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THE INTERPERSONAL BODILY SELF
A link between body and social interactions

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The Interpersonal Bodily Self

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Abstract

The relationship between the body and the self raises a number of questions in psychology, philosophy and neuroscience. What is the body for the self? Is the self embodied or is something completely mental? Does the body guarantee personal identity? Of course, the self is a multimodal, hierarchical construct containing both low-level bodily representations, and higher level attitudes and beliefs. For instance, the “physical self ” is referred to the body ownership and bodily self recognition. On the other hand, the “interpersonal self” represents the attention or intentions of others directed at the self, for instance when a person notices that he or she is being looked at (Sugiura, 2013). Recently, some evidence have suggested that both bodily self representation and social, interpersonal representation of the self are malleable and linked, showing a mutual influence (Maister et al., 2015). When we experience an illusion over a body different from our own, this can change aspects of our self identity and the way in which the self is conceptualized, which, in turn, may change the way in which we interact with other people (Banakou et al., 2013; Peck et al., 2013; Yee & Bailenson, 2007). This evidence reveals the social valence of body representation, and the intimate relationship between basic, body perceptual representations and the complex mechanisms underlying our everyday social interactions.

The importance of one’s own body representation in social interaction, can be due to the elaborate system of visual signals that the social interaction itself requires. Indeed, being gazed upon is an important social cue and representing one’s own body as a visible entity to outside observer, may play a key role during social interactions. The first two studies of the thesis, presented in the Chapters II and III, investigate the social cognitive consequences of having an invisible body. The power of being invisible has captured the imagination of writers and philosophers for millennia and it is clear that the idea of invisibility has a strong intuitive psychological meaning. In particular, the study presented in Chapter II demonstrates that the illusion of having an invisible body modulates the interpersonal space. The interpersonal space refers to the distance that people maintain between each other during a social interaction and into which intrusions by others may cause discomfort (Hall, 1966; Hayduck, 1983). Results show that the experience of invisibility, induces a specific contraction of the interpersonal space, without affecting the perceived reaching-space around the body. Thus, these results support a close relationship between interpersonal space and the conscious representation of the body external appearance. The study in Chapter III shows that the experience of invisibility affects also the perception of gaze direction itself. When people notice that they are being looked at, they become aware that the attention of another person is directed at them. This awareness is fundamental during social interactions and it is distinct from the awareness of one’s own physical body because it requires the existence of another person (Sugiura, 2013).

Humans are very accurate in determining the gaze direction of others. However, although gaze direction can be perceived very accurately in general, observers are prone to assume mutual gaze when another person is looking roughly into the direction of their own face. Crucially, results from the study in Chapter III show that the illusion of having an invisible face affects gaze perception, reducing the expectation that the gaze is directed toward them.

The last two chapters (Chapter IV and V) focus more in depth on the difference between interpersonal and peripersonal space and their relationship with the body appearance and the body schema. In the neurocognitive domain, the peripersonal space is a functional representation of the space near the body, conceptualized as a sensorimotor interface for the body to act on nearby objects (di Pellegrino & Làdavas, 2015). Crucially, peripersonal space is modulated by, and relies on, morphological and sensorimotor body representation. This sensorimotor representation of the body morphology has been termed body schema, and it is concerned with tracking and updating the positions and configuration of body parts in space (Martel et al., 2016). The study presented in Chapter IV shows that a change in body height reveals a dissociation between interpersonal and peripersonal space. In particular, the illusion of having a tall body reduced the interpersonal space, but, at the same, extended the perceived peripersonal space. On the other hand, the illusion of having a short body extended the social interpersonal space, leaving the peripersonal space intact. Body size, indeed, has been related to interpersonal dominance in a variety of social settings (Stulp et al., 2015). At the same time, a change of body height affects also the sensorimotor representation of the arm length, i.e. the body schema. Thus, given this double valence of the body size, a change in body height is effective to reveal a dissociation in the representation of the space around the body, depending on whether this sector of space is used for programming actions or for regulating social dyadic interaction. Finally the study in Chapter V focuses more in depth on the notion of body schema, trying to figure out which is the exact variable that determinates its extent. In particular, I hypothesize that body schema and peripersonal space extent depend on the sense of agency, that is the sense of controlling one's own motor acts and, through them, the events in the external environment.

Taken together these data contribute to the emerging field of research on embodied cognition that suggests the existence of a causal link between central body representations and more social and cognitive aspects of the self. In particular, I argue that the self can be conceptualized as a layer structure. In this hierarchical layered structure each level is highly dynamic and extremely plastic. Moreover, there may be also cross-layer dynamics that operate along different categories of the self.

Chapter 1

From the body in the mind to the mind in the body

This chapter introduces key concepts and gives a theoretical frame for my researches. In the first session, I briefly explain how the brain represents the bodily self. One of the main arguments of this session is that body representation relies on processing multisensory information from the space immediately surrounding the body (i.e. the peripersonal space). Indeed, several researchers have demonstrated that, manipulating multisensory cues in the space immediately around the body, it is possible to induce an illusory ownership over a fake or virtual body parts or whole bodies. Thus, in the first session, I explore how the brain creates the experience of having a body located in space. I refer to this session as “the body in the mind”.

In the second part, I provide evidence that a change in one’s own body representation, can induce a change in more conceptual and psychological representations of the self, affecting social cognition and behaviour. Thus, in the second session I show that changing body changes mind. I refer to this session as “the mind in the body”.

1. The body in the mind

I thought to myself: “Well, here I am sitting on a folding chair, staring through a piece of plate glass at my own brain ... But wait,” I said to myself, “shouldn’t I have thought, ‘Here I am, suspended in a bubbling fluid, being stared at by my own eyes?’” I tried to think this latter thought. I tried to project it into the tank, offering it hopefully to my brain, but I failed to carry off the exercise with any conviction. I tried again. “Here am I, Daniel Dennett, suspended in a bubbling fluid, being stared at by my own eyes.” No, it just didn’t work

Daniel Dennett (1978)

1.1. The concept of body ownership and its relation to multisensory integration

The feeling that conscious experiences are grounded to the self and are bound to a unitary entity (“I”), is often considered one of the most amazing features of the human mind. The body is the point from which we perceive the world: we perceive the world from the perspective of our body. The body is also the medium with which we interact with external world. So, in some sense, the self is first and foremost our body. Thus, one of the approach to

investigate self-consciousness has been to study how the brain process bodily signals and create the experience of a physical self in space, that is the bodily self consciousness (Blanke et al., 2015). One of the fundamental dimension of the bodily self is the sense of **body ownership**. The term body ownership, indeed, refers to special perceptual status of one's own body, in virtue of which one is aware of one's own body as one's own. There has been a growing consensus in the cognitive neuroscience that the perception of one's own body in space critically depends on multisensory integration (Blanke, 2012; Ehrsson, 2012; Tsakiris, 2010). Information from different sensory signals (such as visual, vestibular, and auditory signals) reach cortical convergence zones in the frontal, parietal, and temporal lobes, where the integration of these body signals occurs (Angelaki & Cullen, 2008; Avillac et al., 2007; Graziano & Botvinick, 2002; Graziano & Cooke, 2006; Hagura, et al., 2007; Pouget et al., 2002). Researchers have suggested that multisensory integration of bodily inputs within the space immediately surrounding the body is a key component of bodily self consciousness. Therefore, numerous experimental paradigms used several multisensory stimulations as means for studying and altering the experience of body ownership.

The **Rubber hand illusion (RHI)** is one of the most common experimental paradigm for manipulating the feeling of body ownership. In brief, participants' real hand is kept out of view, while a realistic life-sized rubber hand is placed in front of them. The experimenter uses two small paintbrush to synchronously stroke the rubber hand and the participant's real hand (Figure 1.1). After a short period of stroking, the majority of participants report perceiving the touch as if coming from the rubber hand and the latter as being part of their own body (Botvinick & Cohen, 1998). This illusion does not occur when the rubber hand is stroked asynchronously. One behavioural correlate of the rubber hand illusion is a change in the perceived location of one's own hand, the so called proprioceptive drift. In particular, participants are asked to point blindly to the position of their left hand. Crucially, they give proprioceptive estimations that are shifted toward the rubber hand compared to their estimations before the stimulation. Interestingly, the subjective intensity of the experience of body ownership is positively correlated with changes in the felt location (Botvinick & Cohen, 1998; Longo et al., 2008; Tsakiris and Haggard, 2005). Apart from proprioceptive drift, a further test is to induce an emotional response in participants by simulating an injury to the fake hand. This emotional response can be measured by recording changes in the conductance of the skin (skin conductance response, SCR). Thus, when the rubber hand is threaten with a knife (Ehrsson et al., 2008; Petkova and Ehrsson, 2009) or one of its finger is bent backward (Armel & Ramachandran, 2003), the SCR enhances significantly in comparison to the appropriate control conditions. Another evidence of the illusion is obtained by measuring the skin temperature. Indeed, during the illusion, the real hand's temperature drops by 0.27°.

Importantly, the extent of the temperature drop is correlated with the strength of the illusion (Moseley et al., 2008)

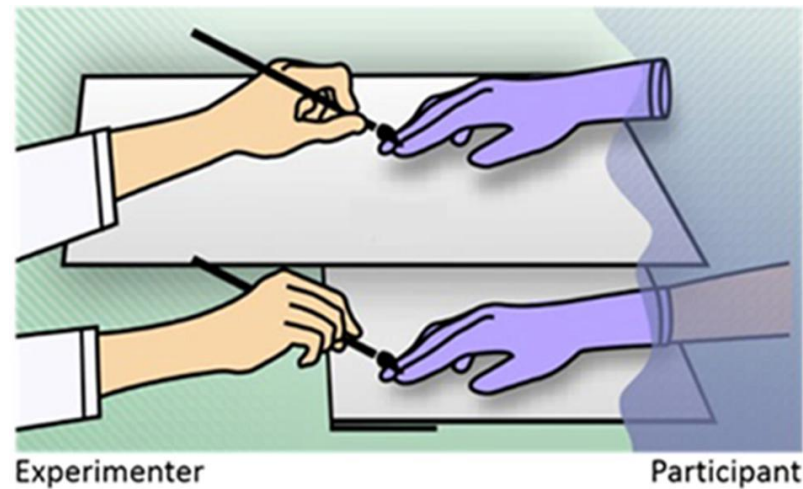


Figure 1.1 The classical setting of the rubber hand illusion. The participant's hidden hand are synchronously stroked by the experimenter. Image from Braun et al.(2018)

As mentioned before, the RHI reflects the malleability of the representation of the body caused by multisensory processing. Multisensory processing aims at the integration of sensory signals and the resolution of potential conflicts to generate a coherent representation of the world and the body. The RHI reflects an interaction between vision and touch. However, the intermodal matching between vision and touch is not a sufficient factor for limb ownership. Multisensory integration of bodily signals, indeed, relies on additional constraints, such as proprioceptive, anatomical and spatial constraints (Blanke et al., 2015). When the rubber hand is positioned in an anatomically implausible posture, the rubber hand illusion is abolished (Figure 1.2A; proprioceptive constraint; Pavani et al., 2000; Tsakiris and Haggard, 2005). The illusion is also significantly diminished when participants are stroked on their right hand and see a left rather than right fake hand. (Tsakiris and Haggard, 2005). Given this anatomical constraint, the illusion does not work with objects that do not resemble a human hand at all, such as a stick or wooden objects [Figure 1.2B ; body related visual information constraint (Tsakiris et al., 2010; Tsakiris & Haggard, 2005)]. Moreover, no illusory hand ownership is induced if the rubber hand is presented far outside the space surrounding the hand (Figure 1.2 C; spatial constraint; Lloyd, 2007). These observations fit well with the idea that the multisensory integration responsible for body ownership operates on representations of near-personal space. Sensory inputs, originally processed in sensory-dependent coordinates (e.g., visual stimuli in eye-centered, auditory stimuli in head-centered, tactile stimuli in skin-centered reference frames), are realigned and integrated into a common reference frame.

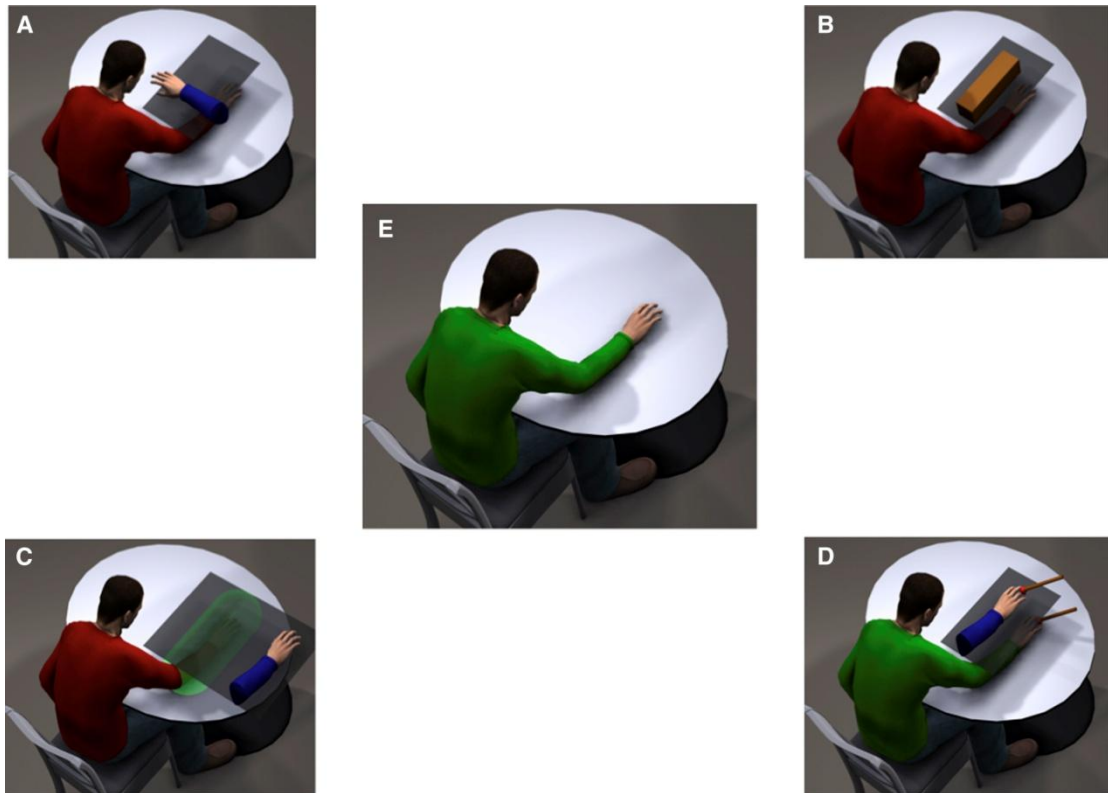


Figure 1.2. Fundamental constraints of the hand ownership. No change in the bodily self representation occurs if the fake hand is placed in a non-matching body posture (A: proprioceptive constraint). No change in body ownership occurs for an object with a non-bodily shape (B: body related visual information constraint), or if the rubber hand is placed outside the near space of the real hand (C: spatial constraint). A change in body ownership is obtained if the real hand and the artificial hand receive synchronous visuotactile stimulation (D: rubber hand illusion). Note that, in normal conditions, all multisensory constraints are present, leading to a normal sense of body ownership (E). Red or green body of the participant indicate, respectively, absence or presence of body ownership for the hand. Adapted from Blanke et al., 2015

The common reference frame of multisensory perception is the subject's body, and the transformation involves processing and integration of additional proprioceptive and vestibular inputs signalling the location of a tactile cue on the body in space and visual inputs related to the configuration of the body in space. Therefore, the system of areas integrating information from the body and from the space surrounding the body, binding visual, tactile, proprioceptive and other multisensory signals, could be the good candidate for the neural substrate of body ownership.

Thus, in the next paragraph, I will focus on a set of neurons, bimodal and multimodal neurons, located in the posterior parietal cortex and premotor cortex, highlighting their properties related to body ownership and multisensory bodily perception. The key feature of bimodal neurons is that they respond not only to stimuli in one modality, such as tactile cues, but also to visual, or auditory signals in the space immediately surrounding the body: the so-called **peripersonal space**.

1.2. Neural basis of the bodily self

1.2.1 Body part ownership

The existence of multisensory body-centred neurons has been revealed at first by electrophysiological research in the macaque monkeys, within a network of interconnected sensorimotor areas, such as the parietal and frontal premotor cortices. The key feature of multisensory neurons is that they respond not only to stimuli in one modality, such as tactile cues, but also to visual, auditory and proprioceptive signals (see di Pellegrino and Ladavas for review). These neurons are mainly located, in the macaque monkey, in the inferior aspect of the premotor cortex (area 6), particularly its caudal portion (i.e. the histochemical area F4 where proximal arm movements respond to tactile stimulation; Matelli et al., 1985). Also posterior parietal lobe, particularly areas 7b and VIP, heavily linked to the F4 region, harbours bimodal and trimodal neurons. These fronto-parietal areas are strongly interconnected, and they project, directly or indirectly, to the cortico-spinal tracts, forming a fronto-parietal multisensory-motor network supporting sensory-motor functions (Rizzolatti et al., 1997, 2002; Colby, 1998; Grefkes and Fink, 2005).

Compared to tactile receptive field in S1, F4 neurons are characterized by relatively large tactile receptive fields covering an entire hand/arm, the head and the neck, as if to form a broad map of the body (Rizzolatti et al., 1981). A large portion of neurons in area F4 are bimodal, discharging in response to both tactile and visual stimuli. Specifically, unlike classical visual neurons, F4 neurons respond poorly to visual stimuli far from the body, whereas they are effectively triggered by three dimensional objects moving close to the tactile receptive field (Gentilucci et al., 1983, 1988; Rizzolatti et al., 1981). Some of such neurons respond only to stimuli very close to the body surface, up to 10 cm away from the body (the so called percutaneous neurons), while others respond also to stimuli located further away, but always within the animal's reaching (the so called distance peripersonal neurons). The visual and tactile receptive fields are in spatial register with one another, so that F4 neurons form a single responsive region mapping the bodily surface and the space immediately adjacent to it. The interaction between different receptive fields is not limited to visuo-tactile information, since F4 neurons integrate also auditory information, indicating that premotor area F4 creates a multimodal representation of the near space (Graziano et al., 1999). Most bimodal neuron in area 7b have even larger tactile receptive field and may cover the arm, the head and the trunk and sometimes even the whole body bilaterally, showing a crude somatotopic organization.

Most of the cells in 7b respond preferentially to visual stimuli moving toward the skin, within about 10 cm of the tactile receptive fields, although stimuli presented further away, but still within a reachable distance, are also effective (Leinonen et al., 1979, 1980; Leinonen and

Nyman, 1979; Hyvärinen, 1981; Graziano and Gross, 1995). The ventral intraparietal areas (area VIP), located in the fundus of the intraparietal sulcus contains mainly visual and visuo-tactile neurons. Unlike area 7b neurons, in most VIP neurons the tactile receptive fields are usually centred on the head and their visual receptive fields are anchored to the region of space around the face (Colby et al., 1993). Moreover, some VIP neurons are trimodal, responding to visual, auditory and tactile stimuli, with the three different receptive fields usually aligned (Schlack et al., 2003). It has been suggested that the area VIP is involved in the construction of a multisensory, head-centred representation of near space.

More relevant for present purposes, an important characteristic of these neurons is that they also integrate proprioceptive and sometimes vestibular signals to anchor their multisensory receptive field to different body parts (see Fig. 1.3). Thus, the receptive fields of these neurons are independent of eye movements remaining in the same position regardless of gaze deviation (Graziano et al., 1994). This is demonstrated by the fact that passive or active displacement of a body part to which the tactile receptive field is anchored, e.g., the arm, causes a shift in the location of the visual or auditory receptive field from the initial spatial position to its new location (Graziano et al., 1994)

In a well known research, Graziano,(1999) recorded the activity of ventral premotor cortex (vPMc) neurons of a monkey, showing that such neurons responded to visual objects presented near a fake arm, placed in a realistic posture. In this study, a fake monkey arm was placed above a barrier that occluded the monkey's real arm, while the monkey saw a visual stimuli that approached the fake arm. The responses of the bimodal neurons were modulated by the seen position of the fake arm. That is, the visual receptive fields of these neuron shifted toward the position of the fake hand. Moreover when the fake hand moved, the visual receptive fields also moved in the same direction, even though the monkey's real arm was stationary.

Similar visuo-proprioceptive coding was found also in parietal area 5. In another study, Graziano and colleagues (2000) selected only neurons whose response depended on the position of the real arm but not of the fake arm. Authors tested neural responses before and after a synchronous visuo-tactile stimulation similar to the rubber hand illusion (i.e. the experimenter stroked synchronously with a paintbrush the fake hand and the monkey's real hand). Crucially, after the synchronous stimulation the neuron become sensitive to the position of the fake arm, a coding which was absent before visuo-tactile stimulation. Moreover, these neurons were not sensitive to the sight of unrealistic substitute for arm and were able to distinguish a right from a left arm. Thus, these results are consistent with the proprioceptive and body related visual constrains highlighted by behavioural studies in humans using the rubber hand illusion.

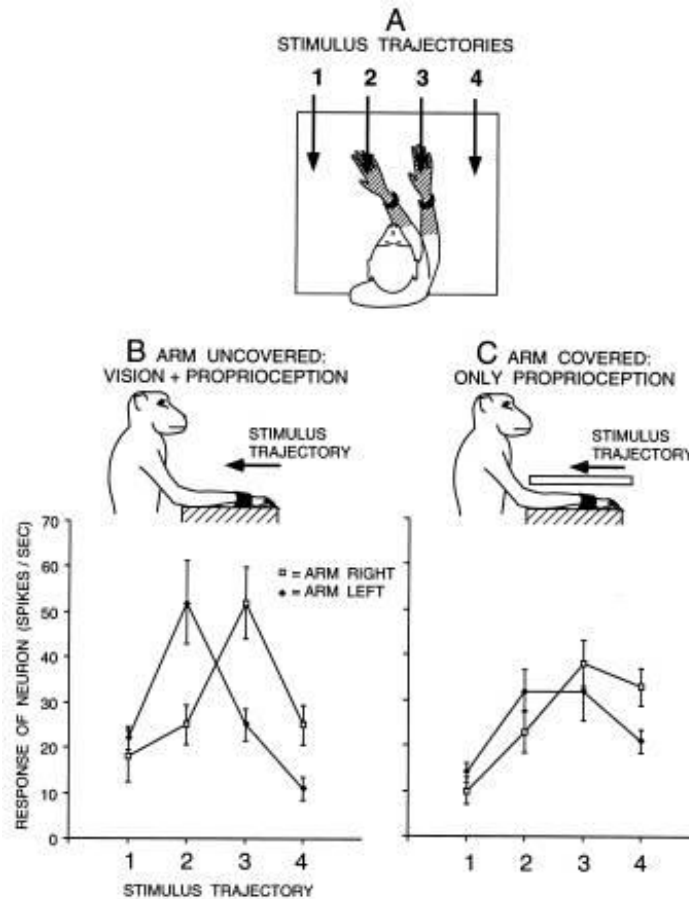


Figure 1.3 Visual responses of a typical premotor neuron with a tactile RF the forearm and hand, and a visual RF within 10 cm of the tactile RF. (A) On each trial, the arm contralateral to the neuron was fixed in one of two positions and the visual stimulus was advanced along one of four trajectories (1–4). For this neuron, the two arm positions were chosen to align the visual RF near the hand and forearm with trajectories 2 and 3. For other neurons, the arm was moved to different extents depending on the location of the visual RF, to better capture the movement of the visual RF with the arm. (B) Responses of the neuron to the four stimulus trajectories when the arm was visible to the monkey. When the arm was fixed on the right, the response was maximum at position 3. When the arm was fixed on the left, the maximum response moved to the left, to position 2. (C) Responses of the neuron when the arm was covered. The movement of the visual RF with the arm was reduced but not eliminated, indicating that the neuron combined both proprioceptive and visual information about the position of the arm. Each point is a mean of 10 trials. Error bars are standard error. From Graziano, 1999

Human imaging studies, indeed, suggest that a similar system for multisensory integration also exist in the human brain. Makin et al., 2007 showed that regions across the posterior intraparietal sulcus, (IPS) the lateral occipital cortex (LOC) and the premotor cortex (PMc) were activated more strongly when a ball approached the participant's hand. Critically the greater activation for near ball was lost when the hand was retracted, indicating that these regions represent visual stimuli with respect to hand position. Moreover in these areas selective responses to objects in near space was abolished when the hand was occluded from view. However, when a dummy hand was placed in a natural position near the objects, these areas responded again, irrespective of the position of participant's real hand. This result was obtained although participants reported that they did not sense an illusion of ownership over the dummy hand. Thus the mere presence of the dummy hand in front of the retracted

subject's hand modulated the preference for a near stimulus in the posterior IPS and the LOC, indicating that the response of these areas is based primarily on visual information about hand position, regardless of information from proprioception. This conclusion nicely accord with the activity recorded in the macaque ventral PMc, modulated by the seen position of the fake hand. In contrast, Makin et al. (2007) found that the anterior part of IPS was characterized by converging proprioceptive and visual information of the hand. This area indeed responded only in the real hand condition, in particular when the real hand was occluded from view. Thus, human anterior IPS showed peri-hand proprieties similar to those reported in single unit studies in macaque area 5, whose neurons responded to the fake hand only after a visuotactile stimulation to induce ownership for the fake arm (Graziano et al., 2000).

Another study showed that these regions of the brain process not only signals that are on or close to the hand, but they also integrate multisensory stimuli delivered within the arm-centred peripersonal space (Gentile et al., 2011). Participants, in the scanner, gazed at their hand, while unimodal tactile stimulation, unimodal visual stimulation and bimodal (visuo-tactile) stimulation were presented on the hand and in the space immediately surrounding the hand. Areas in posterior and inferior parietal cortex and PMc showed an additive response to bimodal as compared to unimodal stimulation. Other regions in the anterior IPS dorsal PMc, insula and putamen showed non-linear, super additive response during multisensory visuo-tactile stimulation, thus nicely matching the neurophysiological data on multisensory integration in non human primates. Moreover, in a subsequent study from the same laboratory (Gentile et al., 2013), authors joined tactile stimulation of the participant's hand with the visual presentation of a virtual hand while manipulating spatial and temporal synchrony. Activation in IPS, ventral and dorsal PMc, in LOC and in the cerebellum depended on spatial and temporal congruence of the visual and tactile signals. Furthermore, visuo-tactile integration requires congruency between the seen and felt orientations of the hand, indicating that multisensory integration in the peripersonal space of the hand requires congruent visual and proprioceptive information from the hand, again in close accord with results in animals.

Thus, neuroimaging studies in humans highlight a network of premotor and parietal areas associated with the integration of visuotactile information occurring within the hand peripersonal space, depending on the aforementioned constraints of the body ownership (i.e. proprioceptive, anatomical and spatial constraints). Further neuroimaging studies linked this peripersonal hand centred system to arm and hand ownership.

A greater activation was found, during the rubber hand illusion, in the ventral PMc and the left intraparietal cortex as compared to control conditions in which temporal asynchrony or spatial incongruency was introduced [(Ehrsson et al., 2004), Fig. 1.4]. The intraparietal cortex was sensitive to both the orientation of the rubber hand and the synchrony of the visual and tactile stimuli. The level of activity in this area during the illusion condition reflected a

summation of the effects of temporal and spatial congruency. Moreover, the vPMC showed a response even more specific to the illusion. In particular, the degree of activity in vPMC correlated with the strength of the illusion, as measured by subjective reports in a questionnaire.

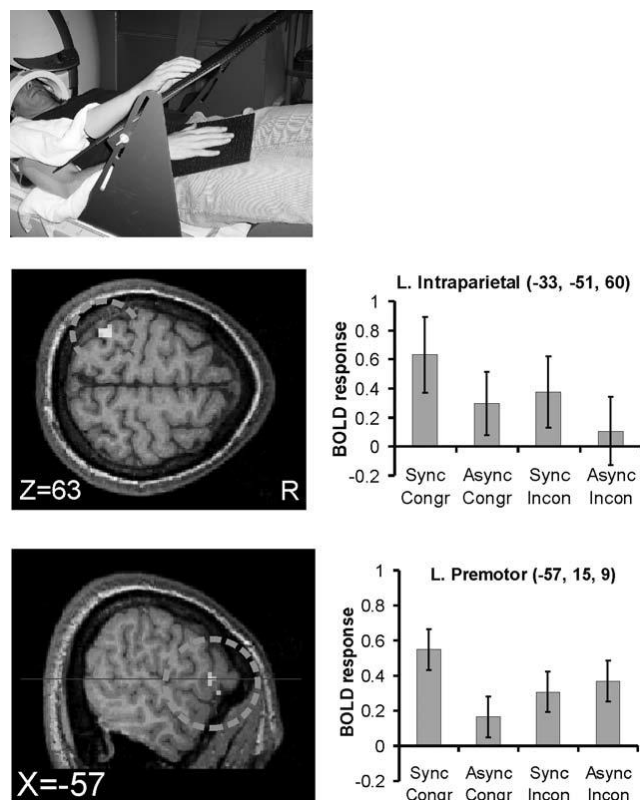


Figure 1.4. fMRI activations in multisensory area during the rubber hand illusion. The top panel shows the position of the participant in the scanner. Activity is seen in both the intraparietal sulcus (middle panel) and the ventral part of the premotor cortex (lower panel). From Ehrsson, 2012

More recently, fMRI adaptation was used to investigate whether, similarly to findings in monkeys (Graziano and Gross, 1995), regions in IPS and PMc remap the peripersonal space of the hand when the hand is moved in space, that is to say whether also in the human brain, peripersonal space is coded in hand centred reference frames (Brozzoli et al., 2012). In line with previous studies, neural populations in human intraparietal, premotor and inferior parietal cortices showed adaptation effect when the stimulus was presented near the hand and, crucially, the effect followed the hand when it was moved across two positions in space. In addition, by using the rubber hand illusion, authors revealed the link between the encoding of the hand peripersonal space and the perception of the hand with respect to its location and identity. In particular, during the rubber hand, the peri-hand space remapped onto the location of the rubber hand when the rubber hand was perceived as one's own. Also, the presentation of an object near the fake hand led to a stronger BOLD response in the premotor, posterior parietal and putaminal regions after the synchronous compared to asynchronous stimulations. Results, moreover, indicated that the adaptation responses in the left ventral

PMC correlated with the subjective feeling of ownership of the seen limb, whereas adaptation responses in the posterior parietal cortex correlated with the proprioceptive drift toward the hand, i.e., with changes in the position sense of the arm. This is in line with the neurophysiological function of posterior parietal cortex in updating the position of the body parts in space and in planning of manual actions. As mentioned before, neurons in area 5 of the macaque encode the arm position by integrating visual and proprioceptive signals. Thus, the posterior parietal cortex could play a role in creating, as authors said, a “*proprioceptive skeleton into which selective visual response can be grounded*” (Brozzoli et al., 2012; 2014)

Taken together, these human neuroimaging studies highlight two main regions (PMC and PPC), within a larger network of cortical areas (including insula, primary somatosensory cortex, LOC and cerebellum), involved in multisensory integration in arm centred coordinates. Human PMC and IPS integrate multisensory stimuli within the hand peripersonal space, based on the spatial and temporal laws of multisensory perception. This is consistent with the neurophysiological data in PMC and area 5 in non-human primates. These data point towards the idea that tuning properties of bi- or tri-modal neurons, mapping the peri-hand space, in the PMC-IPS network (Graziano et al., 1999, 2000; see also Makin et al., 2008) define ownership for one’s own hand, or for an its replacement (i.e. the rubber hand), by integrating multiple hand-related signals within the peripersonal space, on the basis of proprioceptive and visual constraints.

1.2.2 Self identification and self location: the full body illusion

So far in this chapter, I have only considered cases in which subjects experience changes in the ownership of a single limb. However, beyond ownership of a limb, the same principles of multisensory integration have been used to probe questions of full body ownership. For instance, Ehrsson’s research team developed a body swap illusion in which participants feel ownership for an entire artificial body (Petkova & Ehrsson, 2008). In this illusion, participants wear a set of head-mounted displays (HMDs), connected to two cameras which are attached to a life-sized mannequin and positioned so that they are looking down on the mannequin’s body. Thus, when participants wear the HMDs and look down, they see the mannequin’s body where they expect to see their own body. Similar to the rubber hand, to induce the illusion the experimenter touches simultaneously the participant’s belly, out of view, and the mannequin’s belly, in full view of the participant. This procedure creates in participants the illusion of owning the mannequin’s body (See Fig. 1.5A). This effect is quantified with questionnaires and with the skin conductance responses when the participants observed a knife cutting the belly of the mannequin. Importantly, this illusion, just like the rubber hand illusion, seems to conform to the multisensory principles above described. Asynchronous visuotactile stimulation, replacement of the mannequin by a block of wood, or presentation of the mannequin 2 m in

front of the participant, which is outside the peripersonal space, were all conditions that eliminated or strongly reduced the illusion (Petkova et al., 2011b).

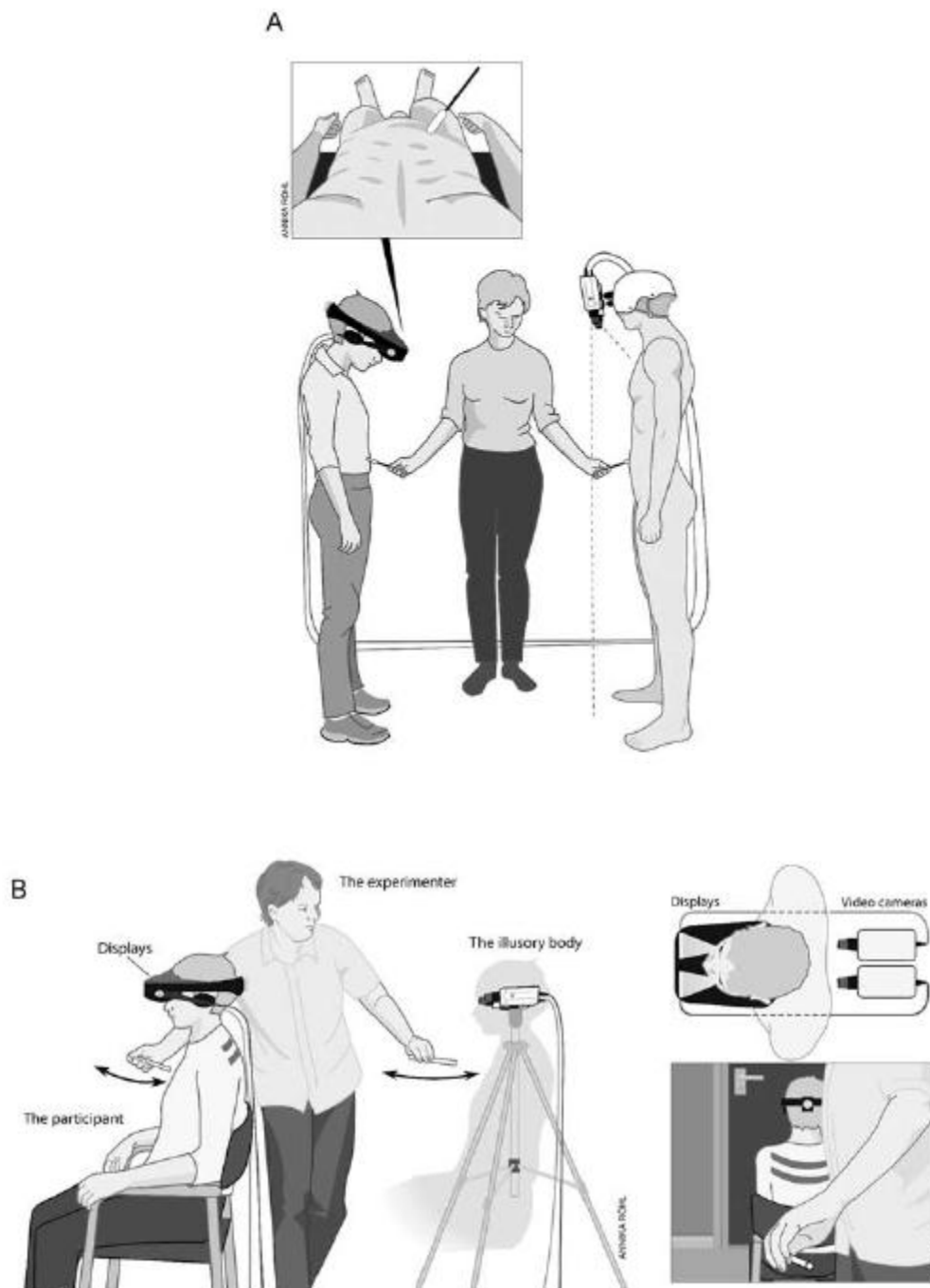


Figure 1.5. Eliciting illusions of entire bodies. (A) The *mannequin illusion* (Petkova & Ehrsson, 2008) and the participant's perspective in this illusion. (B) The *out-of-body-illusion* (Ehrsson, 2007) and what the participants see. The participants are wearing a set of head mounted displays connected to two video cameras placed on the mannequin's head (A), a tripod 1.5 m behind the participant (B). Synchronous somatic and visual events are provided by touches applied to the mannequin's belly and the participant's belly (A), the participant's chest and the "chest" of the "illusory body". Adapted from Ehrsson, 2012

Visuo-tactile stimulation can produce also an "out of body illusion" (Ehrsson, 2007). Participants seat on a chair and wear an HMDs connected to two cameras placed about 2 m behind them. Thus, participants see themselves from the point of view of the cameras, i.e. with

the perspective of a person sitting behind them. To induce the illusion, the experimenter used two plastic rods to touch the person's actual chest, which is out of view, while simultaneously moved another rod in the location just below the camera. The visual impressions of a hand approaching a point below the cameras and the touch felt on the chest, led the participants to experience the illusion of being located 2 m behind their real body (See Fig. 1.5B).

Thus it seems that multisensory stimulation involving larger part of the body, such as the trunk region, leads to alteration of more global aspect of bodily self, like self identification and self location. Another systematic change in self location have been induced by Blanke's research team (Lenggenhager et al., 2007). Usually, in these paradigms participants view the back of their bodies filmed from a distance of 2 m and projected onto an HMD (Fig. 1.6) 2 meters in front of them.

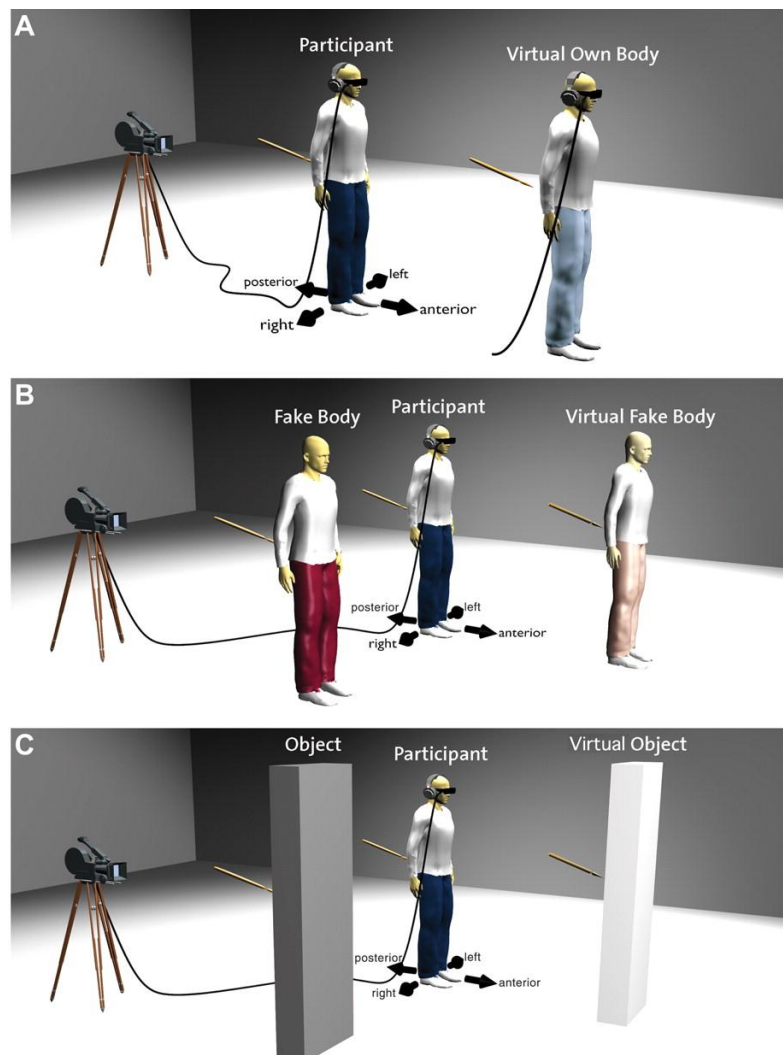


Figure 1.6. (A) Participant (dark blue trousers) see through a HMD his own virtual body (light blue trousers) in 3D, standing 2 m in front of him and being stroked synchronously or asynchronously at the participant's back. (B) virtual fake body (light red trousers) or (C) a virtual noncorporeal object (light gray) being stroked synchronously or asynchronously at the back. Dark colors indicate the actual location of the physical body or object, whereas light colors represent the virtual body or object seen on the HMD. From Lenggenhager et al., 2007

The experimenter strokes the participant's back, thus the participants feel the stocking on their back and see the back of the virtual body being touched two meters in front.

Crucially, participants report that they feel the touch at the position where they see the virtual body rather than on their back. When exposed to this full body illusion, participants identified themselves with the virtual body and show a forward drift in self location toward the position of the virtual body. Also in this case, the illusion does not work if the touches between the participant's back and the virtual back are asynchronous and if the virtual body is replaced with an object.

In the previous paragraph we suggested that changes in hand ownership involve changes and shifts in the spatial characteristics of hand centred multimodal neurons in human parietal or PMC areas. Analogously, it's possible to imagine that the full-body illusions rely on similar neurophysiological tuning changes for trunk, especially in areas VIP or area 7b. Thus, the visuotactile stroking described for the arm and trunk and affecting bodily ownership, change the neural responses of multimodal neurons, resulting in a shift or enlargement of their visual receptive fields, so that they also encode the seen fake hand or body. Bodily illusions, implementing specific spatio-temporal conflicts in multisensory signals, might alter the standard constraints typically ruling multisensory integration of bodily inputs, thus re-shaping peripersonal representation and inducing specific and predicted changes in body ownership. However, although the mechanisms of multisensory integration at the trunk level are similar to those in circumscribed body part, there are important differences. Indeed, multisensory perception of stimuli at the trunk encompasses large parts of the body, or the entire body, thus involving more global aspects of the bodily self. Incidentally, this difference is reflected also in tactile proprieties: since the size of the tactile receptive fields is small at finger/hand and large at the trunk, the tactile spatial resolution at the fingers and hand is very high, whereas it is very low for the trunk (Iwamura, 1998; Graziano and Gandhi, 2000). Moreover, illusory shift in the perceived self location can be induced also for an artificial body presented farther away, outside the peripersonal space. Thus, it has been recently proposed that neural processes of global aspects of bodily self, related to the trunk, are fundamental for self identification and self location and are partially different from those encoding body ownership for circumscribed body parts (Blanke et al., 2015). Only global aspects of the bodily self lead to the experience of being located within a particular portion of space (self-location) and to identify with that portion of space. In everyday life, our position in space coincides with our physical body (self-identification), where our peripersonal space representation is centred. However, if multisensory bodily inputs are manipulated, using specific conflicts under specific constraints, it is possible to induce states of body ownership for other objects or spatial locations, reshaping the periepersonal space representation and altering self-identification and self-location.

Petkova et al., (2011a) combined the body swap illusion with fMRI, showing that the posterior parietal cortex and the ventral premotor cortex were more active when tactile information applied to the participant's belly was spatially and temporally congruent with tactile stimulation seen on the virtual body. Greater activation in such areas was found when the artificial body was presented in a similar location and orientation as the participant's real body as compared to when the body was lying directly opposite the participant. Moreover, the same areas were also activated during illusory ownership for a virtual hand, but these activations were stronger when the hand was visually perceived as part of the virtual body, as compared to when the hand was presented in isolation, detached from the body. These results thus suggest that the integration of visual, tactile, and proprioceptive information in body-part-centered reference frames represents a basic neural mechanism underlying the feeling of ownership of entire bodies. Importantly, a sub-region of the left vPMC was constantly activated when illusory ownership for the virtual body was evoked after synchronous visuotactile stimulation, independently of whether the hand or the abdomen was stimulated. Thus, activity in left vPMC reflects ownership generalized to the entire body, integrating multisensory information across body parts. This type of multisensory integration could be implemented by neurons with large visual, tactile and proprioceptive receptive fields extending over multiple body segments. This idea was further supported by a subsequent study, in which three anatomically different body segments (hand, abdomen and leg) were stimulated to induce a full body illusion over a virtual body (Gentile et al., 2015). Crucially, also in this case patterns of neural activity in vPMC reflected the integration of visual and tactile signals that were associated with the feeling of ownership over the entire body, regardless of the body segment that received the multisensory stimulation. On the other hand, other portions of the ventral PMC, IPS, LOC and putamen showed more selective responses for synchronous visuo-tactile stimulation of specific body parts.

Thus, neural populations in the vPMC contain visuotactile receptive field that encompass multiple body segments, mediating the construction of a multisensory whole-body percept. These results are again in line with the electrophysiological recordings in non human primates that showed neurons containing multisensory receptive field sufficiently large to encompass multiple body segments or the entire body surface. These neuronal populations are pivotal to the construction of a whole body percept via the integration of multisensory information across multiple body segment.

These last two studies manipulated the sense of ownership for the virtual body, but didn't modify the perceived location of the self in space. As mentioned before, some bodily illusions can also alter the perceived location of the self in space. In a study by Ionta et al. (2011), participants felt touch on their back while viewing videos of a virtual body being touched on its back. Participants reported a feeling that their body shifted from the space occupied by their

physical body to a spatial location closer to where they saw the virtual body and some participants reported also a sense of ownership for the virtual body. Thus, differently from the body swap illusion, this illusion has also been shown to induce change in self location, which were found to be associated to an activity in the left and right TPJ and the middle inferior temporal cortex. No activations related to body ownership were observed in PMC and IPS. Interestingly, in this study changes in self-location were associated also to changes in the experienced direction of participants' first-person perspective. In particular, some participants experienced looking upward toward the virtual body (up-looking first-person perspective), and other participants experienced looking down on the virtual body (down-looking first-person perspective). Crucially, the modulation of the TPJ activity varied as a function of how participants felt themselves to be located and orientated with respect to the virtual body. Participants who felt themselves to be looking upwards at the virtual body (up-group), estimated self-location as higher and TPJ activity was lower during synchronous compared with asynchronous visuo-tactile stimulation. Participants who felt themselves at a lower location and to be looking downwards, the estimated self-location was lower and TPJ activity was higher during synchronous compared with asynchronous stimulation. Thus TPJ activity reflects self location and the direction of the first person perspective. The TPJ is an important multisensory area, integrating inputs from the tactile, proprioceptive and visual systems, and, critically, from the vestibular system (Blanke & Arzy, 2005; Lopez & Blanke, 2011; Lopez et al., 2008). Clinical, neurophysiological and neuroimaging data about the TPJ strongly support the involvement of this area in self-location and perception of the world from a perspective originating from one's position in space. A subsequent study (Ionta et al., 2013), used the functional connectivity analysis and showed that during the shift in self location there was a strength in the connection between right and left TPJ and supplementary motor area, ventral premotor cortex, insula, intraparietal sulcus and occipitotemporal cortex. In particular, the functional connectivity between right TPJ and right insula had the highest selectivity for changes in self-location and first-person perspective. The involvement of the insula in bodily self consciousness and self-location is in line with the prominent involvement of the insula neurons in processing bodily multisensory signals including vestibular signals (Indovina et al., 2005; Mazzola et al., 2014). The insula is also the primary region processing interoceptive signals (Craig, 2002; Critchley et al., 2004). A PET study by Tsakiris et al. (2007), for instance, suggests that the insula also underpins bodily self-consciousness during the RHI because activation of the right insula was positively correlated with the strength of the RHI. To this regard, a recent study has shown that interoceptive awareness, measured by a heartbeat detection task, is negatively correlated with the intensity of the RHI. Subjects with higher interoceptive awareness were less prone to experience the illusion.

Finally, in another study, Guterstam, et al.,(2015) used the body-swap illusion with different visual viewpoints from where the mannequin's body and the room were seen. Thus, participants experienced illusory self-location at different places in the scanner room, depending on the mannequin's viewpoint. Activity patterns in the hippocampus and the posterior cingulate, retrosplenial, and intraparietal cortices reflected the sense of self-location, whereas the sense of body ownership was associated with premotor-intraparietal activity. The functional interplay between these two sets of areas was mediated by the posterior cingulate cortex, suggesting that this area has a key role in integrating the neural representations of self location and body ownership .

To sum up, neuroimaging studies in humans suggest that body ownership involves a network of multisensory brain areas in the posterior parietal cortex (IPS/VIP region) and PMC. These areas in IPS and PMC, contain bimodal and trimodal neurons underlying peripersonal space representation. They are widely connected with temporo-occipital regions (LOC; processing high-level visual and multisensory information related to the body), the insular cortex (processing interoceptive bodily signals), and with more lateral regions at the TPJ, including posterior insula and parietal operculum (receiving important projections from the vestibular system). Trunk centred multisensory neurons contain neurons with a large receptive fields anchored to large body regions, encompassing the right or left hemi-body, the upper or lower body half, or in some cases the entire body. Multisensory neural process related to the trunk is fundamental for self identification and self location. In particular, the key regions for self-identification are within the PMC-IPS network, whereas key areas for self location are located in more lateral temporo-parietal regions, encompassing parietal operculum, supramarginal gyrus, posterior superior temporal gyrus, and posterior insula, (Ionta et al., 2011, 2013), as well as posterior cingulate cortex (Guterstam et al., 2015).

1.3 Peripersonal space as the space of the bodily self: from body ownership to body schema

It has been shown in the previous paragraphs that bodily illusions rely on processing sensory information from the space immediately surrounding the body, the peripersonal space, which is a particularly important spatial component of the bodily self. Peripersonal space neurons encode the position of the body in space. Also behavioural studies showed that their receptive fields can shift or enlarge during a change in one's own body representation. One of the best known paradigms that is used to behaviourally investigate multisensory integration in the peripersonal space, is the cross-modal congruency task (Spence et al., 1998; Spence et al., 2004; Spence and Driver 2004; Shore et al.,2006; Macaluso and Maravita, 2010; Costantini et al., 2017). This is a discrimination task in which people are required to respond as

quickly as possible to tactile targets on different digits while they try to ignore irrelevant visual distractors presented to these digits, either on a congruent finger or on an incongruent one. The overall effect is that participants are normally significantly slower and less accurate at discriminating tactile targets when the visual target is presented near to an incongruent finger, rather than to a congruent finger. The difference in performance between incongruent and congruent trials, known as *Cross-modal Congruency Effect* (CCE), is thus a measure of the amount of the crossmodal visuotactile interaction occurring in the space near the hand (Spence et al., 1998, Spence et al. 2004). Crucially, when the real hand is hidden by an occluding screen and the visual distractors are presented near the digits of the rubber hands in full view, CCE is still present (Pavani et al., 2000; Zopf et al., 2010). On the contrary, this effect is absent when the rubber hand is placed in a posture incompatible with the actual posture of participant's hand (Pavani et al., 2000). Importantly, the degree of this cross-congruency effect is correlated to the subjective strength of owning the rubber hand (Pavani et al., 2000) and it is greater following a period of synchronous visuotactile stimulation to induce illusory ownership for the rubber hand (Zopf et al., 2010). This provides objective evidence that the multisensory integration in space surrounding artificial limbs is modulated by the feeling of ownership, as if the peripersonal space was being defined with respect to the rubber hand.

Another behavioural paradigm to assess multisensory integration in the peripersonal space is the *Audio-tactile interaction task* (Canzoneri et al., 2012; Canzoneri et al., 2013; Serino et al., 2007). In this paradigm, authors measured the reaction time to a tactile stimulus at the finger of the right hand, while a dynamic sound was presented, giving the impression of a sound source either approaching or receding from the participant's hand. Tactile stimulation was delivered at different temporal delays from the onset of the sound, such that it occurred when the sound source was perceived at varying distances from the body. Subjects were asked to respond as rapidly as possible to the tactile stimulation, trying to ignore the sound. The rationale of the task is that stimuli from different sensory modalities interact more effectively with one another when presented within the same spatial representation. It was found that the moving auditory stimulus speeded up the processing of a tactile stimulus at the hand when it was perceived within a limited distance from the hand. Thus, authors were able to mark the region within which approaching auditory stimuli facilitated the detection of the tactile stimulus, i.e., what the authors called the boundaries of peripersonal space. Crucially, more recently, Noel et al., (2015), combined the audio-tactile interaction task with the full body illusion in which participants see a virtual body 2 m in front of them. Authors measured the peripersonal space boundaries while participants were exposed to a synchronous visuo-tactile stroking to induce the illusion. Peripersonal space was found to extend in the front-space toward the position of virtual body. The opposite effect was found in the back space, in which peripersonal space boundaries was contracted. Thus, these data indicate that the

remapping of peripersonal space mirrored the induced changes in body ownership and further confirm that trunk-centred, whole body peripersonal space, is strictly connected to the perceived location of the self in space.

Thus, multisensory integration for the body occurs, under normal conditions, within the peripersonal space, however a bodily illusion can alter the boundaries of multisensory bodily integration, reshaping the peripersonal space and inducing body ownership for an artificial body (Blanke et al., 2015).

But which is the exact function of the peripersonal space? Why does the brain construct multiple, body part-centred representations of the space around us? In monkeys, electrical stimulation of neurons in F4 or VIP area results in arm or head movements (Cooke et al., 2003; Graziano et al., 2002). In humans, studies using single pulse TMS have shown that auditory or visual stimuli presented within peripersonal space transiently modulated the excitability of the hand representation in the primary motor cortex as compared to stimuli presented in the extrapersonal space (Avenanti et al., 2012; Serino et al., 2009). For this reason, the peripersonal space has been conceptualized as a multisensory motor interface, which serve to encode the location of nearby sensory stimuli to generate suitable motor acts. This interpretation fits well with the data presented so far. As recalled in the second paragraph, peripersonal space neurons in the fronto-parietal areas project, directly or indirectly, to the cortico-spinal tracts, forming a fronto-parietal multisensory-motor network supporting sensory-motor functions. Moreover, the evidences reviewed until now, showed that peripersonal space neurons provide information about the position of the body or body parts in space, constructing a “proprioceptive skeleton onto which selective visual responses can be grounded” (Brozzoli et al., 2014). Importantly, the visual receptive fields of these neurons remain anchored to the observer’s body parts. This is a fundamental function for planning actions. In order to perform even simple actions, indeed, the motor system needs to compute the position of the visual stimulus relative to the head, hand or both. Thus, the peripersonal space, being centred on a specific body part, serves to encode the arm position in the same coordinates used for nearby objects. This facilitates object-directed actions and provides an effective mechanism to guide actions directed at objects within reaching distances. It remains unclear if motor properties of peripersonal space may primarily subserve goal directed, approaching and appetitive actions, such as grasping an objects, or involuntary defensive reactions in response to threats, although it has been proposed that these two hypothesis are not mutual exclusive (Brozzoli et al., 2014).

The finding of a tight link between peripersonal space and the sense of position of the body in space, provide evidence for a strict connection between peripersonal space representation and the so-called “body schema”. The term body schema refers to a highly plastic representation of the body parts, in term of posture, shape and size, that the brain uses

to execute or plan body movements. This sensorimotor representation entails tracking and updating the position and configuration of the body parts in space at the service of action. There is a common agreement in considering the body schema an implicit representation that usually does not enter into awareness. Thus, body schema is essentially sensorimotor in nature.

Crucially, because these space and body representations are strictly linked with the motor system, both peripersonal space and body schema are sensitive to action-dependent manipulations. An intriguing characteristic, indeed, of both body schema and peripersonal space is that they are extremely plastic. Over the last decades, for instance, several studies, from non human primates to healthy humans, have documented that tool use could modify peripersonal space and body schema representations (di Pellegrino & Làdavas, 2015; Maravita & Iriki, 2004). The general idea is that a visual stimulus in far space, when repeatedly reached with a tool, starts to be processed as if it is near to the body. In other words, by tool use it is possible to functionally remap space so that “*far becomes near*” (Berti & Frassinetti, 2000). The first, extremely influential, study has been conducted by Iriki et al. (1996) on macaques monkeys. Monkeys were trained to use a rake to retrieve food placed outside the reaching distance, thus extending the animals’ reaching distance. Authors recorded activity from bimodal visuo-tactile neurons in the intraparietal cortex, before and after the use of the tool. Crucially, after the monkey had performed food retrieval with the rake, the visual receptive field of bimodal neurons expanded to include the entire length of the tool. This was true for both distal neurons, with a visual field immediately surrounding the hand, and “proximal” neurons, with a tactile receptive field centred on the shoulder and visual receptive field covering the space reached by the arm. After tool use, these latter proximal visual receptive fields expanded to code space now accessible with the rake (Figure 1.7).

In healthy humans, the effect of tool use in far space has been investigated through the aforementioned cross modal congruency task. These studies have shown that the active tool-use increase the salience or effectiveness of visual stimuli presented at the tip of the tool. An extension of peripersonal space after tool use was also found by using the aforementioned *Audio-tactile interaction task*. Serino et al. (2007) showed that such plastic changes in PPS are associated with the expertise for specific tools. In this study, authors investigated the audio-tactile interaction in the space around the hand before and after, healthy participants used a blind cane to explore the environment. Crucially, auditory peripersonal space extended towards far space after an active use of the cane. As expected, when the same participants were tested the following day, the previously extended peripersonal space, shrank back to its original dimension. While in healthy participants active training was required to induce such extension, in blind people, who would use the cane in everyday life, auditory peripersonal

space immediately extended towards the cane tip as soon as they hold their cane, even without any active use of the tool.

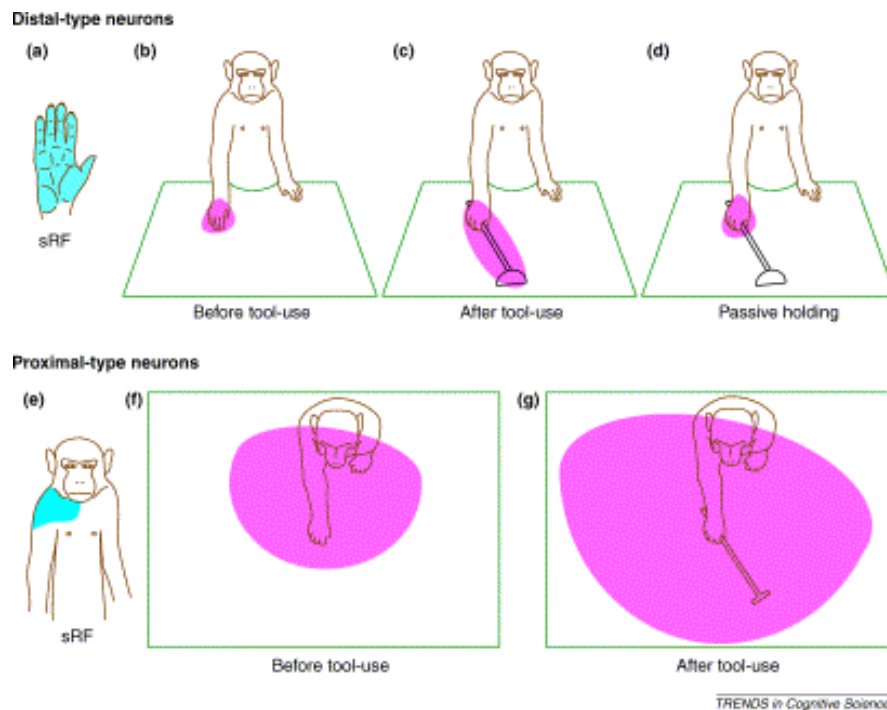


Figure 1.7 Changes in bimodal receptive field properties following tool-use. The somatosensory receptive fields of cells in this region were identified by light touches, passive manipulation of joints or active hand-use. The visual receptive field was defined as the area in which cellular responses were evoked by visual probes (the most effective ones being those moving towards the somatosensory receptive field). (a) somatosensory receptive fields (blue area) of the 'distal type' bimodal neurons and their visual receptive field (pink areas) (b) before tool-use, (c) immediately after tool-use, and (d) when just passively grabbing the rake. (e) somatosensory receptive field (blue area) of 'proximal type' bimodal neurons, and their visual receptive field (pink areas) (f) before and (g) immediately after tool-use. From Maravita and Iriki, 2007

Besides changing in peripersonal space, tool use, as mentioned before, induce changes also in the body representation, i.e., the body schema, increasing the length of the sensorimotor representation of the arm. Cardinali et al. (2009) reported, for the first time, an increased length of the arm representation after tool use. Authors measured the participant's free hand kinematic before and after the active use of a tool. Crucially after tool use, the movement kinematics were drastically modified: participants showed longer latencies and a reduced maximal amplitude in their reaching movement, resulting in a longer movement time. These outcomes are consistent with an increased length of the arm representation: in other words, participants literally acted as if they had a longer arm after tool use. Such changes, moreover, did not occur for the grasping component of the movements, but were limited to the transport phase, suggesting a modification of the representation of the forearm but not of the hand.

Subsequent studies confirmed these data, giving abundant evidence that the active use of a tool, to interact with object placed beyond one's reaching space, modulates body schema extent

(Canzoneri et al., 2013; Cardinali et al., 2011; Sposito et al., 2012). Body schema has been found to be sensitive also to other action dependent manipulations. For instance, Tajadura-Jiménez et al., (2012), found that body schema is modulated by the sound of one's own action. Body schema extended after participants tapped on a surface and listened to a tapping sound originating at a double the distance at which they actually tapped. In terms of its neural underpinnings, the few available studies suggest that the body schema depends mainly on the activity in the somatosensory cortices, posterior parietal cortex, intra parietal sulcus. In particular, the tool use has been associated with activity in the frontoparietal cortices (Gallivan et al. 2013; Jacobs et al., 2010), especially the superior parietal lobule (SPL; Di Russo et al., 2006), and the left intraparietal sulcus [IPS; (Tomasino et al 2012; Valyear et al., 2007)], or the posterior parietal cortex (PPC), which is known to integrate visual and somatosensory information (Inoue et al., 2001). It's worth to notice that the activity in posterior parietal cortex correlated also with the proprioceptive drift after the rubber hand illusion (Brozzoli et al., 2012), suggesting that this area is crucial for updating the positions and the configuration of the body parts in space.

Crucially, it seems that changes in body ownership and changes in body schema rely, at least in part, on a similar neural mechanism, that is the multisensory integration in the space immediately near the body. However, as mentioned before, body schema is an implicit, unconscious representation of the body and it is strongly modulated according to the possibility to act in space. In stark contrast, the sense of body ownership depends on a series of additional constraints, such as the body related visual information constraint. Indeed, it seems difficult to feel ownership over non hand shaped tools (Tsakiris et al., 2010; de Vignemont & Farné, 2010). Therefore, bodily illusions, like the rubber hand or the full body illusion, not only could modify the perceived location of the body or body parts in space, i.e. body schema, but induce changes also in a more conscious representation of the body external appearance, that is, the explicit body image (de Vignemont et al., 2010; Kammers et al., 2009; Longo et al., 2010; Dijkerman & De Haan, 2007) . The term body image refers to a representation of the body, mainly used for perception of the body itself, primary based on vision. The body image represents the way in which the body appears to its owner but also to outside observers. There is a common agreement that this kind of body representation is not involved in action, but plays a key role in emotional and social processing (Gallagher, 2006). In the next chapter, indeed, I describe researches that showed how a change in one's own body ownership can update some aspects of one's own self identity and, in turn, induces changes in our interpersonal attitudes. Self representations, indeed, are essential not only for the self-awareness, but also for the relationship between self and others.

2. The mind in the body

*“Socrates famously urged his followers to ‘know thyself’.
Modern psychology suggests this is much easier said than done”
Amodio and Frith (2006)*

2.1 How many selves?

So far, I focused mainly on the representation of the bodily self without an explicit reference to others component of the self or to social processes. The self, indeed, is a multimodal, hierarchical construct containing both low level, bodily representation and higher level attitudes and beliefs. A comprehensive review of the debate concerning the different components of the “self” is beyond the scope of this chapter, however one of the common distinction in the literature is that between physical and mental aspects of self (Uddin et al., 2007; Lieberman, 2007; Gillihan and Farah, 2005). As it was shown in the previous part of the present chapter, the fronto-parietal system is involved in representing the physical and embodied self. On the other hand, parallel lines of research, inspired by social-psychological constructs, have individuated in the dorsal and ventro medial prefrontal cortex, an instantiation of more social and psychological aspects of the mental self. These networks seem to overlap with areas that comprise the “default mode” network and show an increased activity in tasks that require self referential processing (Wicker et al., 2001), such as self referential judgement (Gusnard et al., 2001), self appraisal (Ochsner et al., 2005), and judgments of personality traits (Lou et al., 2004; Kelley et al., 2002). Thus, while the frontoparietal system is involved in representing the bodily self, the cortical midline structure that comprise the default mode network seems to be more involved in representing the self in terms of mental states or non physical aspects. A similar distinction was proposed by Sugiura (2013). He suggested at least three categories of self, based on neuroimaging findings. The “*physical self*” that is referred to the body ownership and bodily self recognition. It is mainly supported by the sensory and motor areas located primarily in the parietal and premotor cortices in the right hemisphere. The “*interpersonal self*”, which represents the attention or intentions of other directed at the self, for instance when a person notices that he or she is being looked at. The interpersonal self is implemented in several amodal association areas in the dorsomedial frontal and lateral posterior cortices. Finally, the “*social self*” that represents the self as a collection of context-dependent social-values and it is supported by the ventral regions of the medial prefrontal cortex and the posterior cingulate cortex. Thus, the mental representation of the self is a complex construct, containing both perceptual information (such as information regarding the physical appearance of the body, e.g., facial appearance) and conceptual

information, which is composed of varied semantic and episodic knowledge relevant to the self. However some evidence suggested that both conceptual self representation and bodily self representation are malleable and that these different aspects of the self are linked.

Crucially, several recent researches have shown that when we have an illusion over a body different to our own this can change aspects of our self identity and the way in which the self is conceptualized, which, in turn, may change the way in which we interact with other people. In the first paragraph of this sessions, I show how a change in one's own body representation can induce a change in more conceptual representations of the self, from the mere body image to more abstract, psychological representation of the self.

In the second paragraph, I illustrate how these changes in bodily self alter not only more conceptual representation of the self, but also social behaviour and the social processing of others.

2.2 Changing body, changes self

As mentioned before, the mental representation of the self contains both perceptual information, regarding the physical appearance of the body, and conceptual information, composed of varied semantic and episodic knowledge relevant to the self. Thus, a first step in demonstrating that changes in body ownership can elicit changes in the way in which the self is conceptualized, was to demonstrate that the mental representation of our body is not only derived from stable mnemonic representation, but instead is susceptible to the current multisensory visuotactile stimulation.

One of most prolific approach was to investigate the extent to which multisensory stimulation may influence self-other boundaries. To this aim, beyond ownership over body parts, other studies used multisensory visuotactile stimulation to induce similar changes in the representation of one's own face. Now, one's face is the body part that most characterizes self appearance, and recognition of one's face, as distinctive from others', is a fundamental component of self awareness and self identity. Recently, various research group (Paladino et al., 2010; Sforza et al., 2010; Tajadura-Jiménez et al., 2012; 2014; Tsakiris, 2008), used multisensory visuotactile stimulation to study the plasticity of self face representation, showing that self face representation can be updated to include another person's facial features, which in turn can temporary impair self face recognition. This effect has been called ***Enfacement***. In the enfacement illusion, participants are stroked on their face, while they are looking another face being touched in synchrony and in corresponding positions, a procedure that authors termed interpersonal multisensory stimulation (IMS). Crucially, when participants performed a self recognition task before and after IMS, results showed that synchronized multisensory stimulation had a significant effect on self-face recognition. Participants not only perceived the other face as more physically similar to their own after synchronous IMS, but

they are also affected in their ability to discriminate between their own and the other's face (Tsakiris, 2008). In a psychophysical visual discrimination task, participants were shown manipulated images of their own face morphed with varying percentages of another person's face. Participants were required to report whether the face looked more like their own face, or more like the other's face (see Figure 1.8). Crucially after synchronous, but not asynchronous, IMS participants accepted larger percentage of other face's features as their own face (Sforza et al., 2010).

The changes in perceived physical similarity between self and other in the enfacement illusion, suggested that participants' visual representations of their own and another's body had become partially overlapped, or shared. Thus, our body image is not a static mnemonic representation, but it is extremely dynamic and it can be updated by the interpersonal multisensory stimulation.

A



B

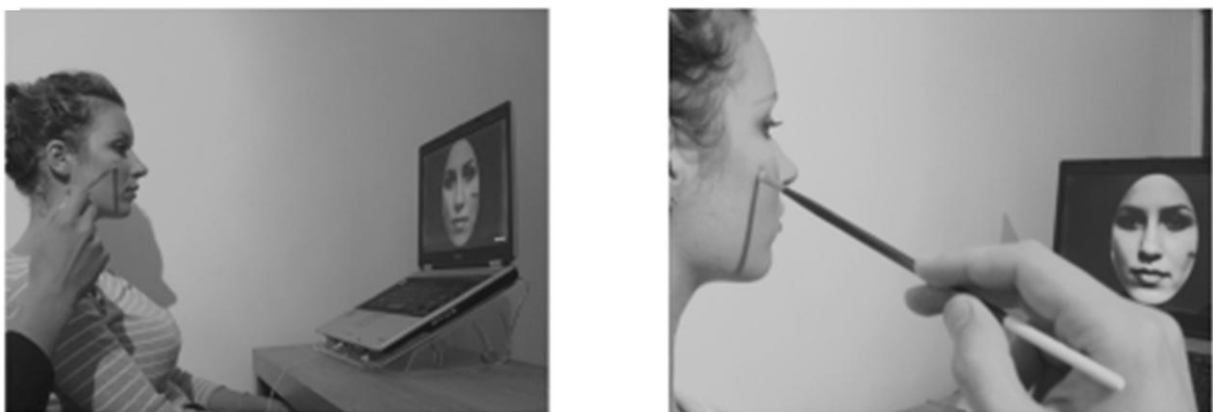


Figure 1.8 (A) shows the morphing procedure and the direction of morphing (from “self to other” or from “other to self”). (B) Participants, and the experimental set-up during the visuo-tactile stimulation. From Tsakiris, 2008

The enfacement not only changes the perceived physical similarity between self and other, but also revealed a clear affective component. Participants perceived the other to be more trustworthy and attractive after synchronous IMS (Tajadura-Jiménez et al., 2012). Paladino et

al. (2010), for instance, showed that, following the enfacement illusion, participants rated the other as conceptually closer to themselves, and also attributed to them more self-like personality traits.

Thus, enfacement illusion does not only tend to blur boundaries of body representation of self and others, but also blur self-other conceptual boundaries. Bernhard Hommel's research team called this latter effect "*feature migration*". In two recent studies, indeed, these authors demonstrated that enfacement promotes features migration in terms of emotional states and intelligence from the representation of other to the representation of oneself. In particular, Ma and colleagues (2016) demonstrated that "enfacing a smile makes you happy". In this study, authors created a virtual version of the enfacement illusion in which participants can control the movements of a face presented on a pc screen. Crucially, when participants enfaced/perceived ownership for a smiling face, they showed a better mood, as explicitly assessed by questionnaires and a better performance in a mood-sensitive brainstorming creativity task, which gave a more implicit measure of participant's mood. Thus, increasing self-other similarity allows also affective features to "migrate" from the representation of the other to the representation of oneself. Authors explained this effect with the theory of event coding (TEC). According to this theory, people represent themselves and others just like other perceptual events, that is "*in terms of integrated networks of sensorimotor feature codes (event files: Hommel, 2004) representing all discriminable features an event or person consists of, such as physical attributes, affective responses, control states, and covert and overt actions associated with a given event.*" (Ma et al., 2016). An important implication of TEC is that the more features are shared by different events (i.e., the more they are similar and the more their representations overlap), the more they can be related to, compared with, or confused with each other. This allows salient feature codes that are activated by (and thus actually represent) one event to become part of, and shape the representation of another event they actually do not belong to. In other words, being confronted with multiple perceptual events can lead to "illusionary conjunctions", bindings of features actually representing different events into one event file especially if the events share other features. Thus, experiencing a virtual happy face as being part of oneself caused participants to confuse their own features and states with the features and states of the virtual face to the extent that affective features of the virtual face became assimilated with participants' self representation. These results were strengthened by a subsequent study from the same group of research (Ma et al., 2018) in which authors investigated whether enfacing members of another species would induce self-other assimilation (and features migration). Participants were presented with a virtual human face moving in or out of sync with their own face, and then morphed it into an ape face. Participants tended to perceive the ape face as their own in the synchronous condition. Crucially, ownership for the ape face reduced the performance in a fluid intelligent

task and increased the willingness to attribute emotion to apes. Thus, also in this case increasing the overlap between the self and the other representation promotes illusory conjunctions, in which features of the other become features of oneself.

The evidence that a change in one's own body representation can lead to a change in other higher order representation of self, has been revealed also in the context of the full body illusion. A notable study showed that when participants embodied an avatar representing a 4year old child resulted in a bias towards associating the self with child like compared to adult like categorizations, as measured using an implicit association test (Banakou et al., 2013). In particular, authors used immersive virtual reality to embody adults participants as a 4 year old child, and as an adult body scaled to the same height. Crucially they found that there was an overestimation of the sizes of objects compared with a non embodied baseline, which was significantly greater for the child condition compared with the short adult condition. Moreover, the implicit association test showed that participants who embodied the children, resulted in significantly faster reaction times for the classification of self with child-like compared with adult-like attributes. These results did not occur in the asynchronous conditions and, crucially, the size estimation and the implicit association test results were influenced by the extent of the illusion of body ownership. This finding suggest that a correlate of a full body illusion is that the type of body carries with it a set of temporary changes in perception and attitudes that are appropriate to that type of body.

It was explained in the first session that our body representation depends on a multisensory integration in the peripersonal space. According to this, it seems that when multisensory data generates an illusory change in the body structure, then the neural network underlying the bodily-self representations maintains the homeostatic and psychological integrity of the body to conform with the changed body. These results suggest the intriguing possibility that this even extends to perceptual processing and implicit attitudes.

So far, I have considered only those researches that showed a change in the way in which the self is conceptualized, due to a bodily manipulation, however it remains unclear whether this link is bidirectional, that is: can a change in more conceptual representations lead to changes in the bodily self representation? There is some evidence suggesting that the converse relationship is also true. Thus, a bidirectional link may exist. Farmer et al. (2013), for instance, report an experiment in which the manipulated trustworthiness of an unfamiliar individual impacted upon perceived similarity between the participant's face and the unfamiliar face. Participants played a trust game with two unfamiliar individuals whose faces were shown on screen. One of the individuals was trustworthy, while the other always betrayed the participant's trust. Before and after the game, participants performed a self-other discrimination task using morphed faces, to measure the perceived similarity between their own face and the faces of both player. Crucially, following the trust game, participants

perceived their face to be more similar to the trustworthy individual than to untrustworthy player.

Taken together, these findings suggest that exists a bidirectional relationship between the conceptual and bodily self representation. Thus, it's possible to hypothesize that a change in low level perceptual representation creates conflicts with more abstract, higher order representations of oneself and of others (or viceversa). This, in turn, induces an update in the attitudes and beliefs about one's self, ensuring that the consistency within the multimodal self-representation is maintained. In the next paragraph, I will show how these transformations in multimodal self representations change social cognition and our behaviour in turn.

2.2 The *Proteus effect*: changing self identity, changes behaviour

In the previous paragraph it was shown that experiencing ownership for a body different to our own body, can change also higher order, conceptual self representation. The changes in perceived physical similarity between self and other was a crucial finding as it suggested that participant's visual representations of their own and other's body had become partially overlapped, or shared. Given the putative role of shared body representations in socio-cognitive processing, the important next step was to investigate how the changes in body representation induced by multisensory integration can affect social cognition. In essence, as we change our self representation, do our self representations change our social cognition and behaviours in turn? The first step toward this direction was to investigate whether an increase in perceived physical self resemblance may also increase resonance with an outgroup. In one of the first study to assess this possibility, Maister et al., (2013) measured participants' implicit racial attitudes before and after they experienced a rubber hand illusion of a different racial group. In particular, light skinned Caucasian participants, performed a skin colour implicit association test to assess their implicit attitudes towards people with dark skin. Participants were then subjected to a session of visuotactile stimulation to induce a sense of ownership for a dark skinned rubber hand, before their implicit racial bias was again measured. Results showed that participants experienced the other-race hand as their own and body ownership occurred regardless of their implicit attitudes towards that race. Importantly, participants decreased significantly their negative implicit attitudes towards dark skin, which correlated with the strength of ownership experienced over the other-race hand. The more intense the participants' illusion of ownership over the dark-skinned rubber hand, more their implicit racial bias decreased.

These results were confirmed using immersive virtual reality setup (Peck et al., 2013). Immersive virtual reality provide a powerful tool for potentially changing the form of

participants' body. The participants wore an head tracked head mounted display and they saw a programmed virtual body substituting their own real body (see Figure 1.9).



Figure 1.9 The virtual body and scenario in Peck et al. 2013. (a) The light-skinned virtual body (EL) as seen in the mirror. (b) The dark-skinned virtual body (ED) in the mirror and directly. (c) The purple-skinned body (EA) as seen in the mirror. (d) A dark-skinned virtual character walks by – the first person viewpoint and corresponding view in the mirror for the ED condition. (e) A participant wearing the HMD and body tracking suit. From Peck et al.(2013)

They could also see this body when looking at their (geometrically correct) reflection in a virtual mirror. Additionally, participants wore a body-tracking suit that provides real-time motion capture. So as they moved their real body they watched their virtual body moved synchronously. By embodying participants in bodies of different skin colours, authors aimed to determine whether it is possible to induce a body-ownership illusion in a differently raced avatar, and whether the body-ownership illusion could reduce negative implicit responses

toward that other race. Crucially, also in this case the embodiment of light skinned people in a dark skinned virtual body reduced their implicit racial bias as measured by a racial implicit association test. To control for the effect of mere perceptual difference between the body of the avatar and participants' actual bodies, in another condition, participants embodied a purple-skinned body, but this condition did not produce any changes in racial bias even though the subjective illusion of body ownership was strong and not significantly different from embodiment of the light- or dark-skinned bodies.

These findings suggest that an increase in overlap between self and other, induced by a change in body representation, was able to alter the perceived boundaries between in-group and out-group to modulate high-level social attitudes. Changes in body-representation may therefore constitute a core dimension that in turn changes social cognition processes. Thus, a change in the perception of a purely bodily aspect of the self, such as the ownership of one's hand or one's own body, alters not only a higher level concept of the self (Banakou et al., 2013), but also the social processing of others (Maister et al., 2013; Peck et al., 2013).

Apart these studies that investigated a generic positive or negative associations with the embodied social group, other researchers examined directly how one's self representation changes our behaviour. Yee & Bailenson, (2007), started out with the idea that, in virtual environments, the avatar that we embodied is not simply a uniform that is worn, the avatar is our entire self representation. Thus, they expected that our avatars have a significant impact on how we behave. People may adhere to a new identity that is inferred from their avatars. Users in virtual environments may conform to the expectations and stereotypes of the identity of their avatars. Or more precisely, they conform to the behaviour that they believe others would expect them to have. Yee and Bainsolon (2007), termed this phenomenon the "*Proteus Effect*", from the Greek god Proteus that is notable for being the origin of the adjective "protean", i.e. the ability to take on many different self representation. In their original study, authors manipulated the attractiveness of the participants' virtual body, so that participants were assigned to have an attractive avatar or unattractive avatar. Participants were asked to walk closer to a confederate and to introduce themselves. Crucially, participants in the more attractive conditions, were willing to move closer to the confederate and disclosed more information to the confederate than participants in the unattractive condition. In a second experiment, participants were assigned to have a tall or short virtual body. Authors argued that height is more often associated with self-esteem and competence. Taller people are perceived to be more competent (Young & French, 1996), more desirable as romantic partners (Freedman, 1979; Harrison & Saeed, 1977), and more likely to emerge as leaders (Stogdill, 1948). For this reason, authors hypothesized that people with a taller virtual body would be more confident in a negotiation game, such as the ultimatum game. In the ultimatum game, two individuals take turns to decide how a pool of money should be split between the two of

them. One individual makes the split, and the other must choose to either accept or reject the split. If the split is accepted, the money is shared accordingly. If the split is rejected, neither of them gets the money. Crucially, Yee and Bainsolon (2007), found that participants in the tall condition were significantly more likely to offer an unfair split than participants in the normal and short conditions. At the same time, participants in the short condition were significantly more likely to accept an unfair split than participants in the normal and tall condition. From this study, the “proteus effect” was observed with many variable. For instance, placing participants in avatars with a superhero ability promotes helping behaviour (Rosenberg et al., 2013). More recently, it was demonstrated that our body representation can also modulate what Sugiura (2013) called the *interpersonal self*, that is the perceived attention of others. (Guterstam et al., (2015) created the illusion of having an invisible body, modifying the experimental setup of the mannequin’s illusion by removing the mannequin’s body and applying the touches to a discrete volume of empty space that represented an invisible body. After the illusion, participants were exposed to a socially stressful situation, that is standing in front of a crowd of unknown people. Crucially the illusion of having an invisible body, as compared to the illusion of having a mannequin’s body, reduced the participant’s heart rate and the subjective level of anxiety in response to the stressful social event. Authors concluded that if the body is represented as an invisible entity, it will be represented as being invisible to outside observers as well, which, in turn, should reduce the brain’s social anxiety response to being the centre of other people’s attention.

However, how can a change in the perception of a purely bodily aspect of the self ultimately alter not only associations with higher level concept of the self, but also generalize to social processing and behaviour? Providing a unifying theory of the self is beyond the scope of this chapter, however it’s worth to notice that a notable theory comes from the predictive coding account (Friston, 2010). This approach rest upon the idea that the brain works as an inference machine that is trying to optimize its own model of the world, by actively predicting the causes of its sensory input. In other words, the brain interprets sensory information in a form of probabilistic representation of the causes on the basis of noisy sensory data, maintaining hypothesis (“generative model”) of the hidden causes of sensory input (Friston, 2005). In this model any mismatch between predicted and actual sensory inputs generates a prediction error that the brain need to minimize in order to avoid surprise (or unpredictability, in mathematical terms).

As previously recalled, the self is a multimodal, hierarchical construct containing both low-level, bodily representations and higher level attitudes and beliefs. On a predictive coding account, these different levels of representation continuously interact, as prediction errors, and when left unexplained at one level, they need to be processed and eliminated at a higher level of the hierarchy. Given the focus of predictive coding accounts on complementary hierarchical

top-down and bottom-up processes, a change in low-level, perceptual representations of one's own body in relation to the body of other creates errors further up in the processing hierarchy, as this new information now conflicts with more abstract, higher order representations of oneself and the other (Tsakiris, 2017). These errors must then be minimized, by updating attitudes and beliefs held about one's self and the other, ensuring that the consistency within the multimodal self-representation is maintained (I will discuss this more in detail at the end of the thesis)

The experimental contributions that I am going to present in the thesis, are in line with the theoretical framework presented in this chapter. In particular, the first study examine the relationship between one's own body representation and a crucial component of the social interaction: the distance that people maintain between each other.

As mentioned before, the space around the body is a central tenet of the bodily self. Fronto-parietal multisensory neurons encode the space surrounding the body in a body centred reference frame (i.e. the peripersonal space). As previously recalled, the peripersonal space has been conceptualized as a multisensory-motor interface that may serve to encode the position of sensory stimuli to generate goal directed action toward objects within the reaching distance. However, human beings commonly perform actions in social contexts, where others are present and interacting to various degrees. Individuals reliably regulate a socially appropriate distance between each other, which typically extends to a point that, if crossed, causes discomfort. This distance that people maintain between each other during a social interaction has been studied mainly by the social psychology and it has been termed interpersonal space. In the next chapter I question whether a change in one's own body representation may influence the space of interaction with other people.

Chapter 2

Come closer, I am invisible!

Invisible body illusion modulates interpersonal space

This study is co-authored by Mariano D'Angelo, Giuseppe di Pellegrino and Francesca Frassinetti

2.1 Introduction

The term interpersonal space (IPS) refers to the protective, safety zone that people maintain around their body during social interaction, and into which intrusion by others may cause discomfort (Hall, 1996; Hayduck, 1983). The spatial extent of IPS may vary across culture (Aiello, 1987) and its boundaries are regulated and constantly negotiated according to the context and emotional states of individuals (Sommer, 2002). For instance, IPS may reduce after a cooperative social interaction (Candini et al., 2016; Gessaroli et al., 2013), or after inducing a positive emotional experience (Tajadura-Jiménez et al., 2011). Thus, studies on IPS have predominantly focused on how social space is modulated by high-order social and cognitive factors concerning the perception of the context or the attitude toward the interacting parts (Holland, et al., 2004; Iachini et al., 2015; Lloyd, 2009; Ruggiero et al., 2017; Scheele et al., 2012).

On the other hand, as discussed in the Chapter 1, a number of studies on embodied cognition have emphasized the importance of one's own body representation in interpersonal attitudes (Barsalou, 2008; Longo et al., 2009; Yee and Bailenson, 2007; Peck et al., 2013). Perceived bodily similarity between self and others may change the way in which subjects interact with other people (Maister et al., 2013; 2015; Paladino et al., 2010), thereby revealing the social valence of body representation (Longo et al., 2009), and the intimate relationship between basic, body perceptual representation and the complex mechanisms underlying our everyday social interactions. Peck and co-workers (2013) demonstrated that inducing the illusion of ownership over a dark skinned virtual body reduces the implicit racial bias. In the same way, Yee and Bailenson (2007) found that participants were more willing to make unfair splits in an ultimatum game when they experienced the embodiment toward a taller than a shorter virtual body.

Recently, Guterstam et al. (2013), modifying the now classical rubber hand illusion, through a multisensory visuotactile conflict, created the illusion of having an invisible hand. A

subsequent study from the same laboratory extended the illusion of having an invisible limb to an entire invisible body (Guterstam et al. 2015). More importantly for our present purpose, authors demonstrated that the illusion of owning an invisible body, as compared to a mannequin's body, reduced participant's heart rate and level of subjective stress in response to standing in front of an audience of strangers. Therefore, authors concluded that this body illusion has unique effect on social-affective cognition. Indeed, being gazed upon constitutes a salient social cue, and perceiving one's own body as invisible can affect socio-affective processing of such cues.

Based on these findings suggesting a dynamic interaction between bodily self representation and social cognitive processes, here we aimed to investigate whether inducing a change in one's own body representation may influence the space of interaction with other people. Specifically, due to the protective, safety value of IPS, we predicted that the experience of invisibility should induce participants to feel themselves more protected and less exposed during another person's approach, thus leading to a significant contraction of IPS boundaries. To this aim, we measured IPS through a comfort-distance task, in which participants were asked to stop an individual approaching them at a position in which they felt most comfortable with the other's proximity (Sommer, 2002; Gessaroli et al., 2013; Patané et al., 2017).

In addition, to rule out the possibility that the invisible body illusion may simply influence space perception, we also assessed how individuals encode the reaching space near the body. As previously recalled, in the neurocognitive domain, the reaching space has been conceptualized as a sensorimotor interface for the body to act on nearby objects, i.e. the peripersonal space (F. de Vignemont & Iannetti, 2015; di Pellegrino & Làdavas, 2015). Thus, in the present study, we measured the peripersonal space (PPS) through a reaching-distance task (Bartolo et al., 2014; Bourgeois et al., 2014) adapted to be similar to the methodology used to assess IPS, with the exception that, in this case, participants were asked to stop the other person at the distance in which they thought they could reach her.

Thus, IPS and PPS were measured using a similar methodology, through a comfort-distance and a reaching-distance task, respectively, which were repeated twice: before and after an invisible body illusion. Due to its effects on aspects of social cognition, we expected that the experience of having an invisible body should reduce the size of IPS, without affecting PPS extension. On the contrary, if the illusion of invisibility modifies the perception of the space around the body per se, a modification of this space should be found independently from the social or sensorimotor valence of the task, and thus involving both IPS and PPS.

2.2 Experiment 1

2.2.1 Methods

Participants. Twenty four participants, all females, to avoid possible gender differences effects (Iachini et al., 2016; Iachini et al., 2014), volunteered for the study (age range = 20-26; mean age = 22.63). Sample size was determined a priori by conducting a power analysis using G*Power 3 (Faul et al., 2007) . A small to medium effect size ($\eta^2_p = 0.20$) was specified based on a previous study conducted in our laboratory (Patanè et al., 2017). Within our chosen sample size and effect size, the power ($1 - \beta$) was approximately .80.

Participants were naive to the experimental hypothesis, and had no self-reported history of neurological or psychiatric disease. All participants had normal or correct to normal vision. They provided written informed consent to participate in the experiments, which were approved by the Ethical Committee of the University of Bologna, in agreement with the 2008 Helsinki Declaration. Participants were instructed to wear a pair of trousers and a t-shirt.

Setting. For the entire duration of the experiment, participants wore a set of head-mounted displays, HMDs, (TRIVISIO VRvision, 800 x 600 resolution, equals 1.4M pixels and full colour, 42° diagonal field of View). The spacing between HMD's oculars was adjusted for each participant to fit their inter-pupillary distance (55-72 mm adjustable). HMDs were connected, through a PC, to a synchronized HD webcam colour (Logitech HD pro webcam C920, full HD 1080p) placed on a tripod adjusted at the same height of the participant's head. Participants were asked to stand upright in a fixed position 40 cm to the left of the tripod. In this way, through the HMDs, participants viewed in real time the part of the room filmed by the webcam, as if their point of view was that of the camera.

Procedure. Experiment was conducted in the same rectangular room (7.5 x 6.5m). The experimental session included two tasks: (i) a comfort-distance judgment to assess social interpersonal space (participants indicated the comfort distance between themselves and a confederate) and (ii) a reaching-distance judgment, designed to assess peripersonal space (participants indicated the reaching distance between themselves and a confederate).

Testing began with a participant standing in a fixed position, 40 cm to the left of the tripod and the confederate standing, facing the tripod from a 5 meters starting position. The confederate was always the one moving toward the camera, which corresponded to the participant's first person perspective. Participants provided both comfort-distance judgments ("stop the confederate at the distance you feel comfortable with her"), and reachability-distance judgments ("stop the confederate at the distance you think you can reach her"). The distance was measured with a digital laser meter, as the distance between the confederate's

chest and a fix point on the tripod just below the camera (Agatec, model DM 100, error $\pm .003$ m). This procedure was repeated twice in separate blocks of five trials for each condition: before and after 2 minutes of visuotactile stimulation to induce the invisible body illusion. The order of tasks was counterbalanced across subjects.

The procedure to create the illusion of owning an invisible body was very similar to the one described in Guterstam et al. (2015). Participants were asked to close their eyes while the experimenter pointed the camera toward the floor. Then participants were asked to tilt their heads downwards as if looking at their bodies and open their eyes. In this way participants saw in the HMD the empty space captured by the camera where they expected to see their own body. To induce the illusion the experimenter stroked, with a large paintbrush, five different participant's body parts while synchronously, in corresponding position, moving another paintbrush in the empty space under the camera (see Figure 2.1). According to the study by Guterstam et al. (2015), the strokes were delivered to the abdomen (A), the left and right lower arm (LLA, RLA) and the left and right lower legs and feet in a pre determined sequence: (A-A-A-A-LLA-LLA-LLA-LLA- RLA-RLA-RLARLA-LLF-LLF-LLF-LLF-A-A).



Figure 2.1 Experimental setup of the invisible body illusion. Participants watched in the HMDs the empty space captured by the camera. To induce the illusion, the experimenter applied touches to the participant's body with a paintbrush and moved another paintbrush in the empty space in corresponding position.

This sequence was repeated two times. The duration of each stroke was 1 second and the interval between one touch and the next touch was 1.5 second.

The entire visuotactile stimulation lasted about 2 min. To identify the portions of empty space corresponding to the stroked body targets of the invisible body, we used a female body as a template. Visual landmarks, which were out of participant's view, indicated the starting and stopping points of brushstrokes. Since the work by Guterstam et al. (2015) has shown that the illusion of having an invisible body is dependent on spatio-temporal congruence of visual and tactile signals, as a control condition we applied asynchronous brushstrokes to the participant's body and to the empty space, matching the total number and length of the strokes.

The experiment was conducted as a within-group counterbalanced design. Participants were randomly allocated to one of two groups, regarding whether they first received synchronous or asynchronous visuotactile stimulation, or vice versa. Synchronous and asynchronous stimulation were administered in two different sessions separate by one week. Two different female confederates, unknown to the participants, were involved in the pre and post sessions. One of the confederates approached the camera for the entire duration of the first session before visuotactile stimulation, whereas the second confederate was introduced in the post experimental session. To avoid any aesthetical confound, the order of confederate facing the camera in the pre and post session was also counterbalanced between participants and within participant's two conditions (Synchronous-Asynchronous visuotactile stimulation). Moreover, the two confederates were instructed to wear similar neutral clothes. During the approach toward the camera, the confederate walked with natural gaits at a constant speed. They were instructed to maintain a neutral expression and to keep their gaze looking straight ahead at a fixed point just below the camera.

To provide a measure of the illusory ownership of the invisible body, at the end of the experimental session, participants were asked to complete a 6-item questionnaire, which served to quantify the subjective experience of illusory ownership during multisensory stimulation. Questions were derived from Guterstam et al., (2015). Participants were asked to indicate the extent of their agreement or disagreement with six statements using a seven-point Likert scale, ranging from -3 ("I completely disagree") to +3 ("I completely agree"), with a response of 0 indicating "neither agreed nor disagreed". Three of the statements examined the perception of the illusion (S1-S3) and the other three statements were designed to control for suggestibility and task compliance (S4- S6) (see Table 1.1).

Table 1 Questionnaire statements	
During the experiment ...	
S1	I felt the touch of the brush in the empty space in the location where I saw the brush moving
S2	It felt as if I had an invisible body
S3	I experienced that the touch I felt was caused by the brush moving in the empty space
S4	When I saw the brush moving , I experienced the touch on my back
S5	It felt as if I had two bodies
S6	I could no longer feel my body

Table 1.1. Questionnaire used to evaluate the subjective experience after visuotactile stimulation: statements S1 – S3 examined the perception of the illusion; Statements S4- S6 controlled for suggestibility and task compliance.

2.2.3 Results

To test effect of the invisible body illusion on the comfort-distance and reaching-distance, the mean distances obtained in different experimental conditions were compared through a three-way ANOVA, with Stimulation (synchronous vs asynchronous), Session (pre vs post visuotactile stimulation) and Task (reaching vs comfort-distance) as within-participants factors. Newman-Keuls post hoc test was used to analyze significant interactions. Data revealed a significant effect of the Task ($F_{1,23}=16.89$; $p<.0001$; $\eta^2_p=0.42$) indicating that the participant-confederate distance was larger in the comfort than in reachability-distance task. The significant interaction Task x Session ($F_{1,23}=11.66$; $p<.01$; $\eta^2_p =0.33$), as well as the interaction Stimulation x Session x Task were significant ($F_{1,23}=7.92$; $p<.01$; $\eta^2_p =0.25$) (see figure 2.2). Specifically, our results show that comfort-distance was smaller after (75 cm) than before (89.8 cm) visuotactile stimulation in the synchronous condition ($p<.0001$), but not in the asynchronous condition (86.8 vs, 90.21 cm, $p=.28$). Moreover, the comfort-distance after the synchronous visuotactile stimulation was significantly smaller than the comfort-distance measured before, as well as after asynchronous visuotactile stimulation ($p<.0002$, in both comparisons). Reachability-distance, instead, was not significantly different between pre and post visuotactile stimulation in both synchronous (62.4 vs. 64.6 cm, $p=.10$), and asynchronous conditions (66.3 vs. 68 cm, $p=.43$). In sum, the critical statistical interaction Stimulation x Session x Task indicates that only the synchronous, but not the asynchronous, visuotactile stimulation affected comfort-distance estimation. In contrast, neither synchronous nor asynchronous visuotactile stimulation modulated reaching-distance

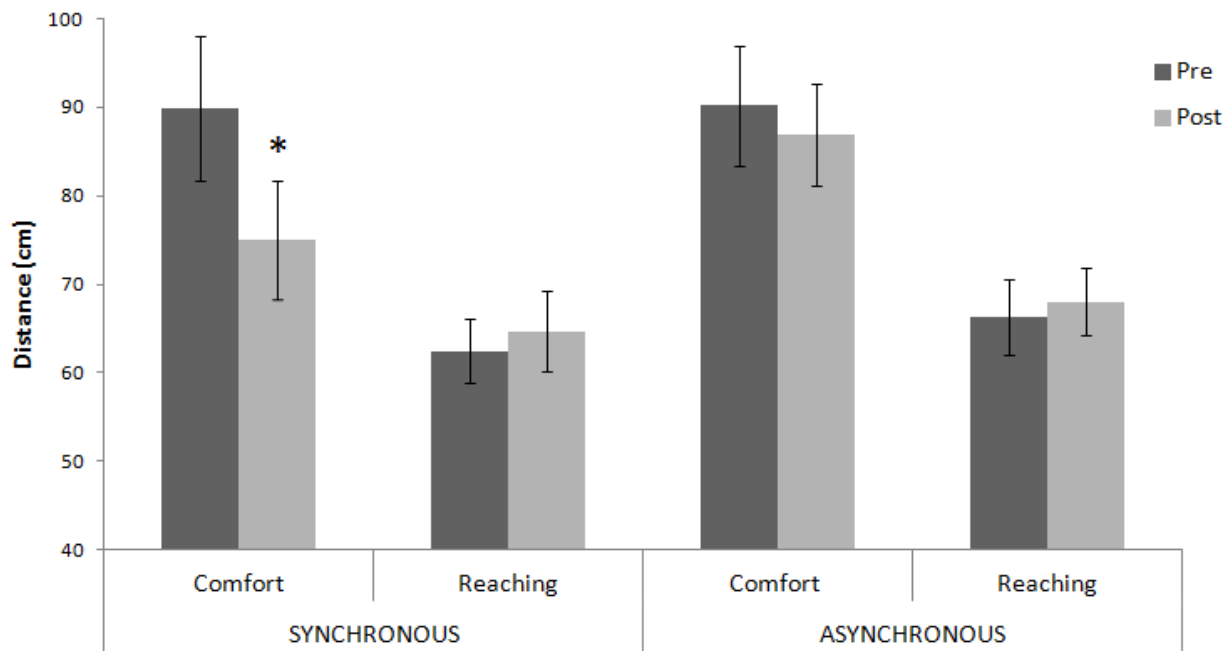


Figure 2.2 Effects of visuotactile stimulation on comfort and reaching-distance. Statistical comparison of mean distance (cm) in the two tasks (comfort and reaching judgment), in the stimulation conditions (synchronous and asynchronous visuotactile stimulation), and in the two sessions (pre- and post-visuotactile stimulation). Error bars indicate standard errors of the mean. The asterisk indicates a significant difference before and after invisible body illusion in the synchronous condition.

To investigate whether participants' subjective experience during multisensory stimulation was affected by experimental conditions, the average rating of the illusion statements (S1-S3) and the control statements (S4-S6) at the questionnaire in the synchronous and asynchronous conditions, were compared. An ANOVA with Stimulation (synchronous vs. asynchronous) and Statement Type (illusion vs. control) as within-participants factors, showed a significant effect of Stimulation ($F_{1,23} = 17.87$; $p < .00001$; $\eta^2_p = 0.68$), Statement Type ($F_{1,23} = 102.78$; $p < .00001$; $\eta^2_p = 0.66$), and of their interaction ($F_{1,23} = 61.22$; $p < .00001$; $\eta^2_p = 0.72$) (see Figure 2.3). Participants in the synchronous stimulation affirmed more strongly illusion than control statements ($p < .001$), and more strongly than in the asynchronous stimulation (both in the illusion and control statements) ($p < .001$ for all comparisons).

These findings show that IPS, as measured by the comfort-distance task, considerably reduces after synchronous, but not asynchronous, visuotactile stimulation. Since, as assessed by the questionnaire, visuotactile stimulation evoked illusory ownership over an invisible body only when touches are synchronously applied, the reduction of IPS is due to the perception of one's own body as invisible. By contrast there was no significant difference in the reaching space between pre and post visuotactile stimulation both in the synchronous and asynchronous stimulation. This suggests that perception of one's own body as invisible does not affect the general perception of space around the body, but it has unique effect when this space assumes a safety value in the comfort-distance task.

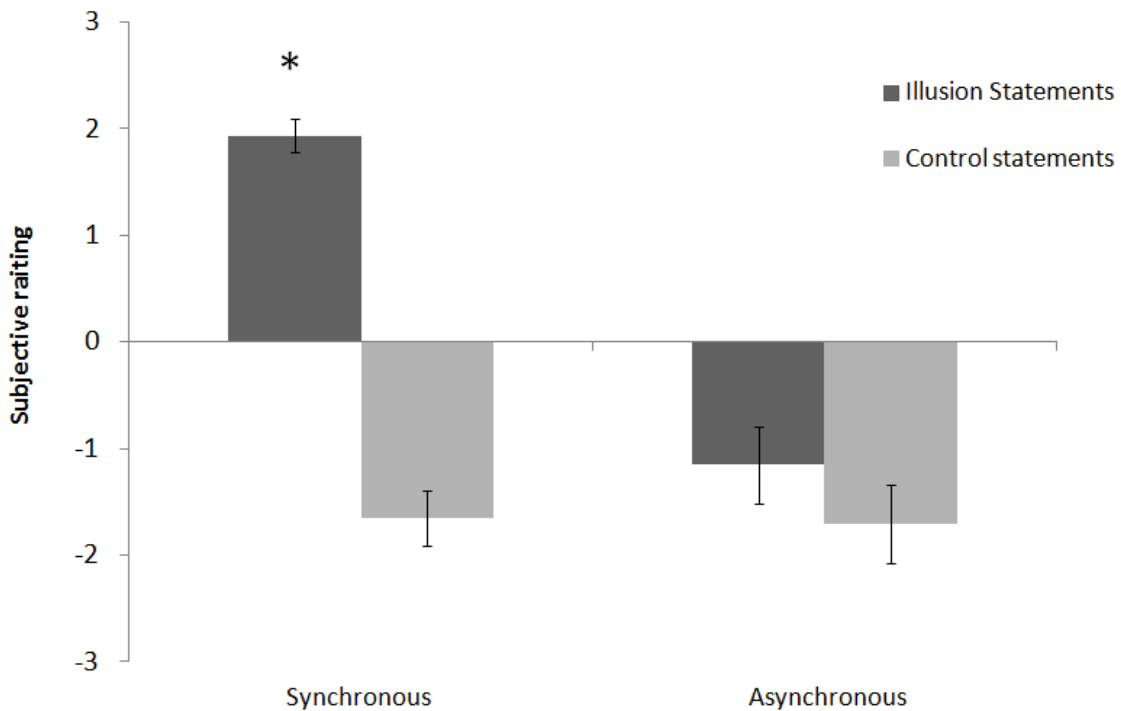


Figure 2.3. Questionnaire evidence for perceiving an invisible body. Mean score of illusion and control statements as a function of the condition (synchronous and asynchronous). Error bars indicate standard errors of the mean. The asterisk indicates a significant difference between illusion statements in Synchronous condition and all other conditions

An alternative explanation of this result can be that reduction of social interpersonal space is not caused by the invisible body illusion per se, but it is due to an altered feeling of presence in the spatial environment as filmed by the camera and presented to the participants through the HMDs (Sanchez-Vives et al., 2005). In other words, it is possible that simply the perception of the other person by means of the HMD may have led participants to feel themselves more shielded, and less exposed to the other’s approach. Related to this issue, participants could have particularly emphasized that what they saw did not correspond to their real first person perspective or to the real position of their body, since they were located 40 cm to the left of the tripod.

Therefore, to rule out the possibility that comfort-distance reduction reflects a general bias due to the HMD’s device and virtual reality system, we conducted another study (Experiment 2) aimed to modulate PPS, without altering social IPS. That is, by using the same methodology used to assess IPS and PPS of the Experiment 1, we investigated the possibility to reveal the opposite dissociation between these spaces. To this aim, we implemented a tool-use paradigm, known to affect PPS (Farnè & Ladavas, 2000; Berti and Frassinetti, 2000; Maravita and Iriki, 2004), adapted to the virtual reality system used in the previous experiment. Accordingly, we hypothesized that the active use of a tool should enlarge PPS, but leaving IPS unaffected,

thereby confirming that variation of IPS size found in Experiment 1 is not merely the consequence of being in a virtual environment.

2.3 Experiment 2

2.3.1 Methods

Participants. A new group of female participants (n= 24; age range = 20-28; mean age = 23.91), naive to the purpose of the study, participated in Experiment 2. All participants had normal or correct to normal vision, no self-reported history of neurological or psychiatric diseases and all but three were right-handed, as assessed by Edinburgh Handedness Inventory (Oldfield, 1971). They provided written informed consent to participate in the experiments, which were approved by the Ethical Committee of the University of Bologna, in agreement with the 2008 Helsinki Declaration.

Procedure In the Experiment 2, participants performed reachability and comfort-distance task before and after 12 minutes of active and passive tool training. Experimental setting and procedure were similar to the Experiment 1, with the exception that in Experiment 2 there were two web cameras: one webcam was on the tripod, and the other one was applied on the head mounted display (HMD) worn by participants. During tool training, the webcam on the tripod was turned off and the webcam applied on the HMD filmed the training, that participants watched online through the HMD. In the active tool training, participants were required to use a 70 cm long rake to perform different tasks with their right hand, with which they were instructed to reach and retrieve, one at the time, different tokens placed on a table-top (see Figure 2.4) at a distance of ≈ 85 cm from the participants' sternum. In the passive tool training, participants held the tool passively with their right hand while they were asked to verbally report some characteristics of the tokens put near the tip of the tool. The experiment was conducted as a within-group counterbalanced design. Participants were randomly allocated to one of two groups, regarding of whether they first performed active or passive tool training, or vice versa.



Figure 2.4. Experimental setup of tool-use. A webcam was applied on the HMDs worn by the participants. Participants were instructed to reach and retrieve different tokens.

2.3.1 Results

To test the effect of the tool training on the comfort-distance and reaching-distance, the mean distances obtained in the different experimental conditions were compared through a three-way ANOVA with Training (active tool vs. passive tool training), Session (pre vs. Post tool training), Task (reaching vs. comfort-distance), as within-participant factors. Significant interactions were explored by Newman-Keuls post-hoc tests. The ANOVA showed a significant effect of the Task ($F_{1,23}=779.35$; $p<.05$; $\eta^2_p=0.16$). As in Experiment 1, the participant-confederate distance was larger in the comfort-distance than in the reaching-distance task.

Task x Session interaction ($F_{1,23}=15,46$; $p<.0001$; $\eta^2_p=0.40$) as well as Training x Session x Task interaction were significant ($F_{1,23}=8.21$; $p<.001$; $\eta^2_p=0.26$). Post-hoc tests revealed that the interaction was driven by an increased reaching-distance estimation after active tool use training (83.8 cm) with respect to before (68.2 cm, $p < .01$), whilst no significant difference between before and after active tool use was found in the comfort-distance task (85 vs. 81.5 cm, $p=.57$) In contrast, in the passive tool use training no significant differences before and after training were found in either reaching (69.7 vs. 67.4 cm; $p = .80$) or comfort-distance (80.8 vs. 79.6 cm; $p=.72$) (see Fig. 2.5). In sum, only active, but not passive, tool use training affected the reaching-distance estimation. Comfort-distance estimation was modulated neither by the active nor passive tool use training.

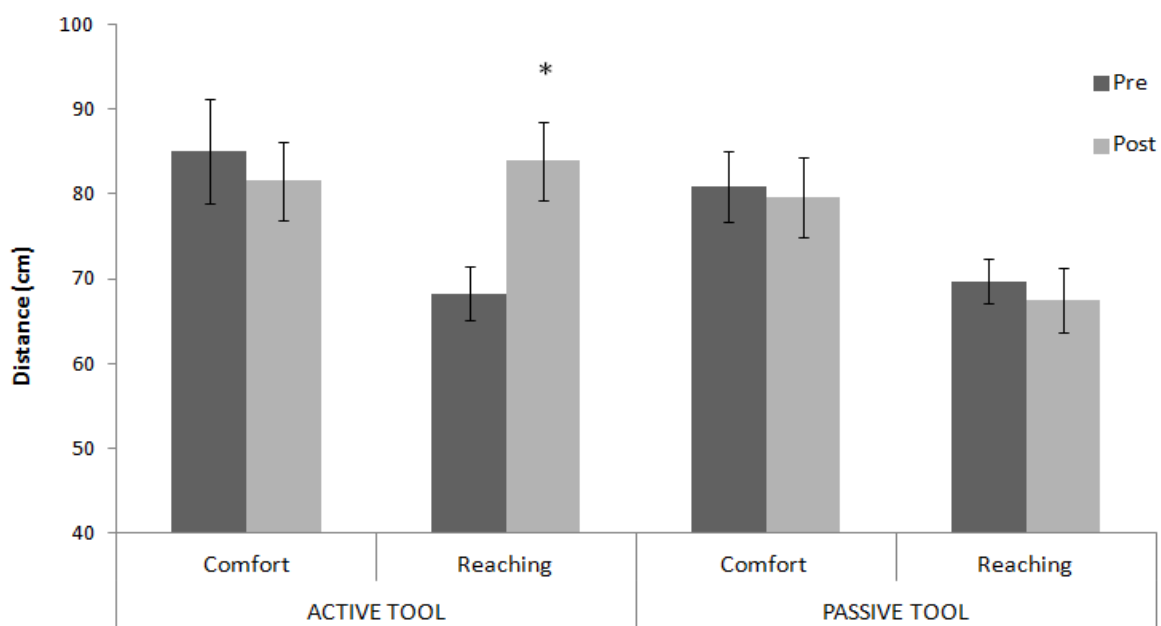


Figure 2.5. Effects of tool use training on comfort and reaching-distances. Statistical comparison of average distances (cm) in the two tasks (comfort and reaching judgment) in the two Tool training conditions (Active and Passive) and in the two Sessions (pre and post training). Error bars indicates standard errors of the mean. The asterisk indicates a significant difference in the reaching distance before and after active tool training.

Experiment 2 shows an increased reaching-distance, but not change in comfort-distance, after an active tool use. No significant differences emerge in reaching and comfort-distance task after passive tool use. Thus, these findings are strongly in favor that the reduction of IPS found in Experiment 1 is not due to a low feeling of presence in the spatial environment presented in the HMDs because, in that case, we would found a reduction of IPS also in Experiment 2.

2.4 Discussion

Available evidence suggests that IPS is modulated by higher order psychological and social factors concerning personality characteristics (Hayduk, 2002), perception of social context (Altman and Vinsel, 1977), and the attitude toward the interacting parts (Gessaroli et al., 2013; Candini et al., 2016; Iachini et al., 2015). In the current study, in light of recent evidence emphasizing the importance of one's own body representation in modulating interpersonal attitude (Maister et al., 2015; Guterstam et al., 2015), we investigated whether a change in one's own body representation can modify social IPS.

In Experiment 1, we show that the illusion of having an invisible body, elicited by temporally and spatially congruent visual and tactile stimuli (synchronous condition), and assessed by the questionnaire scores, significantly reduces IPS extent during the comfort-distance task. On the contrary, following the asynchronous control condition, the experience of the illusion was absent and, crucially, no significant modulation of interpersonal distance was found. These results therefore indicate that IPS reduction cannot be explained by effects that were non-specific to the illusion, such as, for instance, the mere habituation to the task. Rather, these findings support the close relationship between interpersonal distance and the bodily self-representation.

Despite synchronous visuotactile stimulation caused both a change in participant's body perception, and a reduction of the space in which participants feel comfortable with the other's proximity, it failed to modulate the participants' judgement of reaching-distance. We found that reaching space (PPS) did not change either after synchronous or asynchronous stimulation. This latter result allows us to exclude that the observed reduction of IPS is merely due to a modification in the perception of space near the body after the invisible body illusion.

Nevertheless, one can argue that IPS reduction, rather than reflecting a change in participant's body perception, is due to an altered feeling of presence in the spatial environment as observed through the HMDs. Perceiving other person's approach by means of the HMD may have led participants to feel themselves less exposed and more protected as compared to a real, direct approach. This could be sufficient to induce a reduction of the space in which participants felt most comfortable with the confederate.

This interpretation of the findings, however, can be ruled out by the results of Experiment 2. In this latter experiment, a tool-use paradigm, known to modulate PPS (Farnè & Ladavas, 2000; Berti & Frassinetti, 2000), was adapted to the setting of Experiment 1. As predicted, after active tool-use, participants showed a significant enlargement of PPS, as assessed by the reaching-distance task, while social IPS remained unaffected. Thus, Experiment 2 reveals that viewing the surrounding environment through the HMDs does not hinder modulation of PPS by an appropriate manipulation (i.e., active tool-use). Crucially, the lack of IPS change in

Experiment 2 suggests that the reduction of IPS observed in Experiment 1 cannot be accounted for by the feeling of protection associated with the virtual environment. Therefore, our overall findings clearly indicate that the reduction of IPS depends on the perception of one's own body as invisible.

These results fit nicely with previous research by Guterstam et al. (2015), showing that invisible body illusion reduces the level of subjective stress and decreases heart rate in response to standing in front of a crowd of unknown people. Authors argued that if the body is represented as invisible, it will be represented as being invisible to outside observers as well, which in turn reduces social stress and anxiety response. Although in the current experiment we do not have a measure of subjective stress or level of anxiety during the confederate's approach, this argumentation is particularly interesting for the present study. Indeed studies on IPS show that interpersonal distance is strongly modulated by alterations in brain areas involved in fear processing and anxiety responses, such as the amygdala (Kennedy et al., 2010).

Thus, if participants truly experience invisibility, their body should be represented as invisible to others individual as well, which, in turn, might induce participants to feel more protected and less exposed during the confederate's approach. As a consequence, participants may reduce the distance at which they feel more comfortable with the other's proximity, allowing the confederate to be closer to their body. Related to this issue, an important finding of the present experiments is that interpersonal distance is consistently larger than reaching-distance, thereby indicating that participants feel comfortable when they cannot be reached and touched by an unfamiliar other. This finding is in line with an interpretation of IPS as a protective, safety space, while PPS represents a working space, or a space elected for reaching and manipulate close objects (de Vignemont & Iannetti, 2015)

Collectively, results of Experiment 1 and Experiment 2 provide converging evidence for a double dissociation between IPS and PPS. In Experiment 2, we found that the active use of a tool can temporarily alter the representation of the PPS, due to an extension of sensorimotor representation of arm length, as suggested by several previous studies (Cardinali et al., 2009; 2011; Canzoneri et al., 2013; Sposito et al., 2012). Indeed, reaching space is modulated by, and relies on, morphological and sensorimotor body representation (Longo & Lourenco, 2007; Lourenco & Longo, 2009) For instance, the size of near space is scaled as a proportion of one's arm length (Longo & Lourenco, 2007). This sensorimotor representation of the body morphology linked to PPS has been termed *body schema*, and is concerned with tracking and updating the positions and configuration of body parts in space (Paillard, 2005; Martel et al., 2016). This representation typically does not enter into awareness, and is primarily used for spatial organization of action. Accordingly, in Experiment 1, no modification of PPS was found,

since the invisible body illusion does not alter the sensorimotor representation used to guide action and act in space, i.e. the body schema.

In stark contrast, the invisible body illusion directly manipulates the conscious representation of the body external appearance, that is, the explicit body image (Frederique de Vignemont, 2010; Kammers et al., 2009; Longo et al., 2010), as indicated by the questionnaire ratings. The term *body image* indeed refers to a distinct representation of the body used for perception of the body itself, primarily based on vision, but also on somatic perception, and represents the way the body appears to outside observers. It is not involved in action but plays a key role in emotional and social processing (Gallagher, 2006). Therefore, the present findings not only reveal that IPS and PPS are two space representation functionally defined according to different behavioural context, but also suggest that IPS and PPS are linked to different high-order representations of the body, used for the perception (i.e., body image), and action (i.e., body schema) of the body, respectively.

Some may argue that the reduction of IPS found in the present research is not due to the feeling of body invisibility *per se*, but rather to a more general change in body form or appearance. Thus, in principle, any change in one's own body perception might produce similar effects on IPS. Note, however, that Guterstam et al. (2015) have previously shown that the illusion of having a mannequin's body did not induce the same feeling of protection and safety during a socially stressful situation. Thus, evidence from previous research makes it unlikely that reduction of IPS found in the current study was caused by a mere modification of the body appearance. However, we cannot exclude that other changes in one's own body representation can modify the space of interaction with others. For instance, perceiving bodily similarity between oneself and others (Peck et al., 2013; Maister et al., 2013) may be another factor that could result in modulation of the IPS.

On the other hand, it is not our intent to claim that change of body image is the only way by which a modulation of IPS may occur. As mentioned above, IPS can be influenced by several psychological, social and context-dependent factors. Although in the current study the experience of having an invisible body, possibly through an increased sense of security (Guterstam et al., 2015), reduces IPS, we do not exclude that feelings of safety and protection and a consequent reduction of IPS can be achieved through other manipulations unrelated to body image. For instance, interposing a transparent barrier between an observer and others may similarly cause the reduction of IPS without changing the observer's body image.

Finally, the present findings indicating a close relationship between IPS and body representation may have significant implications for the study and treatment of different clinical disorders. For instance, recent studies have shown that children with autism spectrum disorder (ASD) have an altered IPS representation, preferring or larger (Gessaroli et al., 2013; Candini et al., 2016) or closer (Kennedy et al., 2014; Perry et al., 2013) comfort-distances.

People with social anxiety show an abnormal IPS too (Scheele et al., 2012; Perry et al. Therefore, due to the close link between IPS and body image, we should expect an altered body image in ASD population or in people with social anxiety. Moreover, it should be interesting, as already suggested by Guterstam et al. (2015), to verify whether the effects of having an invisible body are stronger in people with social anxiety. Likewise, IPS is expected to be affected in populations with a persistent distorted body image, such as individuals with eating disorders (Horne et al., 1991)

Chapter 3

Are you looking at me? That's impossible, I am invisible

Embodying an invisible face shrinks the cone of gaze

This study is co-authored by Mariano D'Angelo, Raffaele Tucciarelli, Francesca Frassinetti and Matthew Longo

In the study described in the previous chapter, we induced in participants the illusion of having an invisible body and we showed a socio - cognitive “side effect” of perceiving our body as invisible, that is a contraction of the space in which people feel comfortable with the other proximity.

In agreement with the results of Guterstam et al. (2015), we argued that if the body is represented as an invisible entity, it will be represented as being invisible to outside observers as well, which in turn should induce participants to feel themselves less at the centre of other people's attention. Indeed invisibility is, by definition, the impossibility to be gazed upon. Being gazed upon is an important social factor. When an individual notices that he or she is being looked at or hears his/her own name being called, he/she becomes aware that the attention or intentionality of another person is directed at him/her. This awareness is a basic mindset during social interaction. It's possible to imagine that the experience of having an invisible body directly affect this kind of interpersonal awareness that represents the attention or intentions of others directed at the self.

In particular, in the next study we investigated if the experience of invisibility affect the participants' awareness that another person is looking at them

3.1. Introduction

In Book II of Plato's *Republic* (1888), Glaucon relates the myth of the ring of Gyges, a golden ring which makes the wearer invisible. Gyges uses the ring to take over the kingdom of Lydia, seducing the queen and killing the king. In the context of Glaucon and Socrates's discussion of justice, the invisibility conferred by the ring is a symbol of ultimate, even godlike, power and freedom from the consequences of one's actions. The conferral of invisibility by objects of great power is common in literature, from Tolkien's (1937) ‘one ring to rule them all’ to one of the ‘deathly hallows’ in the Harry Potter novels (Rowling, 2007). It is clear that the

idea of invisibility has captured the imagination of writers and philosophers for millennia for its strong intuitive psychological meaning.

Recent research has started to move invisibility from the realm of fantasy to the laboratory. As previously recalled, Guterstam and colleagues (2013) used the logic of the rubber hand illusion to demonstrate that people can be induced to feel body ownership over an empty region of space, as if their hand had become invisible. Other research has extended this logic to induce the experience of owning an entire invisible body (Guterstam et al., 2015; D'Angelo et al., 2017; Kondo et al., 2018). To create this illusion, participants wore an HMD, connected with a camera placed on a tripod and pointing toward the floor. When participants tilted their heads downwards, as if looking at their body, they saw in the HMDs the empty space captured by the camera where they expected to see their own body. The experimenter, to induce the illusion, synchronously stroked the participants' real body with a paintbrush, while moving another paintbrush in the empty space in corresponding positions. This setup resulted in the referral of tactile sensations to the empty space and the perception of having an invisible body.

Intriguingly, experiencing one's own body as invisible has been found to have widespread effects on participants' physiological and cognitive processing. Guterstam et al. (2015) showed that the illusion of having an invisible body, as compared to the illusion of owning a mannequin's body, decreased participant's heart rate and subjective level of anxiety in response to standing in front of a crowd of unknown people. These authors argued that representing one's own body as an invisible entity should make participants feel themselves less at the centre of other people's attention, reducing the social anxiety produced by a stressful situation. The study presented in the previous chapter, showed that the invisible body illusion reduced the interpersonal distance at which participants felt most comfortable with another person (D'Angelo et al., 2017), leaving intact the perceived reaching space. The experience of invisibility induced participants to feel themselves more protected and less exposed during another person's approach, allowing the other person to be closer to their body. Thus, knowing whether one is the recipient of a gaze can be decisive in a social interaction and experiencing one's own body as invisible may affect the social consequences of being looked at. In fact, one's own body is a source of visual information communicating emotional and mental states which can be used by others to predict our future behaviours. To this end, research has emphasized the importance of one's own bodily appearance in interpersonal attitudes, revealing a relationship between body external representation and our everyday social interactions (Maister et al., 2015). For instance, an increase in perceived physical self resemblance may increase resonance with an out-group (Peck et al., 2013; Maister et al., 2013). Moreover, the type of body, over which participants experience illusory ownership, carries with it a set of temporary changes in perception and attitudes that are appropriate for that type of body (Yee

and Bailenson, 2007; Banakou et al., 2013; Tajadura-Jimenez et al., 2017). Therefore, changing one's own body visual appearance can change the way in which the self is conceptualized (Banakou et al., 2013) and, in turn, our interpersonal attitudes to conform to the changed body (Peck et al., 2013; Yee and Bailenson, 2007).

Given the importance gaze in social interactions, it is perhaps not surprising that humans are very accurate in perceiving the gaze directions of others (Gibson & Pick, 1963; Anstis et al., 1969; Gale & Monk, 2000). However, although gaze direction can be perceived accurately in general, observers are prone to assume that they are being looked at when another person is looking even roughly in their direction (Gamer et al., 2011; Ewbank et al., 2009). For instance, observers assume a mutual gaze when the looker's gaze is directed at their mouth or nose (Lord & Haith, 1974). Several studies have measured the range of gaze directions over which an individual perceives another to be looking at them. Crucially, it was found a relatively wide range of gaze directions that were perceived as being directed at the observer. Indeed, the metaphor of "cone of gaze" is used to refer to the range of eye deviations participants judge as being directed towards them (Gamer & Hecht, 2007; Gamer et al., 2011; Mareschal et al., 2013a). The cone of gaze has been shown to be modulated by several emotional, social, and affective factors. For instance, the cone of gaze is wider for faces that appear angry compared to fearful or neutral faces (Ewbank et al., 2009). Moreover, individuals with social phobia show a larger cone of gaze than control subjects (Gamer et al., 2011; Jun et al., 2013). The cone of gaze is also widened by social ostracism (Lyyra et al., 2017).

In the present study, we investigated the link between the representations of one's own body and the perception of gaze direction. Based on data showing that the invisible body illusion reduced social anxiety and the interpersonal distance, we speculated that the experience of invisibility affects the way in which participants process the attention of others toward the self, starting from the perception of gaze direction. Thus, we hypothesized that the illusion of having an invisible face induce participants to feel themselves less observed by others, affecting gaze perception and leading to a reduction of the width of the cone of gaze. One's own face is the body part that most characterizes self appearance, and recognition of one's face, as distinctive from others', is a fundamental component of self awareness and self identity (Tsakiris, 2017). A widely used paradigm to study the plasticity of self face representation is the enfacement illusion (Tsakiris, 2008; Paladino et al., 2010). In the enfacement illusion, participants are stroked on their face, while they are looking another face being touched in synchrony and in corresponding positions. When the two touches are synchronous, participants perceived the other face as more physically similar to their own, moreover they are also affected in their ability to discriminate between their own and the other's face (Tsakiris, 2008; Sfroza et al., 2010).

Here, we combined the classical enfacement setup (Tsakiris, 2007) with the logic of the invisible hand illusion (Guterstam et al., 2012) to create the illusion of embodying an invisible face. In our setup, participants were stroked on different parts of their face, while they saw a video in which a hand used a paintbrush to touch a discrete volume of empty space to define the contours and the shape of an invisible face. In Experiment 1, we assessed the illusion through a questionnaire designed to capture the subjective experience during visuotactile stimulation. In Experiment 2, to provide also an objective evidence of the illusion, we threatened the invisible face and measured the evoked skin conductance response (SCR) as an objective measure of anxiety. This test has been used before to provide physiological evidence of body illusions, and there is a direct relationship between the degree of anxiety evoked by threatening the illusory body and the strength of illusory body ownership (Armel and Ramachandran, 2003; Tajadura-Jiménez et al., 2012; Guterstam et al., 2013; 2015). Finally, in Experiment 3 we directly tested the hypothesis that enfacing an invisible face affect gaze perception, reducing the cone of gaze. To this end, we used a gaze categorization task, in which several faces looking in various directions were presented and participants are required to judge whether the faces were looking to their left, to their right or directly at them. We speculated that if one's own face representation affects the perception of gaze direction, participants should reduce the range of gaze directions perceived as directed toward them, accordingly to the illusion of having an invisible face.

3.2. Experiment 1

3.2.1 Methods

Participants

Twenty individuals (10 women) were recruited for this study (mean age = 26.5 years; SD = 5.8. Participants had normal or correct to normal vision. They all provided written informed consent to participate to the experiment, which was approved by the Department of Psychological Sciences Research Ethics Committee at Birkbeck, University of London. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Stimuli

For the visuotactile multisensory stimulation, we used a video in which a hand uses a paintbrush to stroke different parts of an invisible face. To create such a video, we used the chroma key (or 'green screen') technique. Chroma key is a postproduction video technique by which a colour range (often green) in a video can be replaced by an image background or

another video. In particular, the colour range in the foreground footage is made transparent, allowing separately filmed background or a static image to be inserted into the scene. In our case, we used a life sized 3D model head with a green mask on it and a black smock on its shoulders. Behind the model head there was a green screen as background. In the postproduction, all the green colour was replaced with the static image of an empty room.

Thus, the final video showed the experimenter's hand defining, with a paintbrush, the contours and the shape of an invisible head (Figure 3.1). Four different segments of the head were stroked with long brushstrokes in a predetermined sequence: two brushstrokes from the right cheek to the chin; two brushstrokes from the middle of the forehead to the right temple; two brushstrokes from the lower part of the forehead to the nose; two brushstrokes from the lips to the end of chin. Each stroke lasted 3 seconds and time between the offset of one touch and the onset of the next touch was 3 seconds as well. The entire stroking sequence was repeated for three times, thus the video lasted in total 156 sec.



Figure 3.1. One frame from the movie used for induction of the enfacement illusion. The chroma key technique was used to create realistic visual information about a paintbrush stroking an invisible face. Though the face is not visible, the bristles of the brush were deflected in a way that defined the contours of an invisible face.

Procedure

During the experiment, participants were comfortably seated in front of a table. The induction movie in which a paintbrush strokes different parts of the invisible face was projected on a monitor placed at ≈ 65 cm from the participant's sternum. Participants were asked to wear the same black smock that appeared in video on the invisible face's shoulders. OpenSesame software (Mathot et al., 2012) was used to display stimuli and to collect participant's response. Participants were asked to watch the movie without moving their head, while the experimenter synchronously stroked the participant's face with an identical

paintbrush at specularly congruent locations. We compared the illusion condition, with synchronous touches between participant's face and invisible face, to an asynchronous control condition in which the participant's face and the invisible face were touched in alternation. The synchronous and asynchronous condition were each repeated two times with ABBA counterbalancing, with the first condition counterbalanced across participants. Further, the order of presentations was balanced across individuals. At the end of each trial, we obtained subjective reports about the experience of the illusion during multisensory visuotactile stimulation by asking participants to fill out a questionnaire containing 14 statements presented in a random order on the PC screen (statements were adapted from Tajadura-Jiménez et al., 2012). Participants indicated on a PC keyboard the extent of their agreement with the statements using a 7-point Likert scale ranging from -3 (I completely disagree) to + 3 (I completely agree)

3.2.2 Results and Discussion

In line with previous studies on enfacement, scores at the questionnaires tend to fall in the affirmative range of the scale in some statements (Sforza et al., 2010; Tajadura-Jimenez et al., 2012; Beck et al., 2015; Cardini et al., 2013; Maister et al., 2015). Our statistical analysis focused on the difference between synchronous and asynchronous conditions (Figure 2). Responses given to each statement after synchronous stimulation was compared to the response given after asynchronous stimulation using paired t-tests. There were several items with which participants showed more agreement in the synchronous than in the asynchronous condition, such as touch referral (Q12, Q13), perception of one's own face as invisible or identification with the empty space (Q8, Q9, Q10) and the perceived location of one's own face (Q7, Q14).

The significant differences between synchronous and asynchronous visuotactile stimulation are consistent with other studies of the enfacement illusion (Prociello et al., 2018), suggesting that, also with the presence of an invisible face, multisensory visuotactile stimulation was effective in manipulating the sense of facial identity. Indeed, only in the synchronous condition participants identified their own face with the invisible face, referring tactile sensation on the empty space. Moreover, they could easily imagine their own face in the location where they saw the paintbrush moving, as if they were looking to their reflection in a mirror. Thus, it seems that the current multisensory stimulation induced a change in one's own face representation.

These results demonstrate that the enfacement illusion can be induced even in the absence of a visible face. These results extend recent research on the invisible hand (Guterstam et al., 2013) and invisible full-body (Guterstam et al., 2015; D'Angelo et al., 2017) illusions.

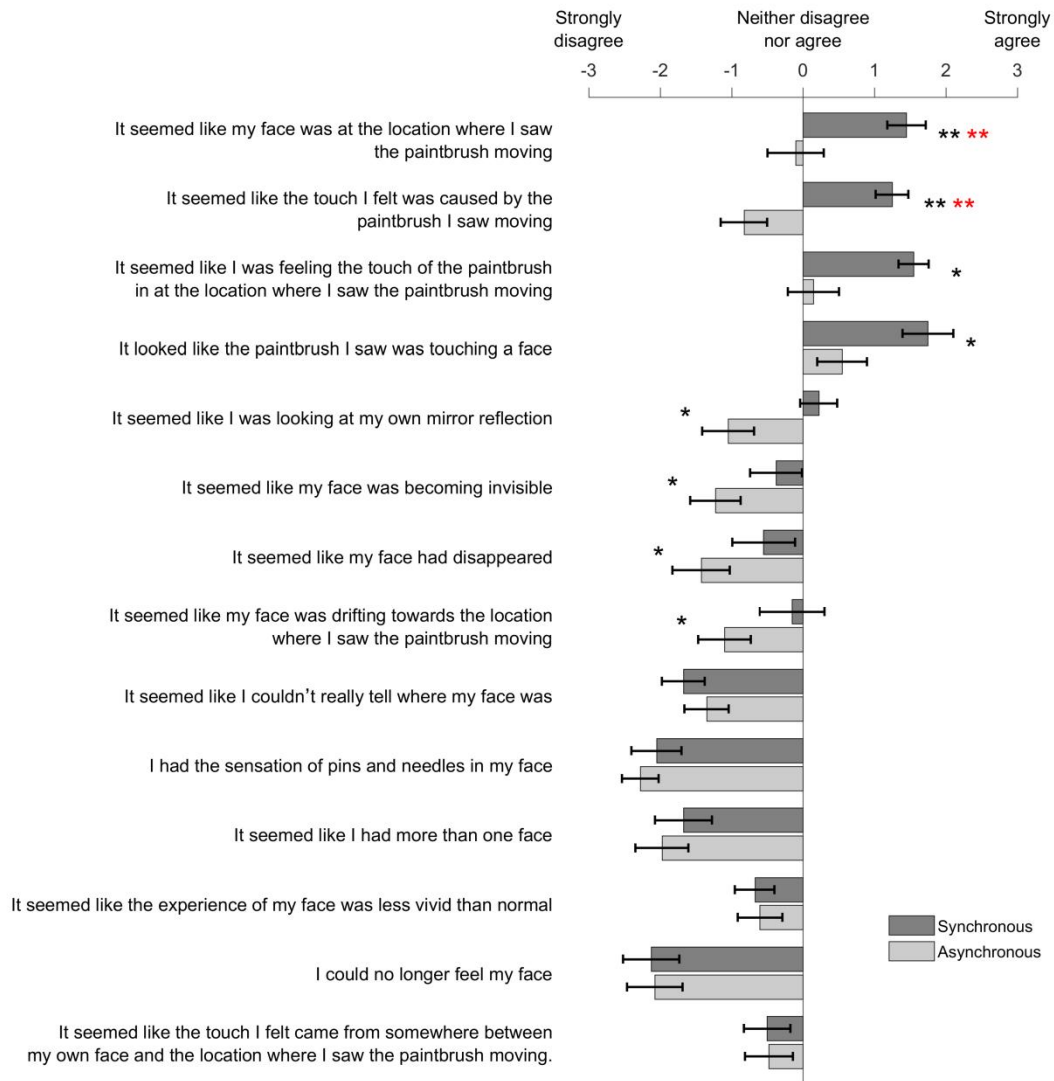


Figure 3.2. Subjective experience of the enfacement. The graph shows the average ratings for each question as a function of the visuotactile stimulation (Synchronous vs Asynchronous). Asterisks mark a significant difference (* $p < .05$; ** $p < .005$; Red asterisk indicate a significant difference after Bonferroni correction ** $p < .0001$). Error bars represent standard error of mean (SEM). Questions are ordered from the more significant to the less significant different.

3.3 Experiment 2

The first experiment showed that subjective experiences of enfacement can be elicited over an empty region of space. In this experiment we investigated the illusion using a more objective test, measuring skin-conductance responses in response to a knife approaching the region of the invisible face. Such autonomic responses have been widely used as an objective

measure of body ownership in studies of the enfacement illusion (Tajadura-Jimenez et al., 2012; 2014), as well as the rubber hand illusion (Armel & Ramachandran, 2003; Ehrsson et al., 2007; Tieri et al., 2015) and the full-body illusion (Ehrsson, 2007; Petkova & Ehrsson, 2008). Therefore if participants truly embodied the empty space, we expected an higher skin conductance response to the knife after synchronous as compared to the asynchronous condition.

3.3.1 Materials and methods

Participants

Thirty individuals (14 women) were recruited for this study (mean age = 25.6 years; SD = 6.4). A statistical power analysis was performed for sample size estimation. We first identified previous studies that used SCRs to objectively measure the effect of a bodily illusion comparing synchronous and asynchronous conditions. Four such studies were identified (Armel and Ramachandran, 2003; Tajadura-Jiménez et al., 2012; Guterstam et al., 2012; 2015). Specifically, Armel and Ramachandran (2003), recorded SCRs after injuring a rubber hand over which participants experienced ownership. Tajadura-Jimenez et al. (2012) combined SCRs with the classical enfacement illusion. Finally Guterstam et al. (2012, 2015), recorded SCRs to a threat after participants experienced the illusion of having an invisible hand or body, respectively. We conducted a random-effects meta-analysis on the effect sizes (Cohen's d_z) for the comparison between synchronous and asynchronous conditions, using ESCI software (Cummings, 2013), which resulted in an average effect size of 0.535. We then conducted a power analysis using G*Power (Faul et al., 2007), with power level of 0.80, which indicated that 30 participants were needed.

Participants had normal or correct to normal vision. They all provided written informed consent to participate to the experiment, which was approved by the Department of Psychological Sciences Research Ethics Committee at Birkbeck, University of London. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Stimuli

We used the same video as in Experiment 1, with the only difference that this time at the end of the stroking, a knife appeared on the left side of the screen, moving towards the invisible face making contact with the right side of the face and then disappearing out of the field of view. The entire movement lasted approximately 3 sec. As previously recalled, such kind of stimulus is very common to objectively test the degree of embodiment in several bodily illusion (Armel and Ramachandran, 2003; Petkova and Ehrsson, 2008; Tajadura-Jimenez et

al., 2012; 2014). The rationale is that bodily threat usually evokes change in autonomic arousal. Thus, if an object is qualified as a part of one's own body, a physical threat to it evokes the same anxiety response and autonomic arousal. To avoid participants being able to anticipate the appearance of the knife, we produced three videos of different lengths: 105 sec, 156 sec, 207 sec before the knife onset. In the 105 sec video, the entire stroking sequence was repeated two times, in the 156 sec video the sequence was repeated three times, and in the 207 sec video it was repeated for four times.

Procedure

The procedure was similar to Experiment 1, with the difference that in Experiment 2 we recorded the skin conductance response as a measure of the emotional response when the invisible face was threatened by a knife after a period of visuotactile stimulation. The skin conductance response was collected through a Biosemi ActiveTwo System (Biosemi, Amsterdam) connected to a dedicated PC through a parallel port. For the skin conductance measures the ActiveTwo uses a 16Hz SC circuit with a 1 μ A current producing a 16Hz signal that is synchronized with the ActiveTwo system's sample rate. The signal was recorded by means of two silver electrodes placed on the volar surface of the distal phalanges (fingertip region) of the left hand. A saline conductive paste was applied to the electrodes to improve signal to noise ratio. OpenSesame software (Mathot et al., 2012) sent triggers coding for the stimulus onset to the skin conductance response trace at the moment in which the knife appears on the screen. Participants wore the electrodes for a few minutes before starting the recording at the beginning of the Experiment in order to allow a good electrode contact and to allow for the gel to become sufficiently absorbed over the measurement area for high quality data (Dawson et al., 2007).

The synchronous and asynchronous conditions were repeated three times using ABBAAB counterbalancing, with the first condition counterbalanced across participants. At the end of each trial, the invisible face was threatened by the knife appearing on the screen.

In addition to the SCRs, at the end of each trial we asked participants to fill out the same questionnaire used in Experiment 1 (see Table 1).

Analysis

We used EEGLab Matlab toolbox (Delorme and Makeig, 2004) to analyze SCRs. The SCR was identified as the peak value on the conductance occurring up to 6 sec after the onset of the threat stimuli. The amplitude of the increase in conductance was measured as the difference between the maximal and minimal value of the response identified in this time-window (Armel and Ramachandran; Petkova and Ehrsson, 2008; Guterstam et al., 2013). We

calculated the average of the all responses including the trials where no response was apparent, thus, analysing the magnitude of the SRC (Dawson et al., 2007).

3.3.2 Results

The SCR results are shown in Figure 3.3. We found a significantly greater threat evoked SCRs after the synchronous (1,28 μ S) as compared to the asynchronous condition (0,86 μ S), $t(29) = 2,92, p < .007; d_z = 0.53$; Figure 3.3).

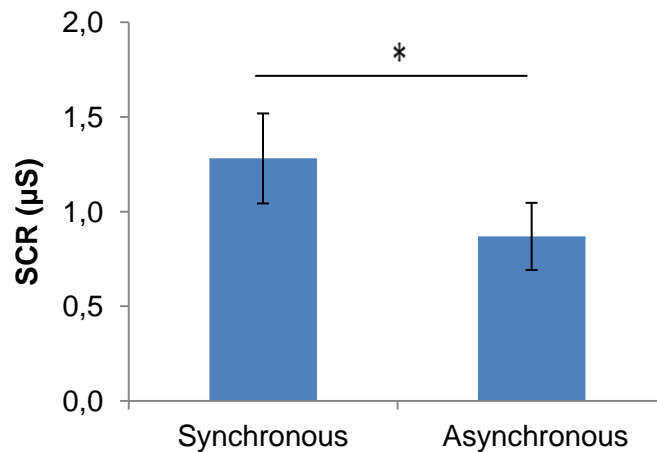


Figure 3.3. Skin conductance responses time-locked to the appearance of the knife threatening the invisible face. There was an increased reaction in the synchronous condition compared to the asynchronous condition. Error bars are indicates the standard error of the Mean (S.E.M). Asterisk indicate a significant difference ($p < 0.007$).

The questionnaire results were similar to those of Experiment 1, and confirmed that the synchronous visuotactile stimulation was effective in manipulating the sense of facial identity. Crucially, also in Experiment 2 we found significative differences between Synchronous and Asynchronous conditions in the critical statements that evaluate the illusion (see Figure 3.4)

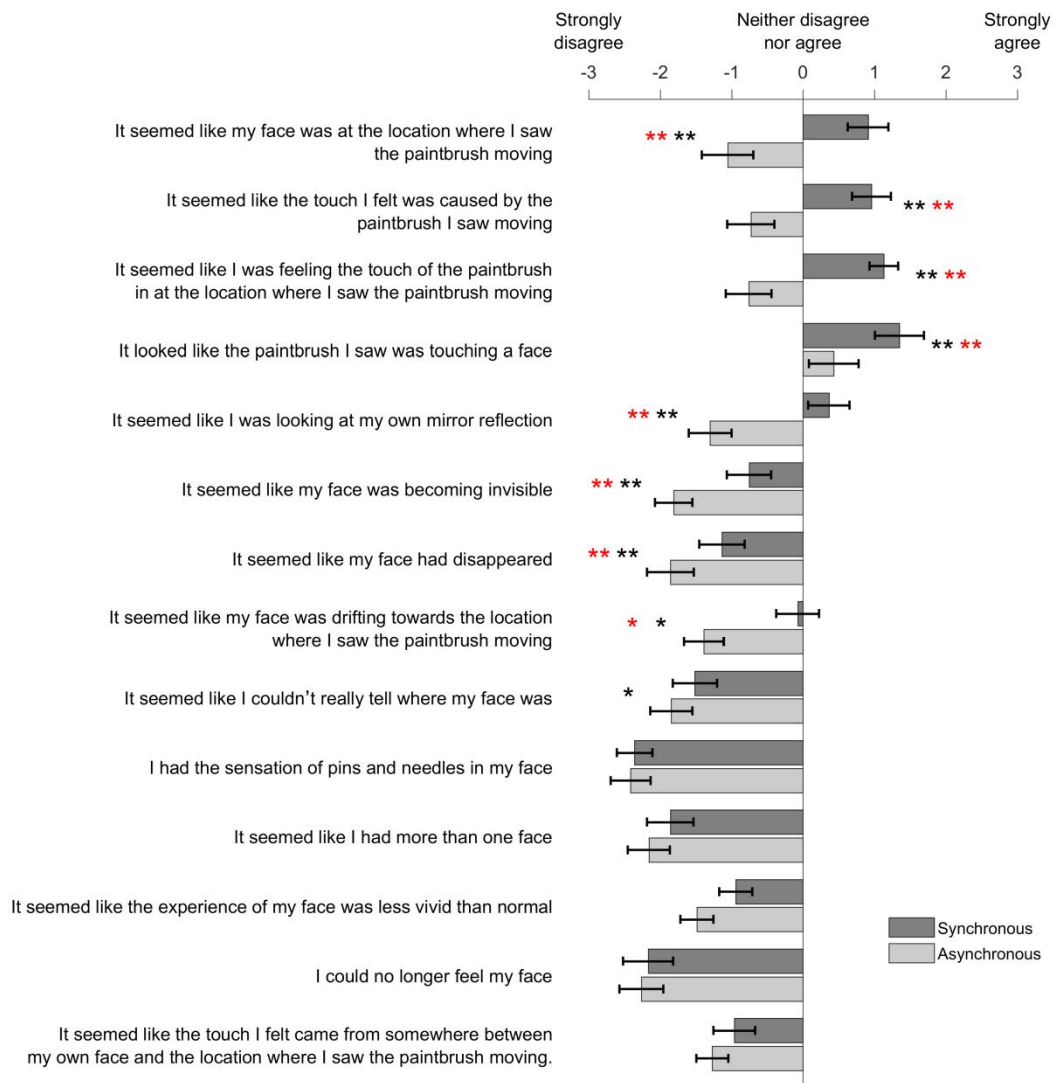


Figure 3.4. Subjective experience of the enfacement. The graph shows the average ratings for each question as a function of the visuotactile stimulation (Synchronous vs Asynchronous). Asterisks mark a significant difference (* $p < .05$; ** $p < .005$; Red asterisks indicate significant differences after Bonferroni correction * $p < .003$; ** $p < .0001$). Error bars represent standard error of mean (SEM)

3.3. Experiment 3

Experiment 1 and 2 showed that synchronous visuotactile stimulation between participant's face and a discrete volume of empty space elicits embodiment for an invisible face, as assessed by questionnaires and skin conductance response. In Experiment 3, we aimed to investigate whether such illusion is effective in modulating the gaze perception. In particular, we hypothesized that if participants truly experienced their own face as invisible they should feel themselves as less observed by others, leading to a reduction of the cone of gaze.

3.3.1 Methods

Participants

Thirty participants (18 women) were recruited for this study (mean age = 25; SD = 3.70). Participants had normal or correct to normal vision. They all provided written informed consent to participate to the experiment, which was approved by the Department of Psychological Sciences Research Ethics Committee at Birkbeck, University of London. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Stimuli

For this study we used four faces identities, two males and two females, with a neutral expression, taken from the Karolinska Directed Emotional Faces (KDEF). The hair and non facial areas were removed from the photographs, so that only the central face area was visible (see Figure 3.5). As in Ewbank et al. (2009), gaze direction was manipulated using Adobe Photoshop. The position of the eyes was shifted to the left or to the right of one pixel per images by up to 10 pixels in each direction. Therefore, we had twenty one gaze deviation along the horizontal axis for each face (from -10 to 10 pixels), manipulated according to the method of constant stimuli.



Figure 3.5 We had 21 gaze directions for each of the four faces used in the Experiment (from 10 pixels left to 10 pixels right). In the figure, one male and one female facial identity for five gaze directions are shown: 10 pixels left, 5 pixels left, direct gaze, 5 pixels right, 5 pixels left.

Procedure

The setting and the enfacement procedure were the same of Experiment 1. Participants were asked to watch the enfacement induction movie, while the experimenter stroked their face either synchronously or asynchronously with respect to the stroking on the invisible face. Counterbalancing of conditions was identical to Experiment 2. In each block, participants received 207 secs of visuotactile stimulation and then performed the cone of direct gaze task. Gaze deviations were tested using a method of constant stimuli. Each face, randomly selected, was presented for 500 ms in the centre of the screen on a grey background, using OpenSesame software. Participants were required to press one of three buttons according to whether they considered the face was looking to their left, to their right or directly at them. After each run, 84 faces were presented, such that there were a total of 252 faces presented for each synchronous and asynchronous condition. In each block, after every 21 gazes we repeated the visuotactile stimulation for 15 secs (corresponding to two brushstrokes). These 15s visuotactile periods served as a top-up to reinforce enfacement effects when they loss could have occurred, given the possibility for participants to move their head.

Analysis

Our analysis was modelled on that used by Mareschal and colleagues (2013b). For each participant, separate analyses were conducted on data from the synchronous and asynchronous conditions. In each case, three curves were fit simultaneously to the data using the *fminsearch* function in Matlab, implementing the Nelder-Mead simplex algorithm. Data from the 'left' and 'right' responses were modelled using logistic curves, and 'direct' responses were modelled as a curve defined as 1 minus the sum of the left and right curves at each point. By definition, therefore, the three curves sum to 1, appropriately reflecting the fact that the participant made a 3-alternative forced choice judgment. To estimate the width of the cone of direct gaze, we calculated the cross-over points between the curves. The left edge of the cone of gaze was operationalized as the location where the curves for left and direct judgments intersected; the right edge was operationalized as the location where the curves for right and direct judgments intersected. The difference between these two boundaries provides the width of the cone of direct gaze.

3.3.2 Results

Results from gaze perception task are shown in Figure 3.6. The model showed excellent fit to the data, with mean R^2 values of 0.984 (range: 0.957 – 0.999) in the synchronous condition and 0.985 (range: 0.950 – 0.998) in the asynchronous condition.

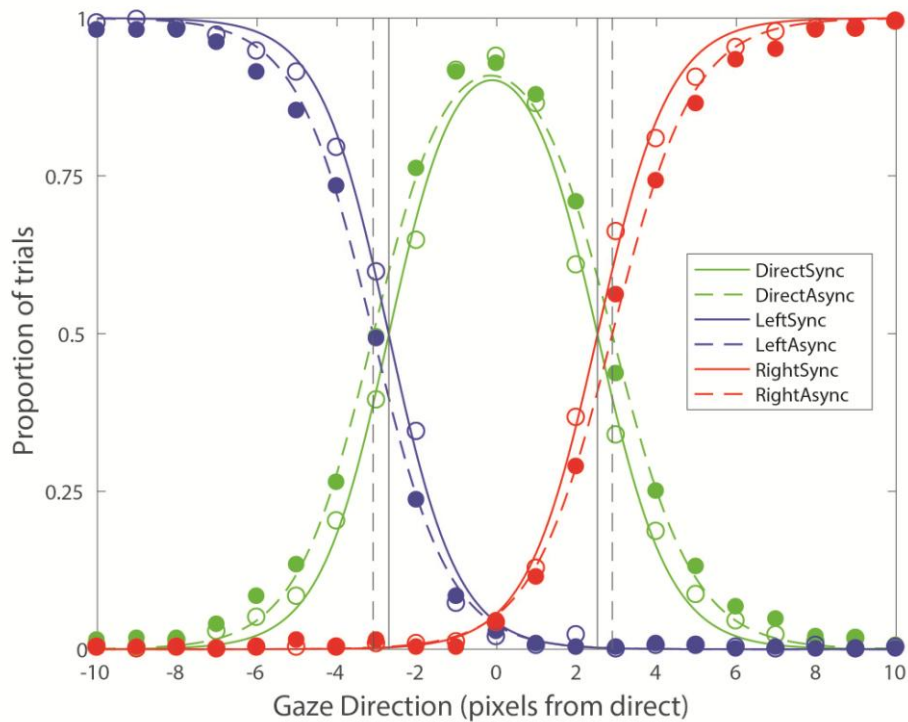


Figure 3.6 Plot showing mean fitted left, direct and right responses as a function of gaze direction in the Synchronous and Asynchronous condition. Vertical lines show cross-over points used to calculate cone of gaze.

We compared the mean width of cone across all participants for the Synchronous and Asynchronous condition through a paired t-test. Crucially the cone of gaze in the synchronous condition (5.37 pixels) is significantly thinner than the cone of gaze in the asynchronous (6.12 pixels) control condition ($t(29) = 6.86, p < 0.0001, d_z = 1.25$; Figure 3.6)

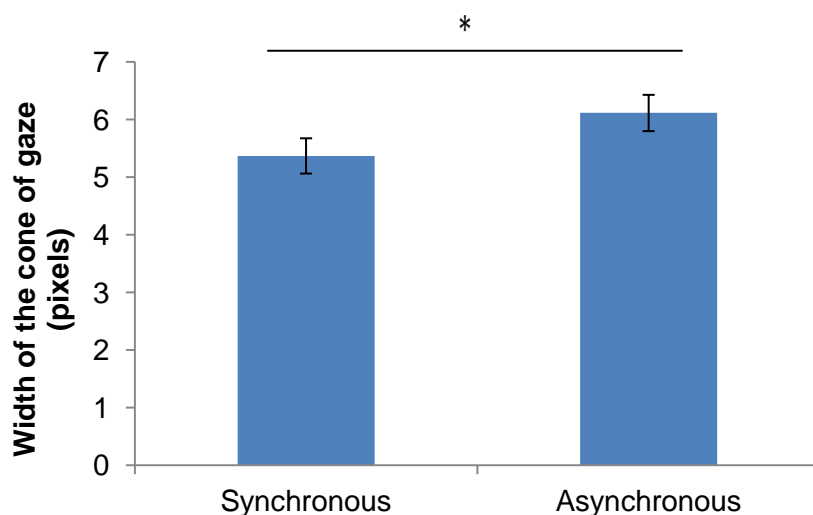


Figure 3.6 Mean width of cone across all participants for Synchronous and Asynchronous condition. Error bars indicate the standard error of the Mean (S.E.M). Asterisk indicate a significant difference

3.4 Discussion

Our results showed that participants experience an embodiment for an invisible face when they received touches on their face and saw a paintbrush moving synchronously in an empty space and defining, through its bristles, the contours and the shape of an invisible face. Crucially embodying the invisible face significantly shrinks the cone of gaze. In Experiment 1, questionnaire ratings after synchronous visuo-tactile stimulation were significantly different from the asynchronous condition, suggesting that the synchronous visuotactile stimulation was effective in modulating the perception of facial identity, inducing in participants a sense of ownership for the invisible face. Questionnaire's results were further confirmed in Experiment 2. Moreover, objective evidence for the illusion was obtained by demonstrating that physical threats to the "invisible face" elicited increased skin conductance responses when participants experienced the illusion after the synchronous visuotactile stimulation as compared to the asynchronous control condition. Finally, in Experiment 3 we demonstrated that synchronous visuotactile stimulation, as compared to the asynchronous condition, affects the perception of gaze directions.

Contrary to previous studies on enfacement, we elicited a manipulation in one's own face representation even in absence of visual inputs from a physical face. The invisible enfacement phenomenon indeed has particularly relevant implications for our understanding of the mechanisms involved in self face recognition. Previous researches on the enfacement illusion surely showed that the sense of facial identity may be more malleable than previously thought (Tsakiris, 2008; Sforza et al., 2010; Cardini et al., 2013). However, previous studies gave particularly emphasis to the changes in the perceived physical similarity between the self and the other, suggesting that the participant's visual representation of their own and another's face become partially blurred. In particular, the enfacement illusion was found to elicit activity in unimodal visual (inferior occipital gyrus) and multimodal visuo-tactile areas, such as the intraparietal sulcus (IPS) and temporoparietal junction (TPJ) (Apps et al., 2013). It has been proposed (Porciello et al., 2018) that TPJ detects a conflict between self tactile and other visual signals and then informs IPS that serves to maintain a coherent body representation. Indeed, IPS contains peripersonal space neurons that are multisensory neurons, anchored to the surface of one body parts (e.g. the face) and responding both to tactile stimuli on body parts and to visual stimuli presented near the same body part (Colby et al., 1993; Graziano and Gross, 1995). Thus, the enfacement illusion may be driven by the remapping of another person's peripersonal space onto one's own peripersonal space, triggered by the visuotactile stimulation (Maister et al., 2015). Crucially, the present study

suggests that this can also happen when visual information of a physical face is absent. However, it's worth to notice that although the face was not visible, the bristles of the paintbrush used for the visuotactile stimulation deflected in a way that defined the contours of an invisible head. Thus, it's possible to imagine that the visual information created by the bristles deflection, was a necessary cue to manipulate the sense of facial identity, although this question is not directly explored in our study.

The most important result of the present study is that synchronous visuotactile stimulation affected the perception of gaze direction. In particular, we used the metaphor of cone of gaze to refer to the range of gaze directions that are perceived as directed at the participant (Gamer et al., 2007). In previous studies the cone of gaze has been shown to be modulated mainly by high order cognitive factors concerning personality traits (Jun et al., 2013; Gamer et al., 2011), emotion perception (Ewbank et al., 2009) and perception of social contexts (Lyyra et al., 2016). Here, instead, we showed that also a mere change in one's own face representation can affect the perception of gaze direction, demonstrating a close relationship between the perception of gaze directions and one's own face representation. These data fit nicely with recent studies on embodied cognition showing the existence of a causal link between central body representations and social cognition or interpersonal attitudes. When we experience an illusion over a body different from our own, this can change aspects of our self identity and the way in which the self is conceptualized (Banakou et al., 2013), which, in turn, may change the way in which we interact with other people (Peck et al., 2013; Yee & Bailenson, 2007). In particular, investigations on enfacement have not only found evidence of changes in perceived physical similarity between self and other, but also blur self-other conceptual boundaries. Ma and co-workers (2016; 2018) called this effect "features migration", referring to the fact that increasing self-other similarity allows also affective and conceptual features to "migrate" from the representation of the other to the representation of oneself. Ma et al. (2016), for instance, demonstrated that enfacing a smiling face, participants showed a better mood, as explicitly assessed by questionnaires and a better performance in a mood-sensitive brainstorming creativity task. A subsequent study from the same research team, showed that enfacing an ape face reduced the performance in a fluid intelligent task and increased the willingness to attribute emotion to apes (Ma et al., 2018). Thus, enfacement illusion paradigm showed that increasing the overlap between the self and another face representation promotes illusory conjunctions, in which features of the other become features of oneself. In our case, enfacing an invisible face may lead participants to share the characteristic of being invisible, i.e., the impossibility of being gaze upon, thus reducing the range of gaze deviations perceived as directed toward the self.

When people notice that they are being looked at, they become aware that the attention or intentionality of another person is directed at them. This awareness is fundamental during

social interactions and is obviously distinct from the awareness of one's own physical body because it requires the existence of another person (Sugiura, 2013). Thus, our results suggest that the experience of invisibility may affect the manner in which we process the attention of others toward the self. These data are strongly in agreement with previous research by Guterstam et al. (2015), showing that the illusory ownership for an invisible body illusion reduces the level of subjective stress and decreases heart rate in response to standing in front of a crowd of unknown people. In particular, these authors argued that when participants experienced the invisible body illusion, their body was represented as invisible to outside observers as well, which in turn should reduce social anxiety related to being the centre of other people attention. This conclusion is particularly interesting for the present study, because researches on the cone of gaze demonstrated that it is wider in people suffering of social anxiety (Gamer et al., 2011; Jun et al., 2013). People with social anxiety show a hyper vigilance-avoidance pattern of attention to threat stimuli (Onnis et al., 2011). Therefore, in the case of socially anxious individuals hyper vigilance may exacerbate the normal tendency to assume other's people gaze as directed toward the self, producing a wider cone of gaze and leading to an exaggerated feeling of being looked at (Jun et al., 2013). Thus, it's possible to speculate that perceiving one's own body as invisible affects the way in which the brain processes the attention of the others toward the self, starting from a hypo-attention to the eye region which is associated to a weaker judgment of those eyes being directed at the observer. As previously recalled, indeed, humans have an expectation that the gaze is directed toward them (Mareschal et al., 2013b). In a notable study, Mareschal et al. (2013b), by applying Bayesian framework, demonstrated that this expectation dominates perception when there is high uncertainty. In this study authors, by adding noise to the eyes, presented participants with faces viewed under high or low levels of uncertainty. They found that participants systematically perceived the noisy gaze as being directed more toward them. In accordance with previous evidence, it's possible to assume that participants, representing one's own face as invisible after synchronous multisensory stimulation, may update also their prior expectation that the gaze is directed toward the self, accordingly with the new body representation.

However it is not our intent to claim that the illusion of having an invisible face is the only body change effective in modulating gaze perception. The cone of gaze is extremely plastic depending on several emotional or affective contexts, thus it's possible to imagine that also other bodily illusions may affect the cone of gaze. For instance, embodying a scared face may lead participants to be hyper-vigilant, thus enlarging their cone of gaze like persons with social phobia. It's possible that the dynamic interaction between one's own face representation and the perception of gaze direction, could happen also at the neural level.. Perception of direct eye gaze is associated with activation in amodal association cortices in the medial frontal and

lateral posterior cortices (Sugiura et al., 2013). In particular, activation has been identified in the medio prefrontal cortex encompassing the anterior cingulate cortex (ACC) (Kampe et al., 2003; Schilbach et al., 2006; Steuwe et al., 2012), the TPJ/pSTS (Pelphrey et al., 2004; Schilbach et al., 2006; Steuwe et al., 2012), the anterior temporo poral cortex (ATC). These regions have often been recognized as a cortical network supporting the inference of another's mental state, namely mentalizing or theory of mind (Amodio and Firth, 2006). We can therefore hypothesize that the observed illusion-induced reduction of the cone of gaze, is reflected in the neural interplay between multisensory representations of one's own face in intraparietal areas and the cortical neural network supporting metalizing and theory of mind. This is an intriguing hypothesis that future studies could put at test.

Chapter 4

The illusion of having a tall or short body differently modulates IPS and PPS

4.1 Introduction

In the second chapter of the thesis it has been shown that the illusion of having an invisible body strongly modulates the interpersonal space (IPS), as measured by a comfort distant task. As discussed, when participants experience their own body as invisible, they feel more protected and less exposed to the other proximity, allowing the other person to be closer to their body. This was in line with an interpretation of IPS as a protective safety space that increases in threatening and uncomfortable situations (e.g. danger, fear, anxiety) and decrease in unthreatening and comfortable situations.

In contrast, the illusion of having an invisible body did not affect the perceived peripersonal space (PPS), as measured by a reaching distance task. Indeed, PPS, as discussed, is an action space that offers a multisensory interface for body–objects interactions to generate goal directed action within the reaching distance. (Brozzoli et al., 2014; di Pellegrino and Ladavas, 2015) . PPS has been linked, indeed, with the actual length of the arm (Linkenauger et al., 2015; Longo and Lourenco, 2007) and it is strongly modulated by action dependent manipulations (Bassolino et al., 2015). We argued that the illusion of having an invisible body did not affect the arm length representation, so that it leaved intact the potentiality to act in space and also the perceived PPS was unaffected.

On the other hand, recent studies have been shown that inducing ownership over a body or body parts of different sizes caused modulations also in near space perception. In a series of elegant studies, Van der Hoort and colleagues (van der Hoort & Ehrsson, 2014; 2016; van der Hoort et al., 2011), modified the body swap illusion to embody participants in a very small or large body. Crucially, these modulations in body metrics not only affected body representation but impacted also on space and object perception.. Thus, identical objects at identical distances were perceived as larger and farther away when participants owned a small body, and as smaller and closer when they owned a large body. In line with these results, Linkenauger et al. (2015), by using virtual reality, induced in participants the illusion of having a long or short virtual arm. Authors found that the distances to targets appeared closer when participants' virtual arm was long, compared to when their virtual arm was short, even if these

modulations occurred only following a reaching experience. Thus, these latter data suggest a close relationship between the representation of our body size, the potentiality to act in space and space perception.

Although one's own body-part size has been connected with the PPS (Linkenauger et al., 2015; Longo and Laourenco, 2007), there are no studies that investigated whether an illusory change in one's own body size can affect also IPS. In the social domain, body size and height have been associated with social status and dominance in both animals and humans (Ellis, 1994; McElligott et al., 2001; Schuett, 1997). Studies have shown that height is positively related to proxies of social status, such as leadership, professional achievement, education, and income. Stulp et al., (2015) showed that shorter individuals tend to give way on a narrow sidewalk and in a busy shopping street to taller individuals. These authors hypothesized that height directly influences the likelihood of an individual winning during a dyadic interaction, as a result of the increased interpersonal dominance of taller people during confrontations with competitors. There is evidence suggesting that individuals' height is related to physical dominance: taller compared to shorter men are physically stronger and perceived to be stronger; physically more aggressive ; show better fighting ability; and feel less threatened by physically dominant men. However, also in non physical contest, taller people are also perceived as more competent, authoritative, intelligent, dominant, and having better leadership qualities.

Setting out from these findings, in the present study we wanted to investigate whether the same manipulation in one's own body height can affect IPS and, moreover, reveal a dissociation between IPS and PPS. To this aim, we measured IPS through a comfort-distance task, in which participants were asked to stop an individual approaching them at a position in which they felt most comfortable with the other's proximity. In addition, we measure PPS in a similar way through a reaching-distance task, in which participants were asked to stop the other person at the distance in which they thought they could reach him. These two tasks were performed before and after participants experienced illusory ownership for a tall body.

Based on the finding suggesting a positive association between height, social status and dominance (Stulp, 2005; Yee and Bainsolon, 2007), we hypothesized that the illusion of having a tall body should induce participants to feel more dominant during a dyadic interaction, thus leading to a reduction of IPS between them and a confederate. At the same time, an increase in body size, in particular of one's own effectors, may affect also the perceived potentiality to act in space. Thus, we predicted that participants experiencing ownership for a tall body should extend their action PPS, accordingly to an increased length of their effectors. Thus, if IPS and PPS are sensitive to the body height manipulation, we should expect a modulation in opposite directions, that is a contraction of IPS and an extension of PPS.

4.2 Experiment 1

4.2.1 Materials and methods

Participants

Twenty three healthy individuals volunteered for this experiment (age range= 19-26; mean = 22.78). A statistical power analysis was performed with GPower 3 for sample size estimation. Based on data from our previous study (D'Angelo et al., 2017), we specified a medium effect size ($\eta^2_p = 0.25$) with power level at 0.80 and correlation among measures of 0.26. All of the participants were instructed to wear a pair of trousers and a black t-shirt. The study was approved by the Ethical Committee of the University of Bologna, in agreement with the 2008 Helsinki Declaration and all participants gave their written informed consent.

Setting

Participants were fitted with a set of HMDs (VRvision, 800 x 600 resolutions equals 1.4M pixels and full colour, 42° diagonal field of view). HMDs were connected, through a PC, to a synchronized HD webcam colour (Logitech HD pro webcam C920 full HD 1080p) placed on a tripod and adjusted at the same height of the participant's head. Participants were asked to stand upright in a marked position to the left of the tripod and to look straight head. In this way, participants viewed in the HMDs the part of the room filmed by the camera, as if their first person perspective was that of the camera.

Comfort and Reaching distance task

Participants performed a Reaching and a Comfort distance task to assess the estimated PPS and IPS between them and a confederate actor. The confederate, placed in front of the tripod from a of 5 meters starting position, moved at natural gait toward the camera. In the Reaching distance task, participants were required to stop the confederate at the distance they thought they could reach the other person by extending their arm. In the Comfort distance task, instead, participants were asked to stop the confederate at the shortest distance they felt comfortable with the other's proximity. In either tasks, participants could fine tune the distance, by asking the confederate to slightly move further backward or forward. The confederate was instructed to avoid any direct contact gaze, looking at a fix position on the tripod just under the camera. Male participants performed the task with a male confederate and female participants performed the task with a female one. Through the tasks, participants stood with their arms extended along the trunk. The Reaching and Comfort distance tasks were

administered in separate block of 6 trials per task. The order of blocks was counterbalanced across participants. At the end of each trial participants were asked to close their eyes, meanwhile the distance between the confederate's sternum and a fix point on the tripod was measured with a digital laser meter (Agatec, model DM 100, error ± 0.3 cm). Then, the confederate came back to his/her starting position for the following trial. To ensure a standardized appearance of the confederates, they had to wear a pair of trousers and a black t-shirt and to maintain a neutral expression. Participants and the confederate didn't speak to each other for the whole experiment.

The Reaching and Comfort-distance task were repeated with the same confederate before and after the body swap illusion.

Body swap with a tall body

Next, participants underwent a body swap illusion with a tall male mannequin (200 centimetres tall). Immediately after the Reaching and Comfort distance task, participants were asked to close their eyes and to tilt their heads downwards as if they looked down at their bodies, meanwhile the experimenter replaced the tripod with the mannequin. On the mannequin's head there was another camera pointing downwards, such that it recorded events from the position corresponding to the mannequin's eyes. The experimenter turned on the mannequin's camera connected, by PC, to the HMDs as well. Then, participants were asked to open their eyes and, in this way, they could see the mannequin's body where they expected to see their own body. To induce the illusion, we used a paintbrush to repetitively stroke different participant's body parts, which were out of view, while synchronously identical strokes were applied with another brush to the mannequin's body, in full view of the participant (for a similar body swap procedure, see Petkova and Ehrsson, 2008; Petkova et al., 2011). This visuotactile stimulation lasted 2 minutes. Then, participants were asked to close again their eyes, while the experimenter placed the tripod in the same location as before. To avoid that the bodily illusion was easily broken, during the following tasks, we adjusted the tripod so that the camera filmed the room from 2 meters high perspective. Thus, participants raised their head, opened their eyes and watched, in the HMDs, the room from a 2 meters high perspective. As a control condition, we applied asynchronous brushstrokes to the participant and mannequin's body, matching the total number and length of the strokes. The experiment was conducted as a within-group counterbalanced design. The order of the synchronous and asynchronous conditions was counterbalanced across participants, who performed both in two different days. To rule out a possible effect of the mere change of perspective, the camera was placed at 2 meters in height also after the asynchronous visuotactile stimulation.

Ratings

In our paradigm the change in body height was accompanied by a change in visual perspective, which in turn may have had an effect on object size and distance perception. In other words participants could have perceived the confederate and objects in the environment as smaller and closer after the visutactile stimulation and the change in visual perspective. Thus, we wanted to rule out the possibility that the modulation in space perception could be caused by a general change in object's size perception, rather than by the ownership sensed for a tall body. To rule out this possibility we asked participants to manually estimate the size of a stool, before and after the body swap illusion. In particular, before the experiment started, the experimenter placed a stool in front of the camera that remained visible for about three seconds. Participants, who saw the stool through the HMDs, were instructed to manually estimate its size. In particular, they were asked to indicate the size of the stool as the width between the palms (see figure 4.1), and to maintain their hands in this position until when the experimenter measured this distance with a laser meter (Agatec, model DM 100, error ± 0.3 cm). This task was repeated also after the body swap illusion and it served as a measure to evaluate a change in object's size perception due to the illusion. The stool in the post illusion session had the same size of the previous one, but it was of different color to prevent participants from recognizing the object across the pre and post body swap sessions.

Moreover, to provide a measure of the illusory ownership over the tall body, at the end of the experiment, participants were asked to complete a 5-item questionnaire (questions were adapted from Petkova and Ehrsson, 2008; Guterstam et al., 2015; see Table 1). Participants were asked to indicate the extent of their agreement or disagreement with six statements using a seven-point Likert scale, ranging from -3 ("I completely disagree") to $+3$ ("I completely agree"), with a response of 0 indicating "neither agreed nor disagreed". Three of the statements examined the perception of the illusion (Q1–Q3) and the remaining two statements were designed to control for suggestibility and task compliance (Q4–Q5)



Figure 4.1 The figure shows the hands' position kept by participants to estimate the stool size.

4.2.2 . Results and discussion

The mean distances in cm recorded in each condition were contrasted by an ANOVA with Stimulation (Synchronous and Asynchronous), Task (Reaching and Comfort distance) and Session (Pre and Post) as within subject factors. Significant interaction were followed by Newman Keuls post hoc. The interactions Stimulation x Task ($F_{1,22}=20.03$; $p<.001$; $\eta^2_p= 0.47$) and Session x Task ($F_{1,22} =17.85$; $p < .001$; $\eta^2_p= 0.44$) were significant. Crucially, also the three-way interaction Stimulation x Task x Session was also significant ($F_{1,22} =16.10$; $p < .001$; $\eta^2_p= 0.42$). Newman-Keuls post hoc revealed the Reaching-distance was significantly extended after synchronous condition, as compared to before (62.05 vs 75.52 cm ; $p< .005$), whereas the Comfort distance following the synchronous condition was significantly reduced with respect to before (66.23 vs 5.79 cm; $p < 0.05$) (See Figure 4.2).

In contrast, there was no significant difference in the asynchronous condition between pre and post neither in the Reaching (59.97 vs 63.24 cm; $p = 0.68$) and in the Comfort distance (66.71 vs 71.19 cm; $p = 0.42$) task. In addition, before body swap no significant difference between Reaching and Comfort-distance amplitudes appeared neither in the Synchronous (62.05 vs 67.23 cm; $p= .49$) and Asynchronous (59.44 vs 66.11 cm; $p = .30$) conditions.

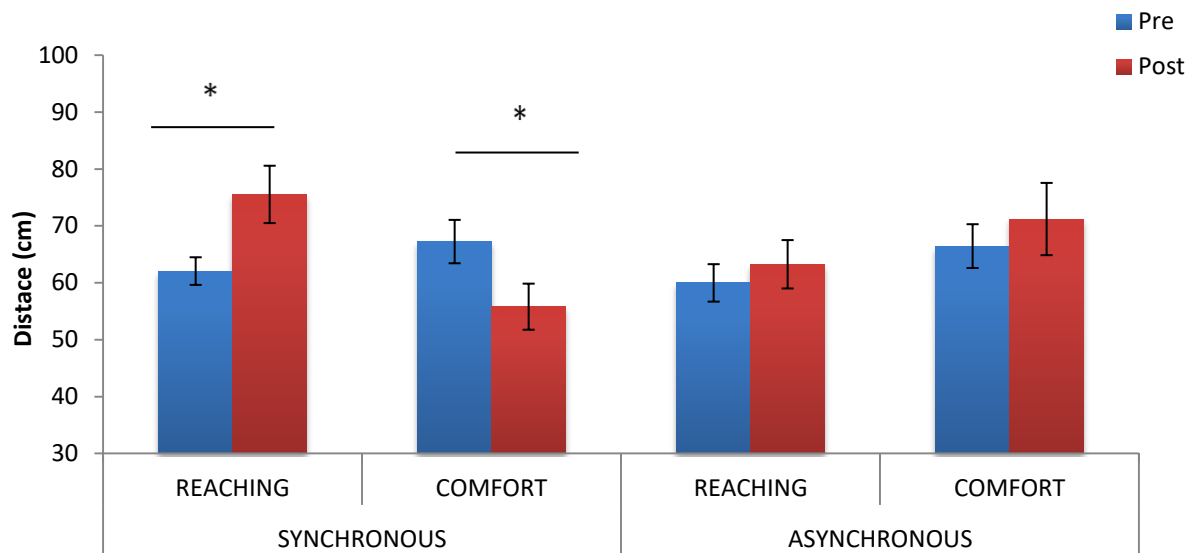


Figure 4.2. Effects of visuotactile stimulation on comfort and reaching-distance. Mean distance (cm) shown as a functions of the two tasks (comfort and reaching), Stimulation conditions (Synch, Asynch) and two sessions (pre and post). Asterisk marks a significant difference. Error bars indicate standard error from the mean

Responses to the questionnaire were analyzed to investigate the subjective experiences of participants during the multisensory stimulation. The response given to each question after synchronous stimulation was compared to the response given after asynchronous stimulation using Paired Wilcoxon Signed Ranks Test cause they are not normally distributed; Mean agreement and results of the statistical comparisons are presented in Table 4.1. As it can be seen in Table 1, stronger agreement with the first three statements indicated that participants experienced the body swap illusion. Importantly, the questionnaire results show that only the three critical illusion questions significantly higher in the synchronous than asynchronous conditions. On the other hand, no significant difference was found in the two control statements ratings between synchronous and asynchronous conditions.

Question	Synchronous M(SD)	Asynchronous M(SD)	z
Q1. "I felt the touch of the brush on the mannequin in the location where I saw the brush moving"	2,43 (0.99)	-0.11(2.24)*	- 3.56
Q2. "It felt as if the mannequin's body was my body"	1.57 (1.24)	-0.87 (1.96) *	- 3.77
Q3. "I experienced that the touch I felt was caused by the brush touching the mannequin"	1.48 (1.56)	-1.48 (1.62) *	-3.05
Q4. "It felt as if I had two bodies"	-0.99 (2.21)	- 0.48 (1.98)	-0.68
Q5 "I could no longer feel my body"	-1.78 (2.21)	- 1.48 (1.62)	-0.69

Table 4.1 Mean ratings (\pm SD) for each questionnaire item in the two experimental conditions (Synchronous vs. Asynchronous)

*p <.005

Crucially, bimanual object size estimation were significantly smaller after the participants watched the stool from a 2 meters height prospective in both synchronous ($p < .01$, paired t-test) and asynchronous conditions ($p < .01$). This means that the only change in perspective is sufficient to induce a rescaling in the perceived object's size (Table 4.2).

	Pre M (SEM)	Post M (SEM)
Synchronous	47.65(3.29)	39.40 (2.72)*
Asynchronous	50.09 (3.89)	42.54 (2.86)*

Table 4.2 The high perspective effect on size perception as measured by the hand aperture. Mean distances between the hands are shown as a function of the session (Pre and Post) and Stimulation (Synchronous and Asynchronous). Asterisk indicate a significant difference ($p < .01$) between pre and post in both Synchronous and Asynchronous conditions

We showed that IPS was reduced after synchronous visuotactile stimulation and, at the same time, the perceived PPS was modulated in the direction of extension. By contrast, there was no significant modulation in IPS and PPS after asynchronous visuotactile stimulation. Crucially, participants reported ownership for the tall body only after synchronous but not after asynchronous visuotactile stimulation. However, a change in body height cause also a change in the visual perspective and a consequent change in the perceived size of the word. Therefore it remains possible that the present results do not reflect ownership sensed for a tall body. Rather, such modulations could be due to the high visual perspective during and after the body swap that cause participants to perceive the confederate smaller as compared to before visuotactile stimulation. However, findings from asynchronous condition rule out this possibility. In the asynchronous condition participants did not report ownership for the tall body but the change in perspective was still present. Although the 200 cm high perspective in the asynchronous condition was not effective in modulating IPS and PPS, it was still effective in changing the visual perception of object size, as assed by the manual estimation of the stool size. Thus, this evidence makes unlikely that the modulation of IPS and PPS was due by the only change in the perceived confederate's size. Rather, present data clearly indicate that the reduction of IPS and extension of PPS depend also (or exclusively) on the perception of one's own body as taller.

To further confirm this hypothesis we conducted another study (Experiment 2) aimed to reveal results opposite to those obtained in the Experiment 1. That is, if a tall body leads participants to feel themselves more dominant in the dyadic interaction and to accordingly modulate the IPS (i.e., enlargement), we should expect an opposite modulation of IPS when participants experience ownership for a short body. In experiment 2, we directly tested this hypothesis, measuring IPS and PPS before and after a body swap illusion with a short (105 cm) body. We expected that participants feel themselves less dominant in the dyadic interaction, leading to

an extension of IPS. Moreover, we hypothesized a contraction of PPS consistent with a reduced potentiality to act in the space around the body.

4.3. Experiment 2

4.3.1 Methods

Participants

A new group of twenty three participants (age range= 20-27 ; mean = 22,87; 12 women), were recruited to the study. Also in this case participants were instructed to wear a pair of trousers and a black t-shirt. The study was approved by the Ethical Committee of the University of Bologna, in agreement with the 2008 Helsinki Declaration and all participants gave their written informed consent.

Procedure and tasks

The procedure was the same as in Experiment 1, with the exception that a short (105 cm) mannequin was used for the body swap illusion. Moreover, after the synchronous and asynchronous stimulation the experimenter adjusted the camera so that participants watched the room from a 105 cm high perspective.

4.3.2 Results

The mean distances in cm recorded in each condition were contrasted by an ANOVA with Stimulation (Synchronous and Asynchronous), Task (Reaching and Comfort distance) and Session (Pre and Post) as within subject factors. Significant interaction were followed by Newman Keuls post hoc. The interaction Session x Task ($F_{1,23} = 10.48$; $p < .005$; $\eta^2_p = 0.32$), as well as Session x Task ($F_{1,22} = 12.00$; $p < .005$; $\eta^2_p = 0.35$) were significant. Crucially, also the three-way interaction Stimulation x Task x Session was also significant ($F_{1,23} = 8.98$; $p < .005$; $\eta^2_p = 0.29$; see Figure 4.3). Newman-Keuls post hoc revealed that the Comfort distance was extended after as compared to before synchronous visuotactile stimulation (61,38 vs 79,66 cm ; $p < .001$). No difference in the comfort distance between pre and post visuotactile stimulation appeared in the asynchronous condition (56,32 vs 64,71; $p = .07$). Unlike to the Experiment 1, the reaching distance was not significantly modulated by the body swap illusion neither in the synchronous (64,53 vs 62,42; $p = .27$ or asynchronous condition (65,97 vs 69,47 cm; $p = .24$).

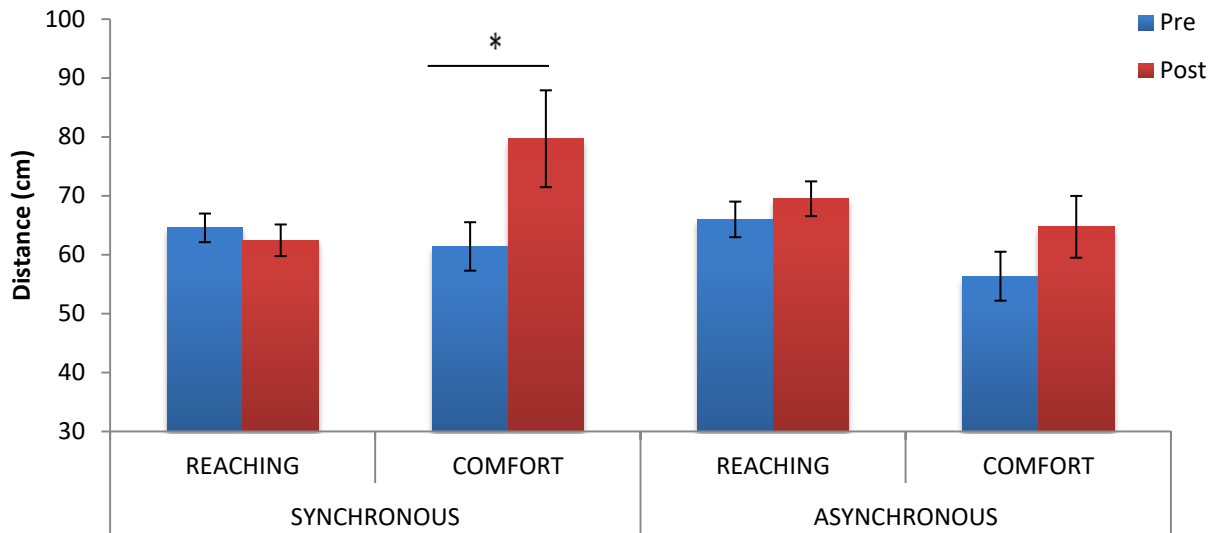


Fig 4.3 Effects of visuotactile stimulation on comfort and reaching-distance. Mean distance (cm) are shown as a functions of the two tasks (comfort and reaching), Stimulation conditions (Synch, Asynch) and two sessions (pre and post). Asterisk marks a significant difference. Error bars indicate standard error from the mean

Also in this case responses given at the questionnaire after synchronous stimulation was compared to the response given after asynchronous stimulation using Paired Wilconxon Signed Ranks Test (Table 4.4). Also in this case, stronger agreement with the first three statements indicated that participants experienced the body swap illusion for the short body. The three critical illusion questions were more strongly affirmed in the synchronous condition as compared to the asynchronous condition. No significant difference was found in the two control statements ratings between synchronous and asynchronous conditions.

Question	Synchronous M(SD)	Asynchronous M(SD)	z
Q1. "I felt the touch of the brush on the mannequin in the location where I saw the brush moving"	2.68 (0.64)	1.00(2.29)*	- 2.95
Q2. "It felt as if the mannequin's body was my body"	1.82 (0.85)	-1.30 (1.18) *	- 4.01
Q3. "I experienced that the touch I felt was caused by the brush touching the mannequin"	1.45 (1.37)	-0.86 (2.05) *	- 2.95
Q4. "It felt as if I had two bodies"	-0.73 (1.38)	- 1.23 (1.79)	- 1.44
Q5 "I could no longer feel my body"	-2.36 (0.95)	- 2.68 (0.77)	-1.11

Table 4.4. Mean ratings (\pm SD) for each questionnaire item in the two experimental conditions (Synchronous vs. Asynchronous)

*p < .005

Bimanual object size estimation were significantly smaller after the participants watched the stool from a 105 centimetres height perspective in both synchronous and asynchronous

conditions. This means that even in Experiment 2, the only change in perspective was sufficient to induce a change in the visual perception of object size (Table 4.3).

	Pre M (SEM)	Post M (SEM)
Synchronous	47.48(3.79)	62.60 (4.03)*
Asynchronous	48.92 (3.99)	56.86 (4.19)*

Tabel 4.3 The high perspective effect on size perception as measured by the hand aperture. Mean distances between the hands are shown as a function of the session (Pre and Post) and Stimulation (Synchronous and Asynchronous). Asterisk indicate a significant difference ($p < .01$) between pre and post in both Synchronous and Asynchronous conditions

In conclusion, Experiment 2 showed that IPS was enlarged after synchronous visuotactile stimulation as compared to before. In contrast, any significant difference in IPS was found after asynchronous visuotactile stimulation. On the other hand, in contrast to our hypothesis, body swap illusion was not effective in modulating PPS in Experiment 2. Indeed, we didn't find any significant modulation in PPS neither after synchronous and asynchronous visuotactile stimulation. This could be seem quite tricky to explain. However, previous studies shown that although body schema extension is recurrently reported, evidence of contraction is very rare (Bassolino et al.,2014 ; Pavani and Zampini, 2007). In healthy individuals, vibratory or visuotactile sensory illusions lead to a perception of body parts as bigger, rather than smaller than their actual dimensions, suggesting an asymmetric tendency to recognize enlarged but not reduced body parts (De Vignemont et al., 2005). Thus, the lack of a reduction of PPS in the present study could be due to this asymmetry.

4.3 Discussion

Body height has been related to interpersonal dominance in a variety of social settings. In the present study, given the social “side effects” of the body height, we wanted investigate whether a temporarily change in one’s own height, by a perceptual bodily illusion, may affect the social IPS. Moreover we also tested if this change is associated also to a modulation in the perceived PPS. To this end, we measured IPS and PPS before and after participants experienced ownership for a tall body (Experiment 1) and for a short body (Experiment 2).

Experiment 1 showed that the illusion of having a tall body, elicited by synchronous visual and tactile stimuli and explicitly assessed by the questionnaire, significantly reduced IPS and, at the same time, enlarged PPS. After asynchronous visuotactile stimulation, participants did not report ownership for the body and, crucially, no significant modulation in both IPS and PPS was found. On the other hand, Experiment 2, further supports the close relationship between body representation and IPS, showing that the illusion of having a short body, significantly enlarge IPS, although, contrary to the Experiment 1, it leaved intact the action PPS. This data nicely fit with previous researches showing that body height play an important

role in the way in which we interact with other people. Yee and Bainsolon (2007), for instance, found that participants were more willing to make unfair splits in an ultimatum game when they experienced the embodiment toward a taller than a shorter virtual body. Stulp et al. (2015), in a series of observational studies showed that height is related to interpersonal dominance in a variety of social setting. They showed that taller individuals were more likely to take precedence when entering a narrow passage wide enough for only a single individual to pass. Moreover, in a second study, they investigated how pedestrians reacted towards confederates of varying height, as they walked along a busy shopping street. Pedestrians were more likely to yield to taller than to shorter confederates by giving way and stepping aside. The present data fit well with the naturalistic observations by Stulp et al (2015). Indeed, it's possible to assume that even a momentary change in one's own body height, like in our study, may lead participants to feel themselves as more dominant or less dominant in the dyadic interaction with the confederate. Thus we argue that such a change in the interpersonal attitude leads to an enlargement or a contraction of the space in which participants felt most comfortable with the other proximity. The current study supports the hypothesis that a momentary change in own-body representation influences the way in which we interact with other people, by contributing to the emerging body of research on embodied cognition that suggests the existence of a causal link between central body representations and various higher cognitive functions. To this regard, it's worth to notice that in the present study, the change in body height was accompanied also by a change in visual perspective. Participants saw the room from a 200 or 105 cm high perspective after the body swap with a tall or short body, respectively. Thus, some may argue that only the change in visual perspective could be sufficient to affect IPS, irrespective of the body swap *per se*. However, the asynchronous condition ruled out this interpretation. Indeed, also in the asynchronous conditions, in which participants did not report ownership for the mannequin's body and no modulations in IPS and PPS was found, we changed the visual perspective after the period of visuotactile stimulation. Thus, our overall findings clearly indicate that having experience ownership for the body was an essential factor to modulate the IPS and PPS and that the visual perspective alone was not effective in modulating space perception.

In Experiment 1 we found that the illusion of having a tall body, significantly enlarged the PPS. PPS is an action space that is modulated mainly by action-dependent variables. For example, it's well known that the active use of a tool to reach far objects significantly enlarge PPS. Cause the length of our effectors (mainly the arms) limits our action space, it has been proposed that the PPS extent strictly depends on arm length representation. For instance, Longo and Lourenco (2007) showed that the extent of PPS scaled as a function of the arm length. Indeed, to this regard, tool use not only affect the extent of PPS but affect also the body schema, increasing the length of the sensorimotor representation of the arm. Thus it's possible

to hypothesize that the illusion of having a tall body updated the representation of participants' arm length, generating new sensorimotor predictions consistent with the new arm representation. However, several studies have shown that performing an action is a necessary factor to obtain a modulation in PPS. Linkenauger et al. (2014), by using virtual reality technology, induced in participants the illusion of having a long or short virtual arm. They found that the distances to targets appeared closer when their virtual arm was long, compared to when their virtual arm was short, but this was true only after participants performed a reaching action with the virtual arm. In contrast, in our study participants did not perform any movements. Anyway, it's possible to assume that during the reaching distance task, participants imagined or programmed a reaching action, keeping into account the new body representation. Indeed, in other studies, the modulation in PPS was found also when the action is just imagined or intended even if it is not actually executed (Witt et al., 2008; Constantini et al., 2011; Davoli et al., 2011; Baccarini et al., 2014). Theories of motor control suggest that the brain uses internal models of the body to perform accurate movements. When a motor command is issued, a "forward model" of the body estimates the sensory consequences of the action (Blakemore et al., 2000; Wolpert & Flanagan, 2001). Thus, PPS space extension may reflect an updating of the sensorimotor representation of the body used by the forward model to predict the sensory consequences of the action (at this regard see the next chapter).

The Experiment 2, contrary to our expectation, failed to find a significant modulation in PPS. However, we retain that the absence of effects on PPS in the short mannequin experiment, is quite interesting. Previous studies showed that, although body schema extension is recurrently reported, evidence of contraction is very rare (Podoll & Robinson, 2000; Bassolino et al., 2012; Pavani et al., 2007). In healthy individuals, vibratory or visuotactile sensory illusions lead to a perception of body parts as bigger, rather than smaller than their actual dimensions, suggesting an asymmetric tendency to recognize enlarged but not reduced body parts (De Vignemont et al., 2005). An asymmetric plasticity of body representation may also reflect daily life activities where we frequently manipulate objects or tools that elongate our body parts, while the reverse effect is uncommon. Thus it is possible that, although the ownership felt for the short body was effective in producing the interpersonal consequences consistent with a short body, it was ineffective in updating the sensorimotor representation of the arm, generating consistent sensorimotor expectations during the reaching distance task.

To sum up, a change in body height modulated both the perceived interpersonal dominance during the dyadic interaction and, at least in the tall condition, the perceived potentiality to act in space. This double effect on both social cognition and sensorimotor programming, allowed us to reveal a dissociation in space perception, depending on whether the space assumes a social or a sensorimotor valence. To this regard, it's worth to notice that before visuo-tactile stimulation reachable and comfort space estimates did not differ, supporting the idea that PPS

and IPS share common functional mechanism and in some circumstances, they refer to the same sector of space. However, despite the fact that the reaching and comfort pre-body swap amplitudes were comparable, the illusory ownership for the mannequin's body revealed a difference in the plastic properties of PPS and IPS and even an opposite pattern in the tall condition. This suggests that both PPS and IPS may be fed by the same sensory inputs, however, in some circumstance, they can diverge. Different prior, different weights ascribed to sensory inputs and different decision criteria may explain the divergence between them. In our case, body size is an important variable involved not only in programming goal directed actions but also in regulating social interactions. Given this double valence of the body size, a change in body height was effective to reveal a dissociation in the representation of the space around the body, depending on whether this sector of space is used for programming actions or for regulating social dyadic interaction.

Chapter 5

The sense of agency shapes body schema and peripersonal space

In the previous chapter we did not succeed in finding a contraction of PPS after participants sensed ownership for the short body. We discussed this result in light of an asymmetric tendency in updating one's own sensorimotor representation of the arm morphology. Indeed, body schema extension is recurrently reported but evidence of contraction is very rare. Moreover, in ecological situations we frequently manipulate objects or tools that elongate our body parts, while the reverse effect is uncommon. We never see in everyday life the effects of our action closer to the body than the action itself. Thus it's possible that the mere sense ownership for the short body was not enough to update the sensorimotor representation of the arm length and to generate consistent sensorimotor predictions.

In the next chapter we will focus more in depth on the notion of body schema and we will try to figure out the exact mechanism underling its plasticity. In particular, we hypothesized that changes in body schema and peripersonal space depend on the experience of controlling the course of events in space trough one's own actions, i.e., the sense of agency. Specifically, here we tested the hypothesis that body schema and peripersonal space representations are the consequence of the simple associations between one' s own intentional actions and their outcomes occurring in space.

5.1 Introduction

The term body schema refers to a sensorimotor representation of the body morphology used for planning and executing body movements. This sensorimotor body representation entails tracking and updating the position and configuration of the body parts in space at the service of action (Frederique de Vignemont, 2010; Longo & Haggard, 2010; Longo et al., 2010). A main characteristic of the body schema is that it is highly plastic. For example, there is abundant evidence that the active use of a tool, to interact with objects placed beyond one's reaching space, changes the body schema, increasing length of the sensorimotor representation of the arm (Cardinali et al., 2009; Canzoneri et al., 2013; Sposito et al., 2012). Body schema has been found to be sensitive also to other manipulations. For instance, after right arm immobilization, participants overused the remaining free arm, modulating its representation. As a consequence, participants perceived their overused limb as longer after,

than before, immobilization (Bassolino et al., 2014). In another study, Tajadura-Jiménez et al.(2012) found that body schema is affected by the sound of one's action. Body schema extended after participants tapped on a surface and listened to a tapping sound originating at a double the distance at which they actually tapped. This evidence emphasizes the strictly connection between body schema, space representation and the motor system.

To this regard, body schema is closely interwoven with a functional representation of the action space immediately surrounding the body, the so-called peripersonal space (di Pellegrino & Làdavas, 2015). As mentioned in Chapter 1, peripersonal space representation depends on the activity of multisensory neurons in fronto-parietal network, including the premotor cortex (PMc) and the posterior parietal cortex (PPc). These neurons respond both to tactile stimuli on body parts and to visual and/or auditory stimuli presented near the same body part. Peripersonal space has not only a sensory function, but also motor function. Indeed, in monkeys fronto-parietal multisensory neurons control movements of the head, arm and hand towards or away from nearby objects (Cooke et al., 2003; Graziano et al.,2002). In humans, auditory or visual stimuli presented in the peripersonal space modulate the excitability of the hand representation in the motor cortex (Serino et al., 2009; Avenanti et al., 2012). Indeed, when we perform an action, the motor system needs to compute target positions relative to head or hand. Thus, peripersonal space is a multisensory-motor interface that may serve to encode the position of sensory stimuli to generate goal directed action toward objects within the reaching distance (di Pellegrino & Ladavas, 2015; de Vignemont & Ianetti, 2015). As body schema, also peripersonal space is highly modulated by several action-dependent manipulations. Far space becomes included into the peripersonal space after tool-use manipulation (Maravita & Iriki, 2004; Farnè & Ladavas, 2000). Moreover, near space representation is contracted when participants perform action while wearing weights applied to their wrist (Lourenco & Longo, 2009). Thus, the possibility to act in space is critical for the construction of both body and space representations.

Setting out from these premises, in the present study, we hypothesized that body schema and peripersonal space extent depend on the experience of controlling the course of events in space through one's own actions.

In cognitive neuroscience, the sense of controlling one's own motor acts and, through them, the events in the external environment, has been termed sense of agency (Haggard, 2017; Haggard & Chambon, 2012). By definition, the sense of agency depends on the mental association between an intentional action and its sensory outcome. Thus, while sense of agency begins with the sensorimotor experience of controlling one's own body, humans can learn new contingent associations between movements and outcome, transferring a sense of agency from one's own limb to objects or events, external to the body. Several studies have shown that it is possible to retain a sense of agency over an external object without necessarily perceive it as

belonging to our body (i.e. the body ownership)(Caspar et al., 2015; Kalckert & Ehrsson, 2012, 2014; Moore et al., 2011). However, although the relationship between body ownership and the sense of agency has been extensively addressed, there are relative few studies that investigate whether and how body schema and peripersonal space may change when we actively control external events through one's own action. Specifically, here we tested the hypothesis that body schema and peripersonal space representations are the consequence of the simple associations between one's own intentional actions and their outcomes occurring in space (i.e., the sense of agency).

Body schema was assessed through the *Forearm bisection task*. In this task, participants are asked to point at their forearm midpoint, a paradigm widely used to assess changes in body metric representation (Sposito et al., 2010; Bolognini et al., 2012; Bartolo et al., 2014). For instance, it has been recently shown that the perceived arm midpoint shifted distally after the active use of the tool, consistent with an increase of the perceived length of the arm representation (Sposito et al., 2006). In the current work, the *Forearm bisection task* was performed before and after the participant's sense of agency over a far virtual hand was manipulated. To this aim, an infrared motion captured device was used to track in real time the participant's hand movements, and control a virtual hand presented on a PC screen placed beyond reachable space. If body schema is sensitive to the experience of controlling far space through one's own actions, we should expect that participants pointed to their forearm midpoint more distally after sensing agency for the far virtual hand. Moreover, given the close functional relationship with body schema (Cardinali et al., 2009), we also tested how peripersonal space changes as a function of agency manipulation. To do so, we measured peripersonal space through a *Reaching distance estimation task* (Bourgeois et al., 2014; Patané et al., 2017; Witt et al., 2005), in which participants were asked to stop a ball, either approaching or withdrawing from them, at a distance at which they thought they could reach it by extending the arm. Since body schema and peripersonal space are functionally linked, we expected that peripersonal space, too, extended following agency manipulation.

5.2 Experiment 1

5.2.1 Methods

Participants

Twenty-four participants (12 females), volunteered for the study (age range= 20-28; mean age= 23.86).

Sample size was determinate a priori by conducting a power analysis using G*Power 3 (Faul et al., 2007) specifying a medium effect size ($\eta^2_p = 0.25$). Within our chosen sample size and effect size, the power ($1-\beta$) was approximately 0.80. Participants were naive to the

experimental hypothesis and had no self-reported history of neurological or psychiatric disease. All, but one, were right-handed, as assessed by Edinburgh Handedness Inventory (Oldfield, 1971). They provided written informed consent to participate in the experiment. All methods, approved by the Ethical Committee of the University of Bologna, were conducted in accordance with the 2008 Helsinki Declaration.

Procedure

Participants were comfortably seated during the experiment in front of a table. They performed a *Forearm bisection task*, in order to assess the sensorimotor representation of the arm length. Participants sat blindfolded with their left and right forearms (from the elbow to fingertips) on the table, positioned at about 30 cm from the midsagittal plane. On each trial (15 in total), they were instructed to indicate, with the left index finger, the midpoint of their right forearm, considering the elbow and the tip of the middle finger as the two extremities. A transparent screen (10.5 cm in height) was placed over the right forearm to avoid tactile feedback. The subjective midpoint was measured with a digital laser meter (Agatec DM100, error ± 3 mm) as the distance between the elbow, corresponding to the 0 mm, and the indicated point.

In addition, peripersonal space was assessed by a *Reaching distance estimation task*. In this task, a small ball (40 mm in diameter), controlled by the experimenter through a linear actuator, moved at constant speed (26,93 mm/s) towards or away from the participants (approaching vs. withdrawing trials). The ball starting position was at 33 cm from the participants' sternum in the withdrawing trials, and at 133 cm in the approaching trials. Participants kept the hands over the table, resting only the wrists over it. They were asked to estimate reaching distance ("stop the ball at the distance you think you can reach it by an extension of your arm"). Participants could fine-tune the ball distance by asking the experimenter to move the ball slightly further or forward. Finally, between trials, they were asked to close their eyes. The task was repeated for 15 trials, counterbalancing approaching and withdrawing trials. To control the ball movement, we used the aforementioned linear actuator (see Figure 5.1). The present linear actuator is operated by a ATmega328P microcontroller with a dedicated firmware; an LCD display was used to report the distance, in millimeters, from the zero-position of the carriage. The drive speed can be adjusted via a potentiometer from 0 to 27 mm/s approximately; two buttons provide forward and backwards motion and a calibration procedure (zeroing) for the machine is performed by a third button. The linear actuator was shielded from view with an opaque barrier to prevent participants from using it as a frame of reference.

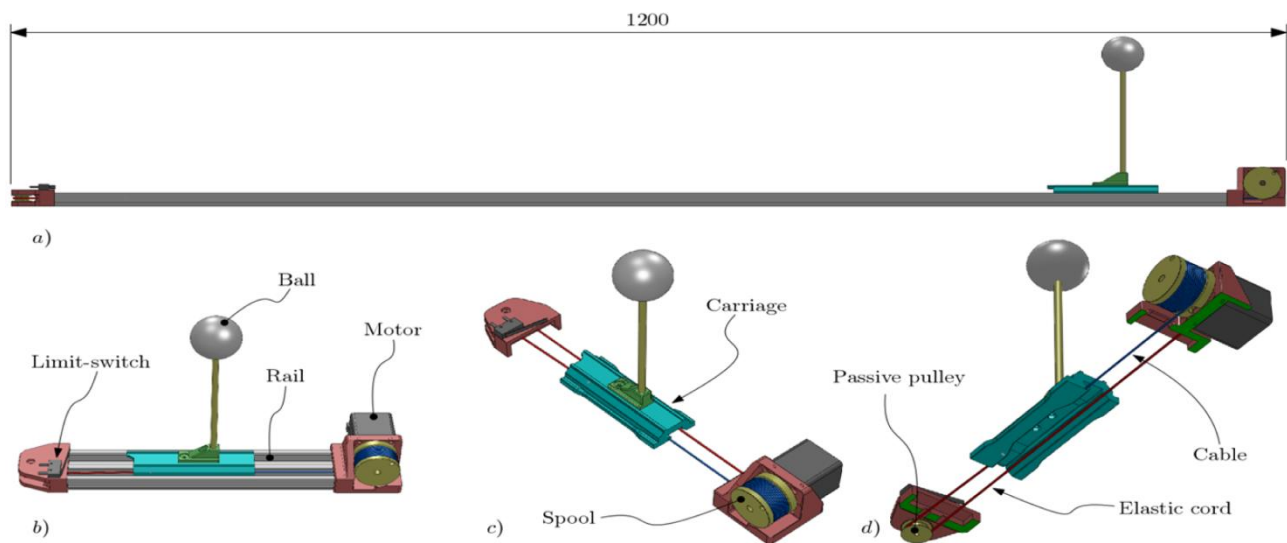


Figure 5.1. The present linear actuator is based on a motorized spool that manoeuvres the carriage by means of a cable and by an elastic element opposite to the cable. When the motor rotates clockwise, the cable is pulled by the spool and this causes the carriage to move in the direction of the motor and the elastic cord is placed into tension. When the rotation of the motor is reversed, the cable is slowly released from the spool, and the tensioned elastic cord provides the force for the carriage to move away from the motor. This type of linear actuator was used mainly for safety reasons: it is a passively safe device, since the only force produced directly towards the participant is given by the elastic cord, and not by the motor itself.

In a) a side view of the apparatus is shown; in b) a reduced length version is shown for clarity; in c) the same short version is shown, this time without the rails, in order to show the complete carriage and part of the cable and elastic cord which drive it; in d) the same version is shown from under the top plane: a cross-section (shown in green) was executed in the illustration to show the passive pulley and the complete path of the cable and elastic cord

The order of two tasks was counterbalanced across participants, who performed them twice, before and after a 15 minutes training aimed at experiencing a sense of agency for a 3D virtual hand. An infrared motion capture device, i.e. leap motion controller, which tracked in real time the participant's hand movement, was used to control the 3D virtual hand presented on a PC screen placed at approximately 140 cm from the participants' sternum. Leap motion controller (Weichert et al., 2013) is an infrared motion capture device designed for hand tracking in virtual reality, consisting of two cameras and three infrared LEDs. Thanks to its wide-angle lenses (the field of view is 150° wide and 120° deep), the device has a large interaction 3D space of eight cubic feet. Both the leap motion controller and the screen were connected to a PC, such that when participants moved their right hand, a virtual hand, projected on the screen, moved synchronously with the participant's real right hand (See Figure 5.2 A). At the beginning of the leap motion training, participants were asked to watch the screen and to raise their right arm in order to perform a game. Participants were instructed to virtually grasp objects and make precision grip by controlling the virtual hand (See Figure 5.2B). We

positioned a barrier on the table, along the participant's right shoulder, to hide both the participant's real hand and the leap motion controller.

A

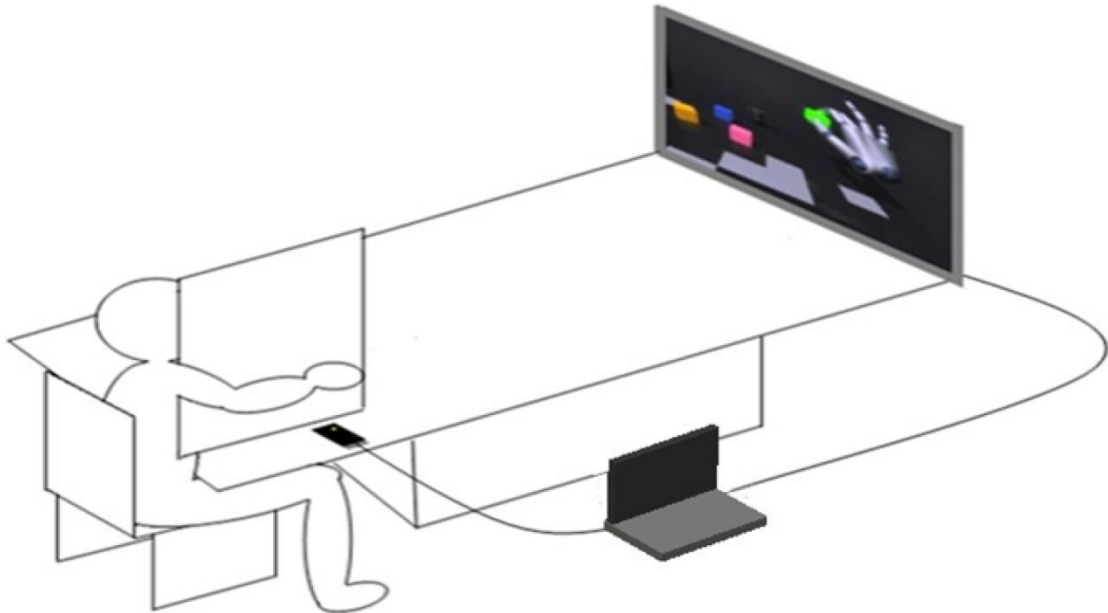


Figure 5.2. (A) Leap motion training: we placed a leap motion controller near the palm of the right hand and a screen at approximately 140 cm from the participants' sternum. Both the leap motion controller and screen were connected to a PC, so that leap motion controller was used to track in real time the participant's hand movements in order to control a 3D virtual hand projected on the screen. (B) Screenshots of two tasks performed by participants during leap motion training (V2 Playground app).

The training consisted of two timing conditions: synchronous and asynchronous visual feedback. In the synchronous condition, participants were shown virtual hand movements responding in real time to their own right hand movements. In the asynchronous condition, 3-second delay was interposed between the participant's real hand and the virtual hand

movements. The order of the synchronous and asynchronous conditions was counterbalanced across participants, who performed both in two different days.

At the end of the experimental session, participants were asked to complete a 12-statements questionnaire to assess the ownership and agency sensed over the 3D virtual hand, using a 7-point Likert scale ranging from -3 (strongly disagree) to 3 (strongly agree). Three statements referred to the feeling of ownership, and three statements described sensations related to agency. The remaining six statements served as control for suggestibility, task compliance and expectancy effect, and were adapted from previous studies (Kalckert & Ehrsson, 2012; 2014) Three statements served as control for ownership and three for agency (See Table 5.1).

Category	
Ownership	I felt as if I was looking at my own hand
	I felt as if the virtual hand was part of my body
	I felt as if the virtual hand was my hand
Ownership control	It seems as if I had more than one right hand
	It felt as if I had no longer a right hand, as if my right hand had disappeared
	I felt as my real hand was turning virtually
Agency	I felt as if I could cause movements of the virtual hand
	I felt as if I could control movements of the virtual hand
	The virtual hand was obeying my will and I can make it move just like I want it
Agency control	I felt as if the virtual hand was controlling my will
	It seemed as if the virtual hand had a will of its own
	I felt as if the virtual hand was controlling me

Table 5.1 Statements used in the questionnaire

5.2.2 Results

For each task, a repeated measure ANOVA was performed on the mean distances, with Timing (Synchronous and Asynchronous conditions) and Session (Pre and Post leap motion training) as within-subject factors. Significant interactions were analysed by Newman-Keuls post-hoc test.

In the *Forearm bisection task*, the ANOVA showed a main effect of Session ($F_{1,23} = 12.38$; $p < .005$; $\eta^2_p = .34$) and, crucially, a significant interaction between Timing and Session ($F_{1,23} = 10.72$; $p < .005$; $\eta^2_p = .31$). Post hoc tests indicated that the interaction was driven by the fact

that, following leap motion synchronous training, participants indicated the subjective forearm midpoint more distally as compared to the pre-training (214 vs. 233 mm; $p < .001$).

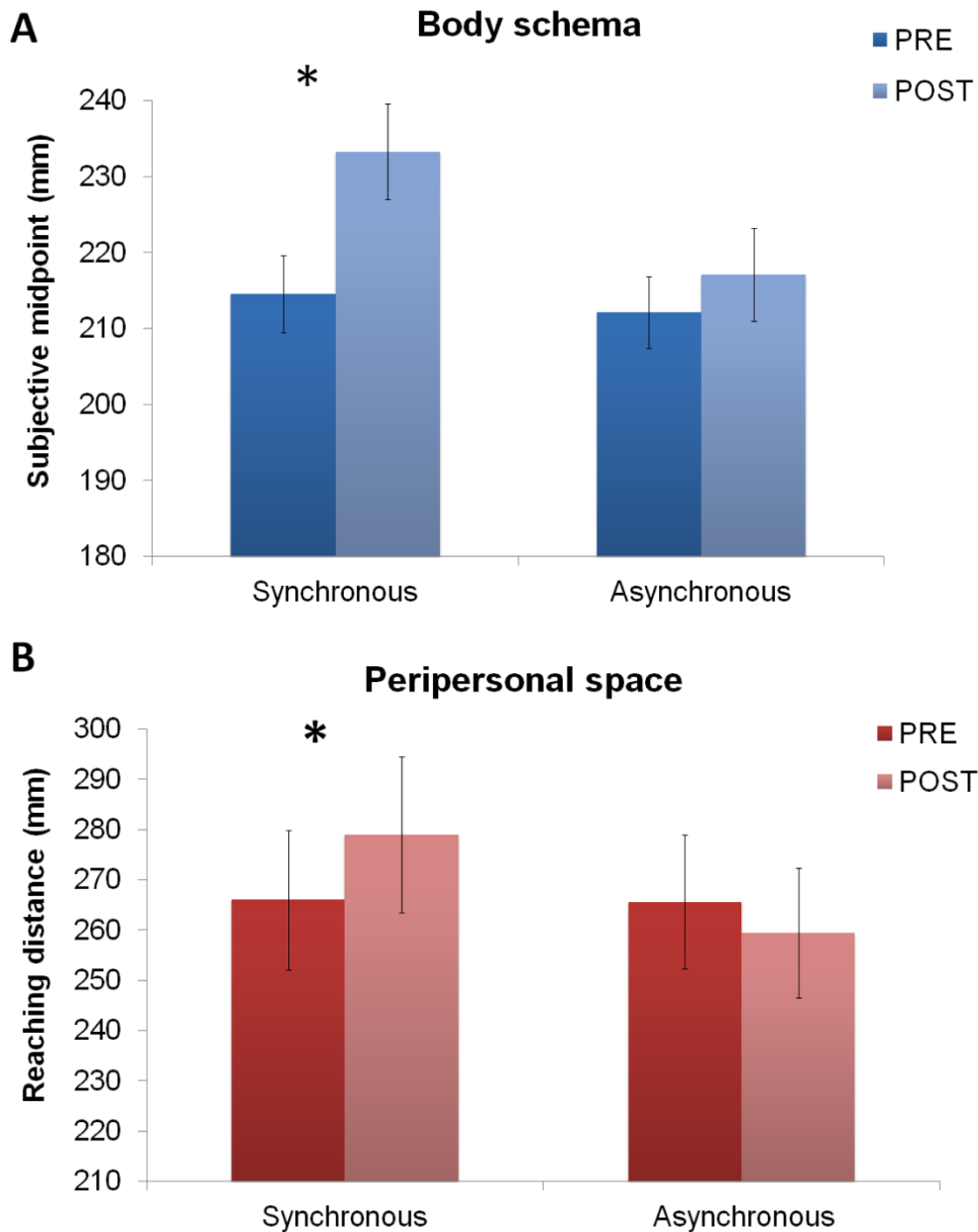


Figure 5.3. Effects of leap motion training with the virtual hand presented farther forward than actual hand location (A) Effects of leap motion training on forearm bisections. The graph shows the statistical comparison of mean distances from the elbow to the indicated forearm midpoint (in mm) as a function of Timing condition (Synchronous and Asynchronous leap motion training) and Session (Pre and Post leap motion training). Asterisk indicates a significant difference in forearm bisections between pre and post leap motion synchronous training. Error bars indicate standard error of the mean. (B) Effects of leap motion training on the Reaching distance estimation task. The graph shows the average reaching distance (in mm) as a function of the Timing condition (Synchronous and Asynchronous leap motion training) and Session (Pre and Post leap motion training). Asterisk indicates a significant difference in the reaching judgments between pre and post synchronous leap motion training. Error bars indicate standard error of the mean.

In contrast, there was no significant difference in the subjective midpoint estimates between pre and post leap motion asynchronous training (212 vs. 217 mm; $p = .23$; See Figure 5.3A). In the *Reaching distance estimation task*, the ANOVA revealed an interaction between Timing and Session ($F_{1,23} = 9.07$; $p < .05$; $\eta^2_p = .28$). Post hoc test showed that the reaching distance was significantly extended after, as compared to before, the leap motion synchronous training (266 vs. 279 mm; $p < .01$). In contrast, the mean reaching distance was not significantly different between pre and post leap motion asynchronous training (265 vs. 259 mm; $p = .23$; See Figure 5.3B).

Since peripersonal space and body schema are not completely interdependent constructs, as they can dissociate in some circumstances (Bassolino et al., 2014), we tested whether the observed effect in one task predicted the observed effect in the other task. Thus, we conducted an ANCOVA on the forearm midpoint estimates prior and following synchronous training, with Session (Pre and Post) as a within factor. To control for the influence of peripersonal space, we entered the difference between post and pre reaching distance in the synchronous condition as a covariate in the analysis. Crucially, the difference in forearm midpoint estimates between pre and post synchronous training remained significant, even when controlling for the effect on peripersonal space ($F_{1,22} = 22,92$; $p < .00005$; $\eta^2_p = .51$), thereby suggesting some degree of functional separation between body schema and peripersonal space representation.

In order to assess the sense of agency and ownership for the virtual hand, we computed a mean score from each of the three ownership statements, and a mean score from the three agency statements. Similarly, we computed average scores of the corresponding control statements. In this way, four single scores were computed: “Ownership”; “Agency”; “Ownership control” and “Agency control”. We interpreted a category as rated positively, or affirmed, when the average score was equal or higher than +1, indicating that at group level, the participants affirmed the experience of ownership or agency (this criterion has been used before (Kalckert & Ehrsson, 2012;2014; Ehrsson et al., 2004). Because Shapiro-Wilk test showed that the questionnaire data were not normally distributed ($p > .05$), we used the non-parametric Wilcoxon test for pairwise comparisons.

The average score was higher than +1 only for “Agency” in the synchronous condition (Average: 2.4). The “Agency” category in the synchronous condition was significantly different from its control category (“Agency control”, $Z = -4.345$; $p < .0001$), and from “Agency” in the asynchronous condition ($Z = -3.526$; $p < .001$), suggesting that participants experienced agency only during the training in which their own hand’s and virtual hand’s movements were synchronized (See Figure 5.4). Moreover, in the synchronous condition, there was also a significant difference between agency and ownership ratings ($Z = -3.86$; $p < .001$), indicating that participants affirmed more strongly agency statements than ownership statements.

Although “Ownership” category was not positively affirmed (Average: 0.71) in the synchronous condition, it was significantly different both from its control category ($Z = -3.21$; $p < .005$) and from “Ownership” in the asynchronous condition ($Z = -3.77$; $p < .005$).

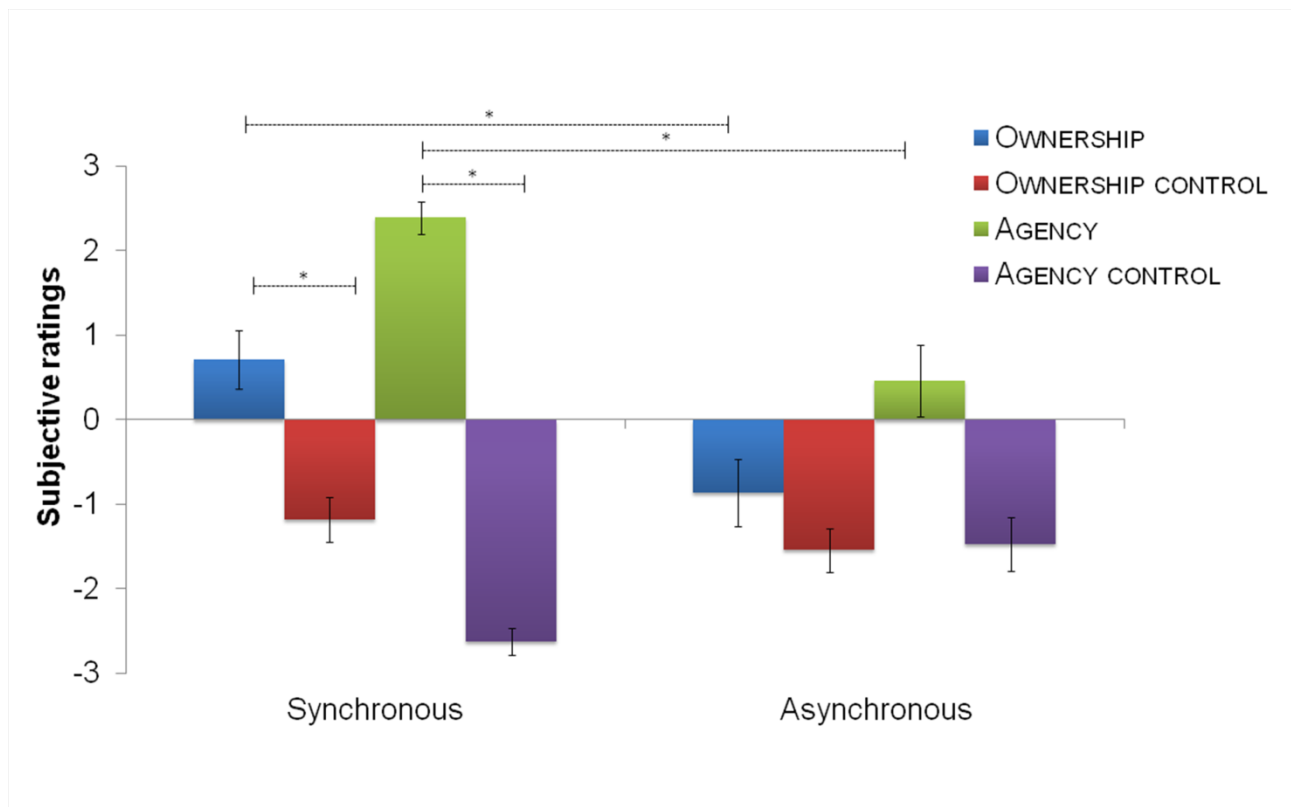


Figure 5.4. Subjective ratings of agency and ownership of the virtual far hand. The graph shows the average ownership, ownership control, agency, agency control ratings on a 7-point Likert scale as a function of the Timing condition (Synchronous and Asynchronous). Sense of agency was present in the Synchronous condition (>1). In contrast, sense of ownership was not positively affirmed. Asterisk indicates that agency category score (the mean of the three statements related to agency) was significantly greater than its respective control category in the synchronous condition, and greater in the synchronous than asynchronous condition. Error bars indicate standard error of the mean.

Finally, we examined the influence of agency and ownership ratings on the effects found on body schema and peripersonal space after synchronous training. Thus, two ANCOVAs for each task were performed with Session (pre and post) as within-subjects factor. To control for the influence of the agency and ownership sensed for the virtual hand, we entered first “Agency” and then “Ownership” category scores as covariates in the analyses. In the *Forearm bisection task* and *Reaching distance task*, the difference between pre and post synchronous training in the forearm midpoint ($F_{1,22} = 1.63$; $p = .21$; $\eta^2_p = .070$), and reaching distance estimates ($F_{1,22} = 6.04$; $p < .05$; $\eta^2_p = .21$), respectively, were no longer significant after controlling for the “Agency” ratings. By contrast, the difference between pre and post forearm midpoint estimates ($F_{1,22} = 10.86$ $p < .005$; $\eta^2_p = .331$), and between pre and post reaching distances ($F_{1,22} = 0.51$; $p = .48$; $\eta^2_p = .23$), remained significant even after controlling for the influence of the “Ownership” scores, thereby suggesting that sense of agency, rather than ownership, plays a

critical role in mediating the effect of synchronous training on body schema and peripersonal space representations.

In sum, the main purpose of the Experiment 1 was to investigate whether the sensorimotor representation of the body can be modulated by manipulating agency sensed over an external object. The results showed that participants experienced agency, explicitly assessed through a questionnaire, over a virtual hand that moved synchronously with their own hand movements. Crucially, experiencing agency for the virtual hand, projected in far space, significantly extended the representation of the arm. On the contrary, when virtual hand and participants' hand movements were asynchronous, and participants did not report any sense of agency at the questionnaire, no significant modulation of the body schema was found. Moreover, as hypothesized, peripersonal space followed the same trend of results. Participants showed a significant enlargement of peripersonal space, as assessed by the reaching distance estimation task, only in the synchronous condition, when they reported agency over the virtual hand. In contrast, after asynchronous condition, participants did not affirm agency for the virtual hand and any significant modulation of peripersonal space was found. Rather, our results suggest that body schema and peripersonal space are sensitive to the experience of controlling the course of events in space thought one's own action. When participants controlled the virtual hand by moving their own hand, limb movements and their outcomes occurred synchronously but in different spatial positions. We speculate that the spatial mismatch between intentional movements and outcomes leads to the updating of the dimension of both body schema and peripersonal space. To further test this hypothesis we conducted Experiment 2 aimed to reveal the opposite modulation of Experiment 1, presenting the virtual hand behind the participant's real hand, and closer to the subjects' body than the real hand. Accordingly, when outcomes of the action are closer to the body than the action itself, we should find a contraction of both body schema and peripersonal space.

5.3 Experiment 2

5.3.1 Methods

Participants

A new sample of twenty-four participants (12 females), volunteered for the study (age range = 20-28; mean age = 22.37). Participants were naive to the experimental hypothesis and had no self-reported history of neurological or psychiatric disease. All but two were right-handed, as assessed by Edinburgh Handedness Inventory. They provided written informed

consent to participate in the experiment. All methods, approved by the Ethical Committee of the University of Bologna, were conducted in accordance with the 2008 Helsinki Declaration.

Procedure

In Experiment 2, participants performed the *Forearm bisection task*, to assess body schema modulation, and the *Reaching distance estimation task*, to assess peripersonal space, before and after 15 minutes of synchronous and asynchronous leap motion training to modulate sense of agency for the 3D virtual hand.

The experimental procedure was identical of Experiment 1, with the exception of the distance at which the virtual hand was presented during the training. The PC screen, in which the virtual hand was projected, was placed at approximately 14 cm from the participant's sternum. Also in Experiment 2, participants performed both synchronous and asynchronous training. The order of two timing conditions was counterbalanced across participants, who performed both in two different days. At the end of the experimental session, participants were asked to complete a 12-statements questionnaire to assess the ownership and agency experienced in relation to the 3D virtual hand.

5.3.2 Results

In the *Forearm bisection task*, an ANOVA with Timing (Synchronous and Asynchronous conditions) and Session (Pre and Post leap motion training) as within-subjects factors, showed a main effect of Session ($F_{1,23} = 11.45$; $p < .003$; $\eta^2_p = .33$) and, crucially, a significant interaction between Timing and Session ($F_{1,23} = 18.65$; $p < .0003$; $\eta^2_p = .44$). Post hoc tests indicated that the interaction was driven by the fact that, following leap motion synchronous training, participants indicated the subjective forearm midpoint more proximally as compared to the pre-training (220 vs. 198 mm; $p < .0003$). In contrast, there was no significant difference in the subjective midpoint estimates between pre and post leap motion asynchronous training (216 vs. 219 mm; $p = .44$; See Figure 5.5A).

In the *Reaching distance estimation task*, the ANOVA revealed an interaction between Timing and Session ($F_{1,23} = 23.30$; $p < .0001$; $\eta^2_p = .50$). Post hoc test showed that the reaching distance was significantly reduced after as compared to before leap motion synchronous training (226 vs. 250 mm; $p < .0001$). In contrast, the mean reaching distance was not significantly different between post and pre leap motion asynchronous training (245 vs. 245 mm; $p = .95$; See Figure 5.5B).

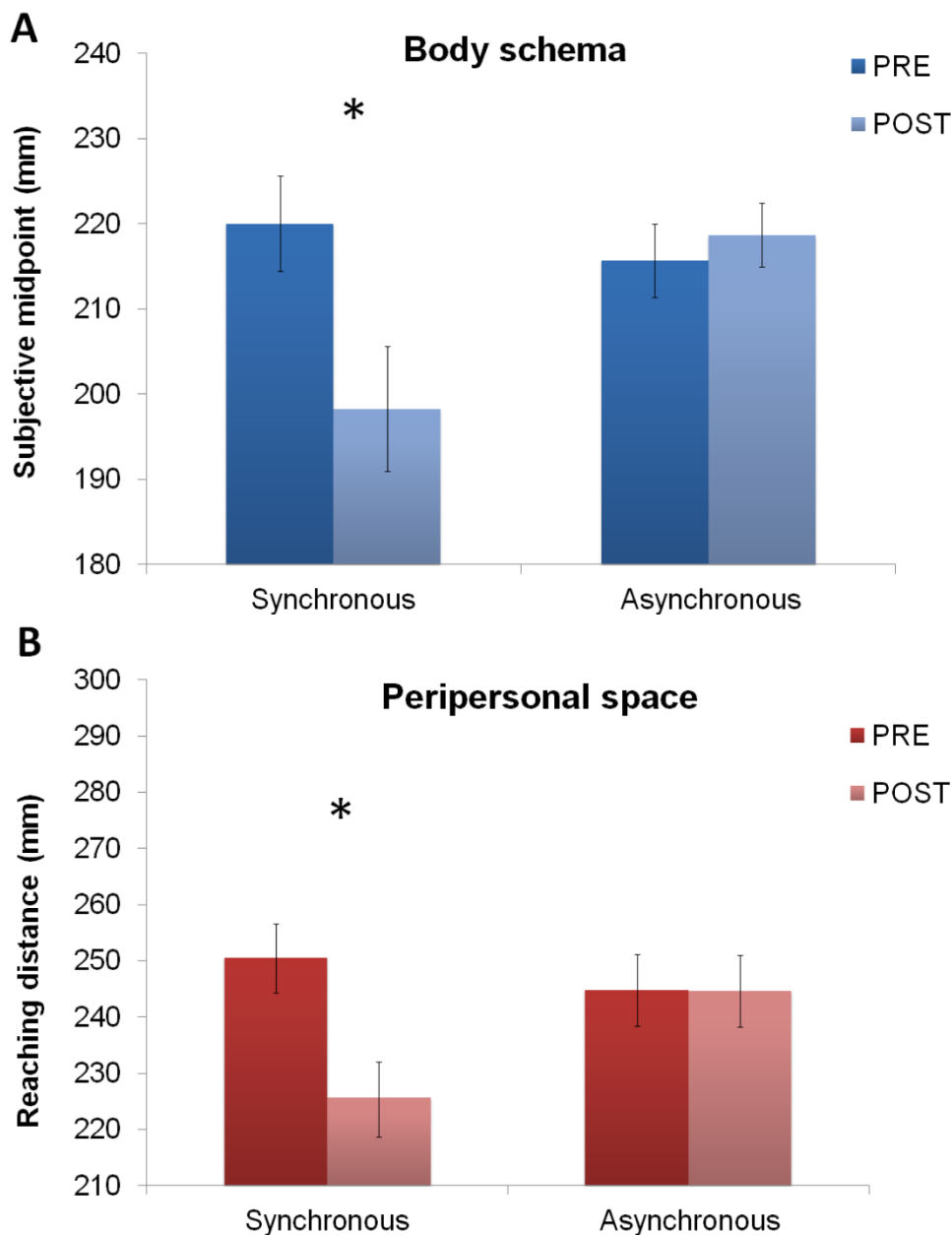


Figure 5.5. Effects of leap motion training with the virtual hand presented closer to the participants than actual hand location (A) Effects of leap motion training on Forearm bisections. The graph shows the statistical comparison of mean distances from the elbow to the indicated forearm midpoint (in mm) as a function of the Timing condition (Synchronous and Asynchronous leap motion training) and Session (Pre and Post Leap motion training). Asterisk indicates a significant difference in forearm bisections between pre and post leap motion synchronous training. Error bars indicate standard error of the mean. (B) Effects of leap motion training on the Reaching distance estimation task. The graph shows the average reaching distance (in mm) as a function of the of the Timing condition (Synchronous and Asynchronous leap motion training) and Session (Pre and Post Leap motion training). Asterisk indicates a significant difference in the reaching judgments between pre and post synchronous leap motion training. Error bars indicate standard error of the mean.

Also for the Experiment 2, we tested whether the observed effect on reaching space predicted the observed effect on the body schema. We performed an ANCOVA on the forearm midpoint with Session (Pre vs. Post) as within-subjects factor and the difference between post and pre reaching distance in the synchronous condition, as a covariate. Crucially, also in Experiment 2,

there was still a significant difference in the subjective midpoint estimates between pre and post synchronous training ($F_{1,23} = .310$; $p < .05$; $\eta^2_p = .310$), even after taking into account the effect on the reaching space as a covariate

Questionnaire data, analysed as in Experiment 1, showed that the average score was higher than +1 only for “Agency” in the synchronous condition (Average: 2.09). The “Agency” category in the synchronous condition was significantly different from its control category (“Agency control”, $Z = -4.20$; $p < .00001$) and from “asynchronous Agency” ($Z = -4.11$; $p < .00001$), suggesting that participants experienced agency only during the training in which their own hand’s and virtual hand’s movements were synchronous (See Figure 5.6). Moreover, in the synchronous condition, there was also a significant difference between “Agency” and “Ownership” ratings ($Z = -4.28$; $p < .0001$), indicating that participants affirmed more strongly agency statements than ownership statements.

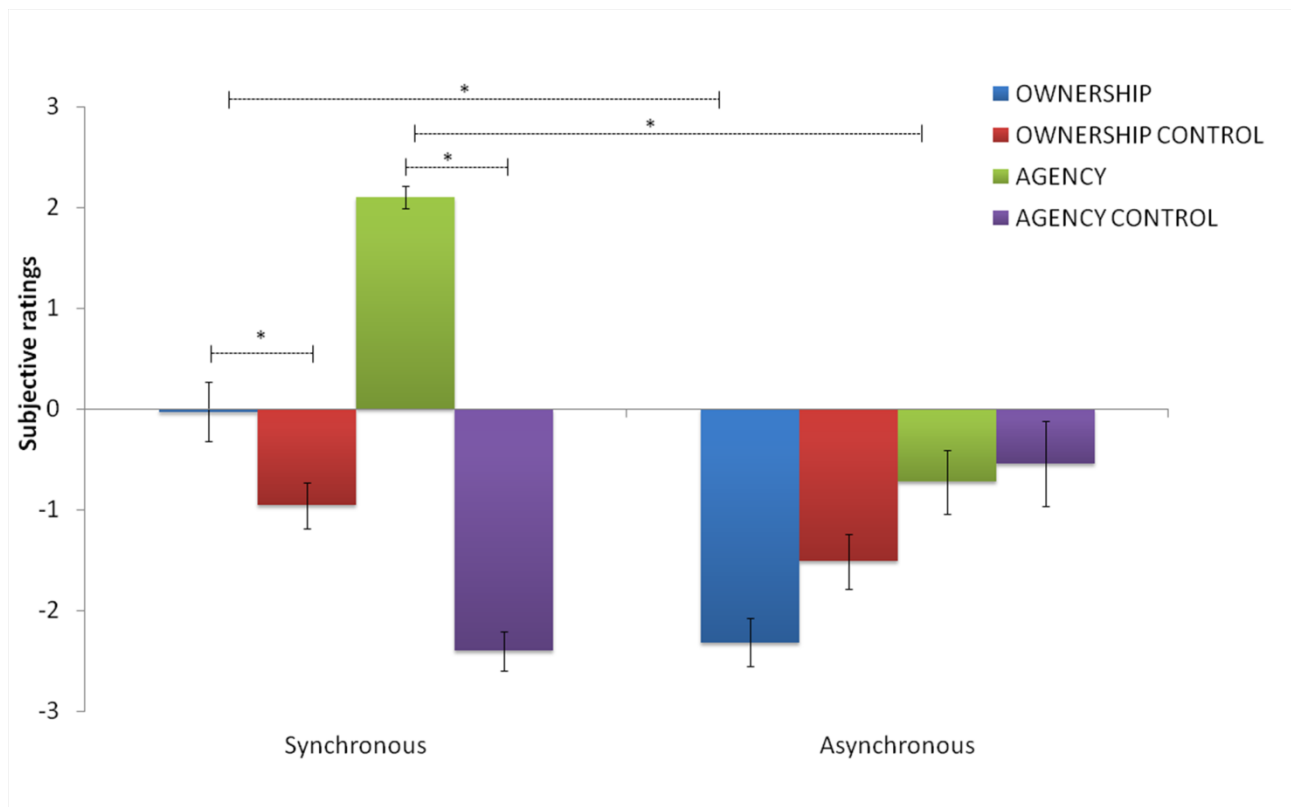


Figure 5.6. Subjective ratings of agency and ownership of the virtual near hand. The graph shows the average ownership, ownership control, agency, agency control ratings on a 7-point Likert scale as a function of the Timing condition (Synchronous and Asynchronous). Sense of agency was present in the Synchronous condition (>1). In contrast, sense of ownership was not positively affirmed. Asterisk indicates that agency category score (the mean of the three statements related to agency) was significantly greater than its respective control category in the synchronous condition and greater in the synchronous than asynchronous condition. Error bars indicate standard error of the mean.

Also this time, “Ownership” category was not positively affirmed (Average: - 0.02) in the synchronous condition, but it was significantly different both from its control category ($Z = -2.02$; $p = 0.04$) and from “Ownership” in the asynchronous condition ($Z = -3.28$; $p < .05$).

Thus, also in the Experiment 2, we examined the influence of “Agency” and “Ownership” ratings on body schema and peripersonal space changes after synchronous training with a virtual hand. Thus, we performed two ANCOVAs for each task, with Session (pre and post) as within-subjects factor. We entered first “Agency” and then “Ownership” category scores as covariates in the analysis.

As in Experiment 1, in the *Forearm bisection task* and *Reaching distance estimation task*, the difference between pre and post synchronous training in the forearm midpoint ($F_{1,22} = 0.529$; $p = .47$; $\eta^2_p = .023$), and in the reaching distances ($F_{1,22} = 2.84$; $p = .10$; $\eta^2_p = .11$), respectively, failed to reach significance after controlling for the “Agency” scores. By contrast, the difference between pre and post forearm midpoint estimates ($F_{1,22} = 17.52$ $p < .0005$; $\eta^2_p = .44$), and between pre and post reaching distances ($F_{1,22} = 24.95$; $p < .005$; $\eta^2_p = .51$), remained significant even after controlling for the influence of the “Ownership” scores.

Experiment 2 shows that it is possible to induce a contraction of both body schema and peripersonal space, presenting the virtual hand, over which participants experienced agency, behind their real hand. After experiencing agency for the virtual hand, participants indicated their forearm midpoint more proximally, as if their arm was shorter. In the same way, participants showed a significant reduction of peripersonal space, as assed by the *Reaching distance estimation task*, only in the synchronous condition, when they reported agency over the virtual hand.

5.4 Discussion

In the present study, we induced changes in the extent of body schema and peripersonal space by manipulating the sense of agency over an external object. As recently suggested, to retain a vivid sense of agency, three conditions need to occur: first an internal volition that provides an experience of intentional action, second the occurrence of a body movement and third the external outcome of the action (Khalighinejad & Haggard, 2016). Humans, and other primates, can learn and exploit new intention-movements-outcome associations, transferring a sense of agency from one’s own limb to objects or events, external to the body (Kalckert & Ehrsson, 2012;2014; Caspar et al.,2015; Moore et al.,2011; Iriki et al.,2001; Heyes, 2012).

Experiment 1 showed that the sense of agency for a virtual hand projected in the far space extends both the body schema and peripersonal space, reproducing plastic modulations similar to those classically found after tool use. These results suggest that body schema and

peripersonal space are concurrently modulated when agents establish new intention-movements-outcome associations to control events in the external environment through one's own actions. Experiment 2 further supported this hypothesis by revealing, a concurrent contraction of both body schema and peripersonal space in healthy participants, when the virtual hand was presented closer to the body than their real hand. Moreover, participants, at the group level, did not rate positively ownership statements for the virtual hand. On the contrary, agency statements were strongly affirmed. This is in line with previous work (Kalckert & Ehrsson, 2012;2014; Caspar et al., 2016) showing that sense of agency is partially dissociable from body ownership, and it is possible to retain a sense of agency over an external object without necessarily perceive it as belonging to our body. In Kalckert and Ehrsson (2012;2014), for instance, the dissociation between body ownership and agency was investigated by using a modified version of the rubber hand illusion. In the classical rubber hand illusion (Botvinick & Cohen, 1998), touching a fake hand in synchrony with participant's hand induces participants to perceive the rubber hand as part of their body. In Kalckert and Ehrsson version (2012,2014), the participant's index finger was connected to the rubber hand's finger by a wooden stick. Thus, when participant moved his or her index finger, the rubber hand's finger moved synchronously with respect to the participant's movement. Crucially, when the rubber hand was placed in far location, or in an anatomical incongruent position with respect to the participant's real hand, participants still reported a clear feeling of agency for the fake hand, even if they did not have anymore the illusion that the fake hand belonged to their body, as in the classical rubber hand illusion. Indeed, different studies with the rubber hand illusion have showed that the strength of the ownership illusion is constrained by the anatomical characteristic and spatial reference frames of the limb (Lloyd, 2007; Makin et al., 2008; Preston, 2013). Note, however, that since in the current study we do not have implicit physiological measure of body ownership, we cannot completely rule out the possibility that participants did not experience ownership for the virtual hand. In fact, a significant difference in ownership ratings was found between synchronous and asynchronous conditions. Nevertheless, our findings show that, when agency ratings were added as covariates, pre and post synchronous training differences in forearm midpoint and reaching distance estimates were no longer apparent, providing support in favour of our hypothesis that the sense of agency, rather than the sense of ownership, plays a major role in the construction of body schema and peripersonal space representations.

This conclusion is in line with a relatively recent study demonstrating that the (illusory) ownership of a long or short arm *per se* is not enough to rescale distances in space (Linkenauger et al., 2015). Linkenauger et al. (2015), by using virtual reality technology, induced in participants the illusion of having a long or short virtual arm. They found that the distances to targets appeared closer when their virtual arm was long, compared to when their

virtual arm was short, but only following a reaching experience. Crucially, modulations in space perception only occurred after participants actively performed reaching movements, thereby receiving sensory feedback from those movements.

This finding nicely fits with the results of present study. In both experiments, indeed, body schema and peripersonal space were updated when the consequences of the action occurred synchronously with participant's movements, but in a different spatial position than expected, based on the actual hand position. This spatial mismatch caused a modulation in body schema and peripersonal space, suggesting that these representations emerge from the precise and dynamic mapping between intentional body movements and their outcomes in space. It is therefore plausible to hypothesize that modulations of body schema and peripersonal space similar to those observed here could be found when agents control a virtual or physical object that is not hand-shaped, or not related to the body at all. This is an interesting experimental question that future studies could address.

Body schema provides proprioceptive and somatosensory information about the body morphology during action planning and execution. Theories of motor control and agency suggest that the brain uses internal models and representations to ensure accurate control of movement (Wolpert et al., 2001). According to these views, when a motor command is issued, a "forward model" (or "internal predictive model") of the moving body estimates the sensory consequence of the action (Blakemore et al., 2000). Sensory information about the body and the environment is then compared with the actual sensory feedback of the action. The result of this comparison is known as prediction error. It is possible to assume that when intentional body movements and their consequences occur synchronously but in different spatial positions, a prediction error is generated. Body schema updating, therefore, reflects the need to achieve control over the body (i.e. an effector) and the environment, minimizing prediction error (Friston, 2010; Friston et al., 2013).

It has been theorized and empirically demonstrated, indeed, that forward models predict similar sensory consequences for actions involving a tool, and natural hand movements. In a recent study, it has been found that the predictive attenuation of touch, observed when people touch their hand with the other, is also observed for touches applied with a hand-held tool (Kilteni & Ehrsson, 2017). Thus, it is possible to assume that the forward model takes into account in its predictions not the location of a body part *per se* but rather the location of the current effector, i.e. the tip of the tool during tool use in the aforementioned study or, in our case, a virtual object controlled at distance.

Likewise, peripersonal space is fundamentally a working space used to compute arm and nearby objects positions in order to plan and execute actions. This sector of space is coded by multisensory neurons in the fronto-parietal areas with a tactile receptive field centred on different body parts and a visual and/or an auditory receptive field (di Pellegrino & Ladavas,

2015), partially overlapping with the tactile one. Stimuli from different sensory modalities occurring on or close to the body, are integrated to provide a working space to act on nearby objects (i.e., peripersonal space). In the present study, like body schema, peripersonal space size was updated when hand movements and visual stimuli occurred synchronously but in different spatial positions.

Incidentally, although we highlighted that body schema and peripersonal space show similar plastic effects, we do not claim that they are completely overlapping functional constructs. Indeed, after controlling for the influence of training on peripersonal space, modulations of body schema were still evident. Together with previous evidence (Bassolino et al., 2015), this suggests that plastic changes of body schema and peripersonal space rely, at least in part, on separate mechanisms.

The current findings on peripersonal space are in agreement with previous evidence showing an extension of peripersonal space by using synchronous audio tactile stimuli. Specifically, Serino et al. (2015) found that peripersonal space was enlarged after synchronous audio-tactile training, in which hand-tactile stimuli and auditory-far stimuli were simultaneously presented. According to Serino et al.(2015) multisensory areas, capturing the synchronicity between the tactile stimulus at the hand and an auditory (or visual) stimulus in the far space, associated the two stimuli, as if they occurred from a functionally equivalent sector of space. However, in Serino et al.(2015), participants passively received tactile stimuli on their hand, whereas in the present study participants actively moved their hand, receiving proprioceptive information, and simultaneously perceived a visual stimulus that synchronously responded to their movements in a different position. The current study, therefore, highlights the importance of intentional action to actively create associations between different stimuli occurring in space. The mere occurrence of proprioceptive and visual stimuli *per se*, indeed, is not sufficient to induce changes in body schema and peripersonal space, as demonstrated by the absence of effects in the asynchronous condition. Rather, these changes occur only when the visual stimulus movements followed closely hand movements, i.e., in a strict temporal contiguity (synchronous condition), causing the emergence of a sense of agency over the external event.

It is well known, indeed, that sense of agency depends on processes of temporal associations between an action and its effect. It is possible that in Serino et al.(2015) participants developed an implicit sense of agency for the far auditory outcomes, following the audio-tactile training. However, this possibility was not explored in their study.

To sum up, collectively Experiment 1 and Experiment 2 suggest that the experience of controlling external events through one's own actions is crucial for determining both body schema and peripersonal space extent. This finding opens a new venue into the interpretation of the relationship between body schema, peripersonal space and action. However, future research is needed to understand what are the precise neurocognitive computations involved

in controlling an external object, and dynamically updating space and body representations. These findings could have several implications in the field of brain-machine interfaces (Marchesotti et al., 2017; Lebedev & Nicolelis, 2017) that enable, through real time decoding of neural signals, the control of external devices, from robotic arms to virtual avatars.

Outlooks

“Into our mental lives there entered a dramatic quality of open-endedness, an essentially unlimited extensibility, as compared with a very palpable limitedness in other species.

Concepts in the brains of humans acquired the property that they could get rolled together with other concepts into larger packets, and any such larger packet could then become a new concept in its own right. In other words, concepts could nest inside each other hierarchically, and such nesting could go on to arbitrary degrees. This reminds me — and I do not think it is a pure coincidence — of the huge difference, in video feedback, between an infinite corridor and a truncated one.”

Douglas Hofstadter (2007)

In the incipit of the thesis, I said that the self is a hierarchical construct containing both low level sensorimotor representations and social and interpersonal representations. The studies in this thesis showed a dynamic interaction between bodily self representation and sociocognitive processes. The first study, in Chapter II, showed that the illusion of having an invisible body reduces the social interpersonal space without affecting the reaching space. In a control experiment, the active use of a tool extended the perceived reaching space without affecting social interpersonal space. We discussed that the experience of invisibility may induce participants to feel themselves more protected and shielded during the confederate’s approach, leading to a contraction of the space in which participants felt most comfortable with the other proximity. Thus, knowing whether one is the recipient of a gaze can be decisive in a social interaction and experiencing one’s own body as invisible may affect the social consequences of being looked at. In particular, the experience of invisibility may affect the manner in which the brain processes the attention of others toward the self (Guterstam et al., 2015). The study in Chapter III, demonstrated that this could happen because the experience of invisibility directly affect the perception of gaze, reducing the range of gaze directions over which participants perceived to be looked at. Thus, the perceived body appearance seems to play a key role in the interpersonal attitudes and beliefs. The dynamic interaction between bodily self and interpersonal attitude is further supported by the study in Chapter IV in which a manipulation in body height revealed a dissociation in social interpersonal and action peripersonal space. Indeed, body size has an impact both in the social domain and in the action programming. In the social domain, body size and height have been associated with social status and dominance in both animals and humans. Also, a change in body height affect the sensorimotor representation of participant’s arm length, the so called body schema. The term body schema refers to a sensorimotor representation of the body morphology used for planning and executing body movements. Thus an illusory change in body height updated the

representation of participants' arm length, generating new sensorimotor predictions consistent with the new arm representation. This led to an extension of peripersonal space when participants experienced an illusory ownership for a tall body. At the same time, the change in body height may lead participants to feel themselves as more dominant (tall body) or less dominant (short body) in the dyadic interaction with the confederate, leading to an enlargement or contraction of interpersonal space. Collectively these data suggest that while the perceived body appearance plays a key role in emotional and social processing, the body schema is an implicit body representation mainly involved in estimating the sensory consequence of the action (Chapter V). The study presented in Chapter V, indeed, showed that the body schema, concurrently to the peripersonal space, is modulated when agents establish new intention-movements outcome associations to control events in the external environment through one's own action.

Overall these data point toward the idea that the self consists of a layer structure. In this hierarchical layered structure, each layer is highly dynamic and extremely plastic. Moreover, there may be also cross-layer dynamics that operate along different categories of the self. These cross-layer dynamics may be, in part, responsible for both the integrity of the categories and the ambiguity across different categories of self. Future researches are needed to explain the neural and computational principles underlying the dynamic interactions between low level body representation and high level socio cognitive representation of the self.

A proposal could be that a unique characteristic or computational architecture is common to the dynamical processes of each layer. Recently, predictive coding model and free energy principle have emerged as a prominent underlying theories of cortical function to explain brain processes underlying perception and action. The starting premise of the free energy principle is that self-organizing organisms have to resist a natural tendency towards disorder in a constantly changing environment. To do so, the brain avoids surprise associated with sensory states (Friston, 2010), which in turn will result in a desired state where the world is highly predictable. Thus, the brain works as an inference machine that is trying to optimize its own model of the world, by actively predicting the causes of its sensory input (Friston, 2005). In other words, the brain interprets sensory information maintaining probabilistic hypothesis ("generative model") of the hidden causes of sensory input. In this model any mismatch between predicted and actual sensory inputs generates a prediction error. However, cause organisms must maintain themselves in a narrow range of desirable state, prediction errors must be minimized (Brown & Brüne, 2012). In order to "explain away" the prediction error, the brain constantly update its predictions by means of sensory input. At the biological level the free energy framework is biologically constrained by the so-called 'predictive coding' models (Clark, 2013). According to the predictive coding model, there is constant filtering of sensations by top-down (backward or descending) predictions and a parallel updating of the

latter based on prediction error that referred to the level above by bottom-up (forward or ascending) connections. Thus, the result is that minimisation of prediction errors is ensured by recurrent message passing among hierarchical level of cortical systems, so that various neural subsystems at different hierarchical levels minimize uncertainty about incoming information by generating a prediction and responding to errors (Hohwy, 2012).

Recently this framework was extended to the self awareness to explain the malleability of the bodily self (Apps & Tsakiris, 2014; Limanowski & Blankenburg, 2013, 2015). Indeed, as biological organisms are embodied in the environment, the “world- model” of a self-organizing system also has to include the sensory apparatus (the body) of the organism, whereby the self is perceived as a result of dynamic self modelling mechanisms (Limanowski & Blankenburg, 2013). Thus, also one’s own body is processed as most likely to be “me”. The likelihood that one’s own body is “me” is created by the combination of bottom up prediction error generated in unimodal sensory area that are explained away at higher levels of hierarchy (i.e. multisensory area) by top down “predictions” about the body (Apps & Tsakiris, 2014). In the case of bodily illusion, for instance the rubber hand, the somatosensory experience of touch on one’s own hand that is temporally congruent with the vision of touch on the fake hand generates a prediction error from unimodal sensory system. This prediction error will be explained away by top down effects from multisensory areas. In turn, perceptual learning process will update representations of one’s appearance, such that the probabilistic representation of one’s own body is different after synchronous multisensory stimulation.

Future studies could investigate whether the predictive coding model can be adapted also to others categories of self, from the very basic sensorimotor representation of the body (i.e. body schema) to the interpersonal or social self, explaining not only their internal plasticity but also their mutual dynamics. For instance, the study in Chapter V found that body schema and peripersonal space were updated when the consequences of the action occurred synchronously with participant’s movements, but in a different spatial position than expected, based on the actual hand position. This spatial mismatch caused a modulation in body schema and peripersonal space, suggesting that these derive from the precise and dynamic mapping between intentional body movements and their outcomes in space. Now, I speculated that these data are compatible with the predictive coding model. Indeed, when participants moved their arm and watched the virtual hand responding synchronously but in different spatial positions, they generated a prediction error about the position of their hand and the extension of reachable space. To minimize the prediction error, the brain updates its initial model about the position of the limb in space, modulating both the sensorimotor representation of the arm length and the extent of peripersonal space.

The existence of predictions and prediction errors also during an individual's social interaction, may be empirically and intuitively plausible. An implicit expectation about the range of possible responses usually arises in situations in which one individual greets another. At the same time, given the focus of predictive coding on complementary hierarchical top-down and bottom up processes, it's possible that different layers or levels of self representation continuously interact and when a prediction error is left unexplained at one level, it needs to be processed and eliminated at a higher level of the hierarchy, by updating the priors (attitudes and beliefs) held about the self. Thus, the prediction error generated in one layer may result in an updating of that layer but also in adjacent layers.

As previously recalled, several studies showed that people have a prior expectation that other person gaze or attention is directed toward them (Mareschal et al., 2013) [an expectation that could be particularly enhanced in some pathological conditions, such as schizophrenia or social phobia (Jun et al., 2013)]. In studies presented in Chapters II and III, we induced in participants a change in low level perceptual representation of one's own body, that is the illusion of having an invisible body or face. Once that the body appearance is updated, this can create other errors further up in the processing hierarchy. Indeed, the information that one's own body is invisible, may conflict with more higher order representations of oneself and the other. In our case, the experience of invisibility may conflict with the prior expectation that other attention or gaze is directed toward one's own body. Thus, participants updated their prior expectation, reducing the cone of gaze or feeling less discomfort to the other approach.

Moreover, future researches could investigate the neural basis and the cortical areas involved in these cross layer dynamics. As discussed in Chapter I, the bodily self is supported by a fronto-parietal system, involving mainly the premotor cortex and the posterior parietal cortex. At the same time, the cortical midline structure seems to support social and psychological aspects of the mental self. It's possible that several cortical areas may play a unique role in the coordination of functioning across multiple layers. For instance, it has been shown the existence of direct connections between the precuneus (major node of the cortical midline structure) and the inferior parietal lobe (the posterior component of the fronto parietal system), suggesting that this is one pathway by which such interactions might occur (Uddin et al., 2007). On the other hand, it has been proposed that the right lateral prefrontal cortex may have a role in resolving conflicts at different layers. This region, for instance, is activated in detecting sensory-feedback errors during an action (Fink et al., 1999) or when agency-attribution judgment (i.e., self or other) is required. Moreover, this region responds to behavior that violates social norms (i.e., error in the interpersonal layer) (Wakusawa et al., 2009) or when there are discrepancies between a subject's self-evaluation and the evaluation by others. Despite the general appeal that predictive coding models have for researches in the field of body and self awareness, more direct empirical support has to be generated. The results

of this thesis can only be taken as a first preliminary evidence to better understand the hierarchical and dynamical structure of the self. Such challenge should and will be addressed in the near future.

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