clarify to what "body schema" refers. The term seems to have had many different meanings and synonyms since it entered the literature in the early twentieth century (Head and Holmes 1911; Bergson 1912; Schilder 1923; Llhermitte 1998). Even Merleau-Ponty blurred the boundaries between "body schema" and other related terms—perhaps even on purpose—creating a terminological morass in the phenomenological tradition (Merleau-Ponty 1963; Merleau-Ponty 2003; Merleau-Ponty 2012). The term remains troublesome across discourses (Gallagher 1986; Campbell 1998; O'Shaughnessy 1998; Morris 2004). As such, I have chosen to avoid it here.

synchronically making a snapping sound near the patient's left ear and right ear or shining a laser pointer near the patient's left hand and right hand (di Pellegrino et al. 1997; Làdavas et al. 1998).[18] This made extinction a valuable method for defining the boundaries of peripersonal space and also, importantly, whether the boundaries of peripersonal space could be moved.

In an elegant experiment conducted by Alessandro Farnè and Elisabetta Làdavas in 2000, a group of patients with damage to the right side of the brain were instructed to use a rake in their right hand in order to retrieve objects in extrapersonal space. But rather than applying stimuli to peripersonal space only, Farnè and Làdavas applied stimuli to both the space near the patients' left hand ("perihand" space) and the space near the tip of the rake ("perirake" space). That is, Farnè and Làdavas applied stimuli to what was initially peripersonal space (perihand space) and extrapersonal space (perirake space). Farnè and Làdavas then ran trials in which stimuli were administered diachronically and synchronically to perihand space and perirake space *before* and *after* active tool use. Before training, they observed extinction about 53 % of the time (on the contralesional side). After training (approximately 5 min), they observed extinction at about 75 % of the time (on the contralesional side)—a 25 % increase. See Fig. 2.[19]

According to Farnè and Làdavas, these results lend support to their hypothesis that the boundaries of peripersonal space are plastic. In their words:

> The act of retrieving distant objects with a rake induced a transient expansion of the spatial extent of patients' perihand space… This result constitutes direct evidence that the representation of perihand space was expanded along the tool axis to include its length. (Farnè and Làdavas 2000, p. 1648)

There are, however, two interpretations of what actually was "induced" to expand by "retrieving distant objects with a rake." On the one hand, the preferred interpretation is that the data are indicative of the plasticity of *peripersonal* space, as Farnè and Làdavas claim. So active tool use directly induced an expansion to the patients' functional range of action, thereby altering the boundaries of their peripersonal space. But, on the other hand, the unconsidered interpretation is that the data may be indicative of the plasticity of *personal* space. That is, the training period resulted in the rake being incorporated into the patients' bodies, thereby altering the boundaries of their personal space. Now, on this unconsidered interpretation, peripersonal space would indeed have expanded as well. This change, however, would be a mere *secondary* or *inadvertent* effect of increased body size due to tool incorporation, not a *primary* or *genuine* effect of bodily activity—which does not seem to be what Farnè and Làdavas believe they had shown. Therefore, because the expansion of peripersonal space could have been induced by either of two processes, there is no "direct evidence" that bodily activity alone expanded the boundaries of peripersonal space.

[18] Cross-modal sensory extinction (e.g., vision and tactation) in personal and peripersonal space has also been documented (Làdavas et al. 1998; Maravita et al. 2001; Maravita et al. 2002; Farnè and Làdavas 2002; Làdavas and Farnè 2004; Makin et al. 2007).

[19] Figure 2 is adapted from "Action-Dependent Plasticity in Peripersonal Space Representations" (Làdavas and Serino 2008).

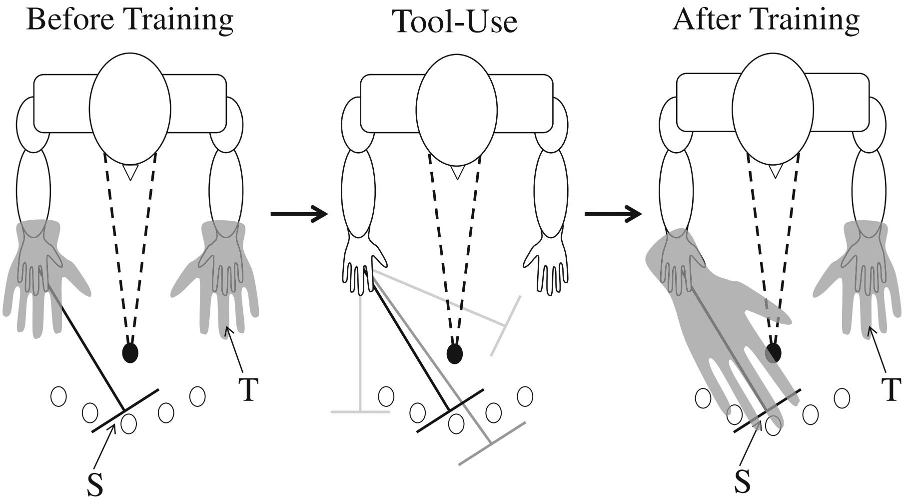

Fig. 2 Expanding peripersonal space. Before training, when stimulus *S* was applied in perirake space concurrent with stimulus *T* applied in perihand space, there was no extinction. After training, there was extinction. Peripersonal space (represented by the *transparent gray hand*) appears to be expanding

Pseudoneglect in normal human subjects

Effects similar to visual neglect can be found in normal human subjects. This phenomenon called "*pseudoneglect*" has been used to test whether the boundaries of peripersonal space representation are expandable. In one experiment, conducted in 2006 by Matthew Longo and Stella Lourenco, a sample population of healthy adults was asked to bisect lines using either a *stick* or a *laser pointer* at four distances: 30, 60, 90, and 120 cm (average arm length was 70 cm, so distances 60 cm or less were considered within arm's reach and therefore in peripersonal space). Displacement was measured in relation to line length and directionality. So, for example, on a 20-cm line, a recording of "+40 %" would signify the subject had marked the line 4 cm to the right of true center, and a recording of "−20 %" would signify the subject had marked the line 2 cm to the left of true center.

When subjects used the laser pointer, Longo and Lourenco found rightward displacement that increased in direct proportion to distance between subject and line (*viz*., the further away the line, the greater the displacement). However, when subjects used the stick, Longo and Lourenco found no major increase or decrease in displacement at any distance.[20] See Fig. 3.

In the discussion of their results, Longo and Lourenco acknowledge that the expansion of peripersonal space may have two explanations, writing that "the strength of representations of near space may be in inverse proportion to the degree of effort required to act, and rather than being coded as the space within arm's reach, near space may be scaled as a ratio of arm's length" (Longo and Lourenco 2006, p. 980). In other words, neural activity correlated with sensory stimulation in

[20] Longo and Lourenco found a small but constant left displacement when subjects used the stick, which Longo and Lourenco attribute to neural activity in the right posterior parietal cortex—an area associated with representations of sensory stimuli in peripersonal space (Longo and Lourenco 2006, p. 980).

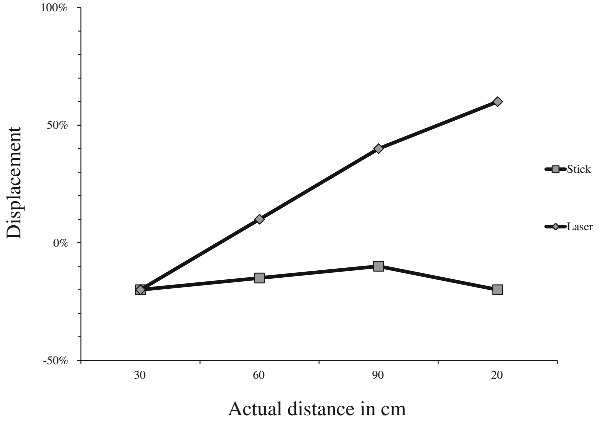

Fig. 3 Pseudoneglect in normal subjects (a positive value on the *y*-axis represents rightward displacement, and a negative value on the *y*-axis represents leftward displacement). As the actual distance from the perceiver increased, Longo and Lourenco found that displacement increased with the laser pointer but not the stick

peripersonal space may be proportionate to either one of two measures: the range of bodily activity (in this case, the length of the reach) *or* the size of the body (in this case, the length of the arm with or without the tool). This is exactly the right distinction to make. For instance, compare reaching for an object as you would normally versus reaching for an object by only moving your arm. It is surprising just how much of what is "within reach"—and thus in peripersonal space—depends not just on the movements of the arm but also on the movements of the rest of the body: leaning forward, bending at the waist, twisting the torso, and so forth (Longo and Lourenco 2006, p. 980).

And yet, even though Longo and Lourenco appear quite sensitive to this issue, they treat their data as supporting the hypothesis that, "tool use expands the range of near space" in the same way that bending at the waist expands the range of near space (Longo and Lourenco 2006, p. 980). So, once again, the data are interpreted as being indicative of the expansion of peripersonal space as constituted by the increased range of bodily activity due to tool use, when instead the data are equivocal between that interpretation and one whereby the expansion of peripersonal space is the secondary effect of the incorporation of tools into the body.

Perceived distance by normal human subjects

In an experiment conducted in 2005 by Jessica Witt, Dennis Proffitt, and William Epstein, a sample population of normal human subjects were asked to estimate the perceived distance of an object, while varying the so-called reachability of that object. Witt et al. varied the distance between perceiver and object from approximately 40 to 120 cm. They also varied the reachability of the object by introducing a tool—in this case, a 40-cm baton. Witt et al. instructed subjects to reach for the object using either their hand or the baton. The object was either outside both baton's reach and arm's reach, or within baton's reach but outside arm's reach. Subjects were then asked to estimate the distance between themselves and the object, either verbally (by giving a numerical estimate) or behaviorally (by placing two markers or holding their hands a certain distance apart).

Witt et al. found that subjects perceived an object to be closer if it was within reach, and farther if it was not within reach, even if the object was exactly the same distance away in both cases.[21] For example, an object 80 cm from the subject was not within arm's reach but was within baton's reach. Subjects who reached with their arms reported that the object was approximately 77 cm away, while subjects who reached with a baton reported that the object was approximately 70 cm away. Although reports across trials and among subjects seem to vary, regression analysis yielded a difference of about 7 cm between the two reaching conditions. See Fig. 4.

In discussing their results, Witt et al. write that "when holding the baton, near space expanded, and targets that were remapped into near space were perceived as being closer" (Witt et al. 2005, pp. 883–884). That is, changes in reachability are concomitant with changes to the boundaries of peripersonal space, such that objects within reach (whether by hand or by tool) look closer than objects that are out of reach (whether by hand or by tool), even when the distance between perceivers and objects remains the same.

In this experiment, it is once again unclear whether the modulations in perceived distance are the direct effect of the expansion of the range of bodily activity or the expansion of the size of the body. Witt et al. write:

> The extent of our reach defines the boundary of our immediate action space. The range of this space can be extended by having a hand tool. Perception is influenced by this affordance for immediate action. Objects that are within reach are perceived to be closer than those that are not. When a hand tool is used, objects that were previously out of reach become reachable, and, consequently, they appear closer than when the tool was not held. (Witt et al. 2005, p. 887)

From this quotation, it is clear that Witt et al. think bodily activity, *not* tool incorporation, is expanding peripersonal space. But, once again, it seems that there are two explanations for the changes in perceived distance, and therefore two interpretations of why there seems to be an expansion of peripersonal space in the reaching-with-tool paradigm.[22] On the preferred interpretation, as Witt et al. claim, peripersonal space might expand due to changes in the range of the subjects' bodily activity—thereby constituting a genuine expansion of the boundaries of peripersonal space. On the unconsidered interpretation, peripersonal space might expand due to changes in the size of the subjects' body—such that the expansion of the boundaries of peripersonal space is merely derivative of other processes.

[21] Witt et al. at the same time conducted another experiment to determine whether there was a "cognitive correction" at work—that is, subjects perceived the targets to be the same distance, but for other reasons (e.g., inference from reachability to closeness) estimated their distances differentially. The data suggest that there was no cognitive correction and that it was the perception of distance that changed (Witt et al. 2005).

[22] There is even an equivocation in Witt et al.'s choice of "hand tool"—which could mean either a tool meant to be used with one's hand or the incorporation of a tool into one's hand.

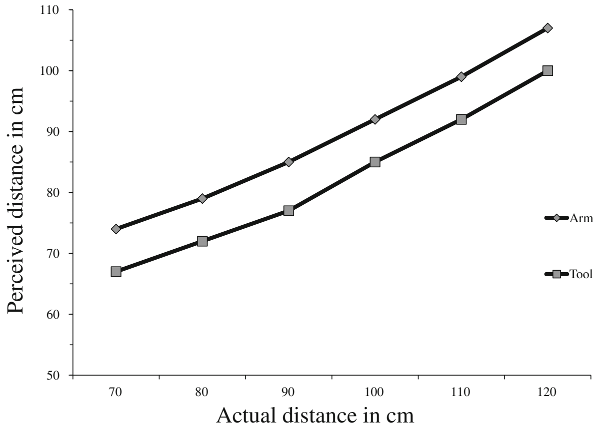

Fig. 4 Objects in peripersonal space look closer (the *x*-axis represents actual distance between perceiver and object, and the *y*-axis represents perceived distance between perceiver and object). Witt et al. found that active tool use shortens the perceived distance between perceiver and object

Possible problem with experimental design: tool use

Two assumptions would appear to have been made in the design of the experiments testing the plasticity of the boundaries of peripersonal space. First, *tool use is an action*, so the functional range of skillful bodily activity changes before, during, and after tool use. Second, *tools are not body parts*, so the space occupied by the body remains the same before, during, and after tool use. The first assumption seems harmless enough. But the second assumption, while in some sense intuitively obvious, may be problematic.

The reason the second assumption may be problematic starts with the common-sense notion that artifacts—the blind man's cane, the amputee's prosthetic hand, the cellist's bow, Roger Federer's tennis racket—can become an extension of the body under the right conditions. And there is now a whole family of empirical research suggesting that this notion is not just a bit of folk psychology, most famously in Matthew Botvinick and Jonathan Cohen's 1998 article, "Rubber Hands 'Feel' Touch That Eyes See."[23] It appears that artifacts can be *incorporated* into personal space, in the literal sense of the term (*viz*. "formed into the body"), even if this incorporation is partial or transient.[24] What counts as one's own body, it seems, is malleable.

In experiments testing the plasticity of the boundaries of peripersonal space, subjects are given tools with which to familiarize themselves—in the four

[23] In the 1998 experiment conducted by Botvinick and Cohen, a subject is seated with her left hand resting on a table. A screen hides the subject's real left hand from view, while a life-sized rubber hand is placed directly in front of her. With eyes fixed on the rubber hand, Botvinik and Cohen used two paintbrushes to simultaneously stroke both the subject's real hand and the rubber hand. After a few minutes, the subject reported that she felt the stroke of the paintbrush on the rubber hand (not on her real hand). The "rubber hand illusion," as it is now called, is paradigmatic of how easily the incorporation of artifacts into personal space can occur (Iriki et al. 1996; Yamamoto and Kitazawa 2001; Maravita and Iriki 2004; Tsakiris and Haggard 2005; Umiltà et al. 2008; Cardinali et al. 2009; Carlson et al. 2010; Crèem-Regehr 2010; Iriki 2010).

[24] There is an arguable difference between extensions of the body due to tool use and extensions of the body due to prosthetic use that I do not address here (De Preester and Tsakiris 2009).

experiments that I presented here rakes, batons, and sticks. As a consequence, tool use may have caused subjects to incorporate these artifacts into their personal space. To be sure, this is a perfectly valid result. Researchers would have shown that the boundaries of personal space and peripersonal space are plastic for the simple reason that as the body gets bigger, the space around the body gets bigger too. But I do not think this is what they had hoped to demonstrate.

Recall Rizzolatti and his colleagues' surprise that bodily activity itself—not body size—structures the neural representations of stimulation in perceptual space. What we need is an experiment that preserves this crucial distinction between body size and bodily activity in order to determine whether action plasticity alone—not size plasticity—can be responsible for restructuring the borders of peripersonal space. In other words, actual body size and the range of bodily activity are dissociable at the personal level, but are the representations of near space sensitive to that dissociation at the subpersonal level?[25] And how might we design an experiment that heeds this potential dissociation?

I would like to wind down this section by animating my concern with a thought experiment. OVERdrive is a pharmaceutical company that has developed a drug, *Hydra*, that they claim prevents dehydration in healthy adults. OVERdrive has conducted studies finding that athletes who maintain their normal hydration regimes and take *Hydra* are less dehydrated than athletes who maintain their normal hydration regimes but do not take *Hydra*. It may seem like *Hydra* prevents dehydration. But suppose one dose of *Hydra* requires swallowing six large uncoated pills. So in order to take *Hydra*, athletes must imbibe approximately 12 oz of water (2 oz per pill). The question then becomes what is causing the decrease in dehydration: (1) the water injested to swallow *Hydra*, or (2) *Hydra* itself? You might respond that the reason this question even can be asked is because the studies are improperly designed. *And that is exactly my point*. If you are interested in testing whether *Hydra* prevents dehydration, then you need to determine a way for athletes to take *Hydra* without ingesting the additional water.

Skillful action in peripersonal space

One approach to designing this kind of experiment involves modeling peripersonal space on Merleau-Ponty's conception of bodily space. And we are now in a better position to understand the connection between Rizzolatti et al.'s research and Merleau-Ponty's work on perceptual space. Recall Rizzolatti et al.'s findings that sensory stimulation near the body correlated with the activation of sensory areas, sensorimotor pathways, and motor areas in the brain. Their empirical discoveries connect nicely with a theoretical model whereby the spatial location of objects is presented as an enactive situation for the perceiver. That is, if the perceptual field is structured by the perceiver's skillful bodily activity, then the representation of sensory stimulation will have an inescapable motor component, directing the perceiver—in a practical way—towards locations in space. Moreover, because skillful bodily activity

[25] I am employing Daniel Dennett's classic distinction between personal levels of explanation and subpersonal levels of explanation (Dennett 1969)

is particularly oriented towards near space, we find the neuroscientists and the phenomenologist again in agreement that objects near the body possess a special kind of motor significance that their far space counterparts lack, and that sensory stimulation emanating in near space will be represented accordingly.[26]

If we use this model, then it would follow that *the development or degradation of bodily skill* can become the variable against which body size can be held constant. In other words, if peripersonal space is a zone demarcated by the extent of our skillful bodily activity, then *changes to our know-how*—insofar as they vary this range of our bodily activity—should modify peripersonal space without also inadvertently altering personal space. The experimental protocol that emerges from this paradigm shift could be similar to those experiments already conducted except that, instead of tools, subjects would use *their own bodies* to perform behavioral tasks. Crucially, by not using tools to perform these tasks, we sidestep the problem I have been articulating.

Consider an experiment with the following general structure. Assign subjects a behavioral task. Importantly, the task must be one they *cannot* perform with significant success at the start of the trial. Subjects are then taught a sequence of movements that—when linked together over a short period of time—allow the assigned task to be performed. The subjects are allotted a training period to learn these movements, and to perform them quickly, such that by the end of the trial, they can perform the task with significant success. In other words, the subjects are required to *learn a simple skill*. The experiment would then measure whether the boundaries of peripersonal space had changed, using methodologies similar to those in the current research (e.g., extinction, line bisection, distance estimation, etc.). It would be reasonable to expect that changes to the boundaries of peripersonal space in the new experimental paradigm would be smaller than those measured in the old experimental paradigm. But even a small expansion of peripersonal space would be a significant finding.

Some examples of the behavioral tasks that I have in mind are, as examples, playing a simple melody on a keyboard or manipulating their fingers to retrieve small objects.[27] The latter example calls to mind the children's game *Operation*. For the

[26] Rizzolatti continues to be cognizant of the connection between his research and Merleau-Ponty's work. In *Mirrors in the Brain*, Rizzolatti and Sinigaglia write, "objects are simply hypotheses of action and therefore places in space cannot be integrated as 'objective positions' in relation to an equally alleged objective position of the body, but must be understood, as Merleau-Ponty pointed out, in their 'marking, in our vicinity, the varying range of our aims and gestures.' This range dictates our possibility of distinguishing between peripersonal as opposed to extrapersonal space and of understanding the dynamic nature of the boundary that separates one from the other" (Rizzolatti and Sinigaglia 2008, p. 77). The links between bodily activity and perceptual space, the distinction between near space and far space, and the plasticity of the boundaries of peripersonal space are all established here. Also implied is the claim that bodily activity (not mere bodily movements) structures perceptual space, a claim repeatedly offered by Merleau-Ponty. Other articles also integrate aspects of Merleau-Ponty's idea of motor intentionality and neural representations of perceptual space (Varela et al. 1991; Petitot 2000; Pachoud 2007; Sinigaglia 2008; Cappuccio 2009; Costantini et al. 2011; Butterfill and Sinigaglia 2012).

[27] Learning to play an instrument or a sport with sufficient expertise also would qualify, but these behavioral tasks would be too difficult to acquire in one lab visit. Instead, I listed a few examples of skill development that may be learned (and unlearned) quickly. It would be interesting, though, whether developing musical or athletic expertise manifests changes to the boundaries of peripersonal space over extended periods of time.

uninitiated, this is a skill game, the basic structure of which is to remove small pieces embedded in the game board using a tool. In *Operation*, the tool is a pair of tweezers, the board is Cavity Sam (the "patient"), and the embedded pieces are small bits of plastic: his funny bone, a butterfly in his stomach, his bread basket. The game is made more challenging by the fact that the pieces are inside compartments with electrified walls, so that if you (the "surgeon") were to nick them with the tweezers, then Cavity Sam's nose flashes red and a loud buzzer goes off.

Now imagine a variation of *Operation*, in which subjects must learn to manipulate their *fingers* in a particular way to retrieve some object from a compartment without touching the sides. Using a similar experimental setup to the one explained earlier in Farnè and Làdavas's work, before and after training, we could apply stimuli diachronically and synchronically to the space near the hand and to a location just outside of perihand space—for instance, the bottom of the compartment. If there were no extinction before training (*viz*. both stimuli were recognized) and there were extinction after training (*viz*. only one stimulus was recognized), then we would have demonstrated that peripersonal space had expanded down into the compartment as a direct result of changes to the patients' skillful bodily activity. See Fig. 5.

Assuredly, there are more elegant experiments to be designed than the rough draft I have outlined. But the general idea for a new experimental protocol is importantly distinct from the existing protocol. If tools were not used to perform behavioral tasks, and instead only the range of the subjects' skillful bodily activity were varied, then the empirical data that would emerge (if indeed positive) could be interpreted only as the genuine, non-derivative, expansion of the boundaries of peripersonal space.

There is a concern worth addressing, here at the end, as to whether the distinction between the preferred interpretation and unconsidered interpretation is ultimately a real one—a "distinction with a real difference." Recall, the preferred interpretation is that tool use modifies the range of the perceiver's bodily activity, and therefore expands the boundaries of peripersonal space; the unconsidered interpretation is that tool use changes the perceiver's body size, and therefore expands the boundaries of personal space. But suppose, for instance, we were to discover that the neural representations of peripersonal space are not sensitive to the difference between changes to bodily activity (due to tool use) and changes to body size (due to tool incorporation). It then would not matter whether those representations are being modified by changes in bodily activity, by alternations to body size, or both. If the neural representations of peripersonal space are indeed "promiscuous" in this way, then the two interpretations of the empirical data might not matter at the subpersonal level (allowing that it might still matter at the personal level).[28] And the proposed

[28] Does the phenomenology support promiscuity at the personal level? Looking to Merleau-Ponty, the answer is uncertain. He wrote, "to habituate oneself to a hat, an automobile, or a cane is to take up residence in them, or inversely, to make them participate within the voluminosity of one's own body. Habit expresses the power we have of dilating our being in the world, or of altering our existence through incorporating new instruments" (Merleau-Ponty 2012, pp. 144–145). At first glance, this quotation reads like an endorsement of promiscuity. But upon closer examination, it is unclear whether the "participation" or "residence" of artifacts ever becomes total, in the sense that my arms do not merely "participate" or "reside" in my own body but rather are wholly part of my own body.

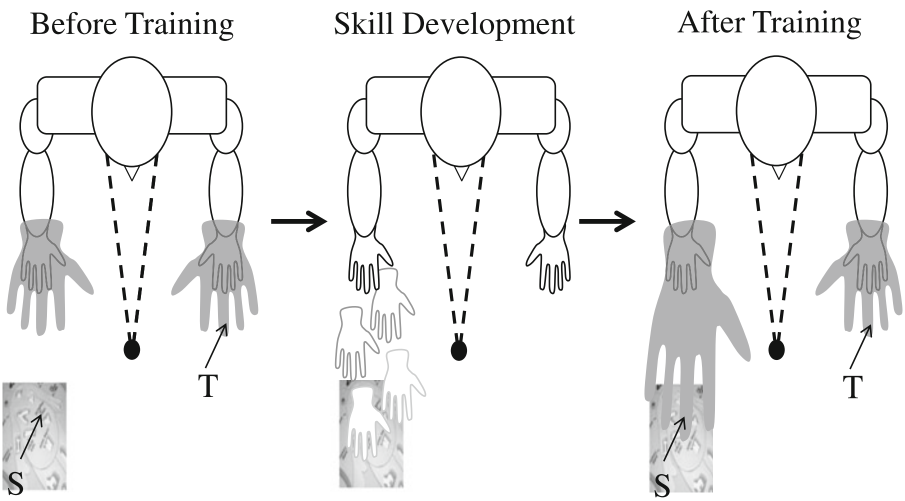

Fig. 5 Can bodily skill alone expand peripersonal space? Before training, there is no extinction when stimulus *S* is applied to the space on the board concurrent with stimulus *T* applied in perihand space. After training, there might be extinction when *S* is applied to the space on the board concurrent with *T* applied in perihand space

distinction between the preferred interpretation and the unconsidered interpretation would be moot.

To respond to this concern, I would like to suggest that promiscuity does not affect my *proposal* for refining how we should investigate the plasticity of the boundaries of peripersonal space (viz., by insisting on a new experimental protocol, whereby we induce changes to the range of bodily activity without the aid of tools), but it might affect how we interpret the *results* of the new experimental protocol. Thus, further empirical study would be required to determine whether or not the neural representations of peripersonal space are indeed promiscuous.

On the one hand, a negative result (viz., there are no changes to peripersonal space after skill development) would suggest that modifications to the range of skillful bodily activity *sans* tools are insufficient to remap peripersonal space. This would be an interesting finding. Neural representations of peripersonal space *would be* sensitive to the difference between changes to activity enabled by bodily skill and changes to activity enabled by tools—that is, neural representations of peripersonal space would *not* be promiscuous.

On the other hand, a positive result (viz., there are changes to peripersonal space after skill development) would suggest that any modifications to the range of skillful bodily activity are sufficient to remap peripersonal space. This too would be an interesting finding. Neural representations of peripersonal space would *not* be sensitive to the difference between changes to activity enabled by bodily skill and changes to activity enabled by tools—that is, neural representations of peripersonal space *would be* promiscuous.

Of course, a positive result (unlike a negative result) may well undermine the proposed distinction between the preferred interpretation and unconsidered interpretation at the subpersonal level. But I am happy to accept this kind of undermining.

My point is that the “distinction without a real difference” concern cannot be addressed wholly from the armchair, which I believe is a perfectly handsome thing to say in this context.

Conclusion

Neurophenomenology—as the reigning *modus operandi* of relating phenomenology and neuroscience—is a collaboration that has produced a great many things, including possibly the research on peripersonal space itself. In this article, however, I suggested that a certain inattention to phenomenology may have created a problem for neuroscience. I argued that experiments demonstrating the plasticity of peripersonal space are actually unclear in what they show. But returning to the phenomenological insights present at the inception of the research on peripersonal space furnished some clarity. I proposed defining the limits of peripersonal space as that which falls within range of our skillful bodily activities. The plasticity of the boundaries of peripersonal space then becomes a function of fluctuations in skill (the development or degeneration of know-how)—which can be isolated as an appropriate object for scientific investigation.

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