Self-Attribution and Telepresence

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Abstract

Anthropomorphically-designed teleoperation systems may result in the phenomenon of telepresence: The experience of being there at the remote site. Yet, there is another aspect to the phenomenon of telepresence, which has received relatively little attention: Self-identification with the slave robot. In this paper, we aim to further explicate the relationship between self-identification (or self-attribution) and telepresence. For this purpose, we will review recent studies that have used the experimental paradigm of the rubber-hand illusion. In this illusion, people attribute a fake hand to themselves; feeling as if it is actually part of their own bodies. We will discuss the perceptual and cognitive mechanisms behind the brain's remarkable capability to incorporate external objects as phenomenological extensions of the self, and discuss how research on (tele)presence and body-representations can benefit from each other.

Keywords--- **Teleoperation systems, multisensory integration, body image, rubber-hand illusion.**

1. Introduction

> *In walking I felt as though I were moving along above the shoulders of the figure below me, although this too was part of myself,—as if I were both Sinbad and the Old Man of the Sea.*
>
> —Stratton, 1899

Teleoperation systems allow people to control and manipulate real-world objects from a remote location by means of advanced media technology. Such systems enable humans to work in hazardous (e.g., nuclear plants) or otherwise demanding environments (e.g., space or undersea exploration). The general components of such systems are the human operator who controls the teleoperation station (i.e., the master system; sometimes called a suit [1]), and a slave robot operating at the remote site. In anthropomorphically-designed teleoperation systems, the human operator can make natural movements to control or steer, for example, the slave robot's arms and head. A series of sensors record the operator's movements which in turn control the slave robot. Sensors at the slave robot provide the human operator with continuous feedback regarding his or her actions. Typically, the teleoperation system allows the human operator a three dimensional view on the remote site by means of a stereoscopic display connected to two cameras attached to the slave robot's head. In addition, the system can be extended with audio and haptic feedback to provide the human operator an even more immersive interaction with the remote site. Anthropomorphically-designed teleoperation systems may result in the phenomenon of telepresence: The experience of being there at the remote site [2], or the experience of being in the location of the slave robot [3].

2. Views from a Robot

Research on telepresence (e.g., [3,4]) has often made reference to Daniel Dennett's thought provoking "where am I?" [5]. In this science fiction story, Dennett describes a rather odd episode in his life. Dennett is asked by Pentagon officials to aid in the recovery of a nuclear warhead a mile underneath Tulsa, Oklahoma. Since the radiation emitted by the warhead would expectedly cause major trauma to brain tissue, they needed a volunteer who would be willing to have his or her brain surgically removed, and while kept alive in a vat, be connected to the body by means of radio technology. This, the scientist at Houston concluded, would allow a person to safely dismantle and recover the warhead. Needless to say, only a philosopher like Dennett would be so compelled by the prospect of experiencing first hand what it is like to have his brain placed in a vat, that he would disregard all concerns for his personal safety. After the surgical procedure, Dennett finds himself looking at his brain in the vat and wondered "Where am I?":

> *"Being a philosopher of firm physicalist conviction, I believed unswervingly that the tokening of my thoughts was occurring somewhere in my brain: yet when I thought "Here I am," where the thought occurred to me was here, outside the vat, where I, Dennett, was standing staring at my brain."* (p. 219)

After having descended into the earth, Dennett, with his brain floating safely in a vat in Houston, starts dismantling the nuclear warhead. Soon, however, mayhem strikes when gradually, but irreversibly, all the radio connections between his brain and his body fail. After his brain lost all communications with his body, Dennett does a remarkable observation:

"It occurred to me then, with one of those rushes of revelation of which we should be suspicious, that I had stumbled upon an impressive demonstration of immateriality of the soul based upon physicalist principles and premises. For as the last radio signal between Tulsa and Houston died away, had I not changed location from Tulsa to Houston at the speed of light? And had I not accomplished this without any increase in mass?" (p. 224)

David Sanford wrote a more technologically plausible version of Dennett's story, titled "Where was I?" [6]. After Dennett's unfortunate attempt to recover the warhead, the Houston scientists concluded that it had been better not to send any biological matter down to the warhead at all. This time they would send a robot, which was to be controlled by Sanford from the Houston location by means of a teleoperation system. The system consisted of several advanced technologies, of which Skintact and the Motion And Resistance System (MARS) were probably the most astonishing. Skintact is a fabric that is worn directly on the skin (they made a suit out of it) and provides very accurate tactile sensations by stimulation of the appropriate receptors in the skin. MARS was another fabric, supposed to be worn over the Skintact suit. The MARS suit was an advanced exoskeleton recording human motion and at the same time providing haptic feedback. Both the human operator and the slave robot wore a MARS suit, thereby closing the perception-motor loop. Before he was set up in the teleoperation system, Sanford was, perhaps somewhat naively, convinced about where he would come to locate himself:

"Although it might be as if I were deep in the tunnel under Tulsa, I would know perfectly well where I really was, safe in the laboratory..." (p. 235)

Could he have been more wrong? The moment he was set up in the control room, he had the greatest difficulty to locate himself there—to localise himself anywhere else than in the position of the slave robot. Now, the scientists had several slave robots available to them, and a switch box allowed Sanford to choose which robot to activate. While switching from one robot to the other, Sanford experienced something similar as Dennett:

"I persisted to locate myself in the position of the active sentient robot and thus had the experience, or at least seemed to have the experience, of spatiotemporally discontinuous travel from one location to another without occupying any of the positions in between." (p. 236)

Both Sanford and Dennett indicate the importance of point of view in the localisation of the self. However, next to the problem of localizing himself, Sanford is faced with an additional problem. In contrast to Dennett, Sanford's point of view was from a robot rather than from his own (brainless) body:

"My point of view had been from the location of a robot, and I had been strongly inclined to locate myself at my point of view. Although I regarded the location of a robot as my location, I was less comfortable regarding myself as identical to a robot. Although I had no clear conception of myself as something other than the robot, I was willing to entertain the possibility that I and the Robot, though distinct, occupied the same place at the same time. I was less troubled with the discontinuous changes in location than with the idea that whenever the channels were switched I suddenly ceased to be identical with one robot and became identical with another." (p. 239)

The additional problem Sanford is facing is one of self-identification. In his fictive story, Sanford cannot accept being identical with the robot. But as the story unfolds, Sanford, still at the point of view from the slave robot, is watching the robot being dismantled:

"While I watched in a mirror, I saw the technicians unzip the layers and peel them back. It turned out that I, David Sanford, the living human being, was underneath." (p. 239)

It turned out that the scientist had played a trick on Sanford while he was asleep. They had put the slave robot's MARS garment and Skintact transmitters over the suits Sanford was already wearing, and they had attached the robot's audio and visual recorders directly to Sanford's head-mounted display and earphones. Before discovering about the scientists' joke, Sanford was looking into the mirror without accepting to identify the mirror image with himself. Yet, Sanford and the mirror image were identical all this time: He was physically there under all these layers of teleoperation technology! The misidentification of Sanford is equivalent to not recognizing one's mirror image when dressed up in a witch costume for a Halloween party. To accept that one is identical with the slave robot, therefore, should be as unproblematic as it is to accept that one is in the same location as the robot. Could it be that Sanford just couldn't imagine that he would come to identify with the robot as himself, just as he initially was convinced that he would find himself to be located in the control room?

Sanford's tale, as is Dennett's, is, of course, a work of fiction, and the scientists in Sanford's story had the perfect teleoperation system at their disposal. Their teleoperation system consisted of such transparent media technologies, that any human operator would quickly "forget" the technology—would feel and act as if the technology is not there (e.g., [7]). Current day technology still lacks this kind of transparency, yet Sanford's description of the phenomenon of telepresence is very close to what operators of existing teleoperation systems actually experience. In their "On the immunity principle: A view from a robot", Cole, Sacks and Waterman describe their experience of the phenomenon when they used a teleoperation system at Johnson Space Center in Houston [8]:

> *"...one sees and controls the robot's moving arms, without receiving any peripheral feedback from them, (but having one's own peripheral proprioceptive feedback from one's unseen arms). In this situation we transferred tools from one hand to another, picked up an egg, and tied knots. Making a movement and seeing it effected successfully led to a strong sense of embodiment within the robot arms and body. This was manifest in one particular example when one of us thought he had better be careful for if he dropped a wrench it would land on his leg!"* (p. 167)

Next to the experience of being in the location of the slave robot, Cole and colleagues describe an experience that Sanford was unable to develop in his fictional story. At some point in time, they came to attribute the robot's arms as belonging to their own bodies:

> *"... there is a misidentification of the sense of ownership of one's own body, this being transferred into a set of steel rods and stubby robotic hands with little visual similarity to human arms."* (p. 167)

Self-identification with the slave robot is, indeed, less problematic as Sanford proposed. Although we intuitively expect our bodily boundaries to be a fixed property, experiences as those described by Cole and colleagues point toward highly malleable body representations in which external, and inanimate, objects can be incorporated as well. In 1991, Held and Durlach already pointed toward the relation between self-identification and telepresence [1]. They argued that telepresence might be experienced more strongly when the human operator is able to identify his or her own body with the slave robot. Yet, to our knowledge, the relationship between self-identification and telepresence has received little attention since then. In the present paper, we aim to further explicate the relationship between self-identification (or self-attribution) and telepresence. For this purpose, will review recent studies which have used the experimental paradigm of the rubber-hand illusion to investigate the brain's remarkable capability to include external objects as a phenomenological extension of the self.

3. Self-Attribution in the Rubber-Hand Illusion

The rubber-hand illusion, which was first described by Botvinick and Cohen [9], is induced by having a person watch a fake hand being stroked and tapped in precise synchrony with his or her own concealed hand by means of two small brushes (see Figure 1A). In the rubber-hand illusion, many people report, without being prompted, that the fake feels as if it is actually their own. Some even report, again without being prompted, that they felt as if they could move and use the fake hand much like their own [10]. Armel and Ramachandran [11] showed that when the fake hand is threatened, for example by bending a finger of the fake hand in a anatomically impossible and hence potentially painful manner, people show increased signs of arousal (objectively assessed by recording skin conductance response). This finding has recently been corroborated in a brain imaging study by Ehrsson, Wiech, Weiskopf, Dolan and Passingham [12]. They show that threatening the fake hand in the rubber-hand illusion induces activity in brain areas associated with anxiety and interoceptive awareness. The rubber-hand illusion also results in a distortion of proprioception. After

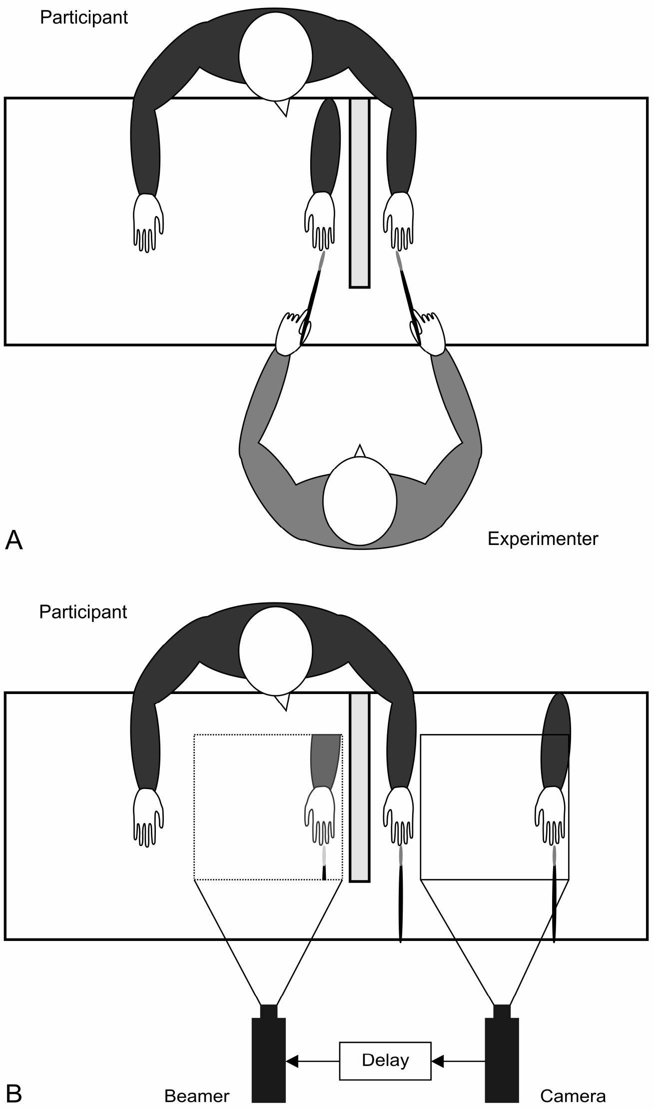

Figure 1. Experimental setup for the rubber-hand illusion (A), and virtual rubber-hand illusion (B)

experiencing the illusion, people misperceive the location of their concealed hand toward the direction of the fake hand (i.e., proprioceptive drift; see, e.g., [9,13]). Two aspects of the illusion are remarkably fascinating. First is the relative speed with which the illusion develops. Most people report to have experiences like those described above within only a few minutes of multimodal stimulation. Secondly, people develop the illusion despite the obvious absurdity of the experimental setup (also [14]). People are well aware of the fact that there is a fake hand lying on the table and that two brushes are used to stimulate the fake hand and their own concealed hand. Yet, for most people, this knowledge does not appear to be an obstacle.

The proprioceptive bias that occurs during the rubber hand illusion seems similar to that found in prism adaptation studies (see [15] for an overview). When seen and felt position of a limb are in conflict, the visually displaced limb is usually felt where it is seen; a phenomenon know as immediate visual capture [16]. Prolonged exposure to prism-induced visual displacements often results in after-effects including misreaching in the direction opposite to the previous visual displacement. Similar effects have been reported in adapting to teleoperation systems and virtual environments (e.g., [1,17]). Although proprioceptive drift is sometimes regarded as equivalent or highly similar to the experiential strength, or vividness of the rubber-hand illusion (e.g., [18]), there appears to be no evidence that this is actually the case. In a recent and relatively large scale study (n = 127), Haans, Kaiser, and IJsselsteijn [19] found only a small correlation between the vividness with which people experienced the illusion and their proprioceptive drift ($r \leq .30$). Secondly, Holmes, Snijders and Spence showed that watching a fake hand can induce proprioceptive drift without eliciting the phenomenology that marks the rubber-hand illusion [20]. Finally, proprioceptive drift is limited to areas around the stimulated fingers. Tsakiris and Haggard [13] found that when synchronous stimulation was applied to, for example, the index fingers of the concealed hand and the fake hand, people felt their index finger to be closer to the fake hand, but not their little finger. Yet on the phenomenological level, the complete fake hand is experienced as a part of the body rather then the stimulated finger alone. This corroborates that we tend to experience our body as a unity (see, e.g., [21]). The findings of Tsakiris and Haggard were replicated in a more recent study by Tsakiris, Prabhu and Haggard [22]. Using a somewhat different experimental paradigm, in which people watched a two-dimensional projection of their own hand (rather then an obvious fake hand), they found that proprioceptive bias was localized to only the finger that was stimulated by a brush (as in the rubber-hand illusion), or passively moved by the experimenter. When the participants, however, actively moved a finger, proprioceptive bias was generalized to other fingers as well. According to the authors, these findings suggest that the experience of unity of the body is due to action rather than sensation.

Botvinick and Cohen interpret the rubber-hand illusion as an effect of visual information overriding the incongruent proprioceptive information [9]. Since vision has a higher spatial sensitivity than kinaesthesia (especially in the case of a motionless arm), the brain relies more on vision, tricking people into believing that their tactile sensations originate from the location where the fake hand is touched rather than from their own occluded hand (i.e., visual capture of touch; also [23]). Armel and Ramachandran, however, demonstrated that the illusion can be elicited by merely stimulating the tabletop in front of the participant, which bears no visual resemblance to a human hand [11]. They, therefore, argue that the illusion mainly arises from Bayesian multimodal integration. Bayesian integration allows the brain to extract statistical correlations between the information received from different modalities upon which it reconstructs a meaningful representation of the world, including one's own body. In the rubber-hand illusion the seen and felt stimulation co-occur with such a high probability, that the brain cannot do else but deduce that the fake arm is part of the body.

3.1. The Effect of Temporal Asynchrony

If the brain is not able to extract a sufficient correlation between vision and touch, for example when a small asynchrony is introduced between the stimulation of the real hand and the fake hand, then the rubber-hand illusion will diminish or break (e.g., [9,11,13]). Held and Durlach investigated the effects of temporal asynchrony in a simplified teleoperation system [1]. This system consisted of a handle, with which people could control a single spot on an oscillator (i.e., the cursor), and an optical system, consisting of a mirror and a lens, that superimposed an image of the cursor on the handle. Their participants performed a series of reaching task with different amounts of delay in the system. They found that people could not adapt to temporal asynchrony when delays exceeded 60 ms (see Figure 2). Phenomenological data revealed that for short delays, participants had the impression that they were dragging their hands through a viscous medium. However, at delays of a couple of hundred ms delay, the seen image was experienced as dissociated from their own hand. As result of this dissociation, the authors argue, self-identification, and thus the experience of telepresence, breaks down. Haans and colleagues [19] recently investigated how the experientially felt strength, or vividness, of the rubber-hand illusion is affected by increasing the amount of asynchrony between seen and felt situation from 0 to 500 ms. To enable reliable delays between seen and felt stimulation, they used a technologically mediated version of the rubber-hand illusion. In this virtual rubber-hand illusion [24], participants are not looking at the fake hand directly, but are looking at a projection of the fake hand and its stimulation (see Figure 1B). While the experimenter applied synchronous stimulation to the participant's left hand and the fake hand, a delay unit, placed between the camera and the beamer, allowed for a

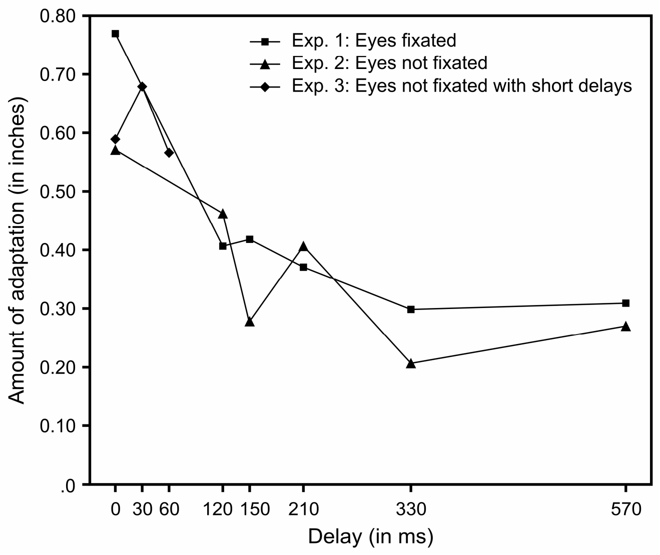

Figure 2. Effect of delay on adaptation in a teleoperation systems (adapted from [1]).

controlled manipulation of the asynchrony. Their results are depicted in Figure 3. In the synchronous (i.e., 0 ms delay) condition, an average person had, for example, a 58% probability of claiming to have felt as if the fake hand was his or her own. In contrast, the probability of claiming to have felt that he or she had complete control over the fake hand—to have felt as if he or she was able to move the fake hand—was 35%. By increasing the delay between seen and felt touch, these probabilities steadily declined. In the 300 ms delay condition, these probabilities were reduced to 32% and 15% respectively. In the 500 ms delay condition, the probabilities were reduced to, respectively, 17% and 7%.

3.2. The Effect of Information Content

The brain's ability to extract a sufficient correlation between seen and felt stimulation, and thus the vividness with which people experience the illusion, depends not only on temporal synchronicity, but on the amount of information in the stimulation as well [11]. If the stimulation of the real and fake hand is done in a random and unpredictable (but synchronous) fashion, then the brain is less likely to decide that the co-occurrence of seen and felt touch is a coincidence. Therefore, the more information in the stimulation, the higher the extracted correlation, and the stronger the illusion is expected to be. The effect of information content on the vividness with which people experience the illusion was investigated by Haans and colleagues [19]. They found that shortly stroking the fingers of the fake and real hand (i.e., high in information), compared to tapping the fingers (i.e., low in information), significantly increased the vividness with which people were able to develop the illusion.

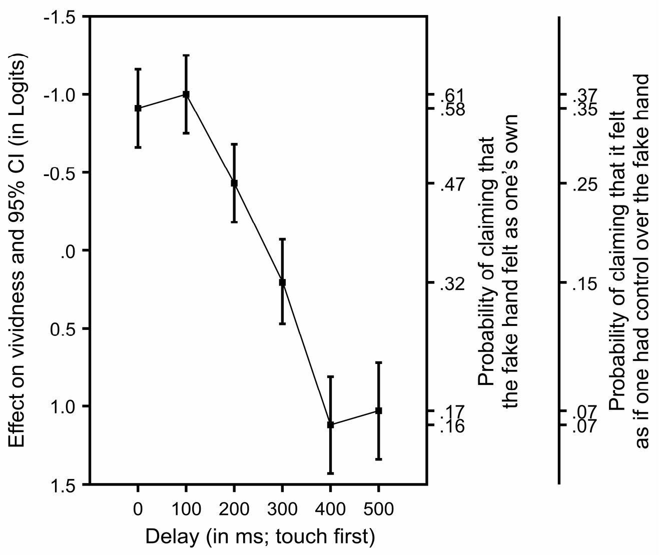

Figure 3. Effect of delay on the vividness of the rubber-hand illusion (adapted from [19]). Note that the effect on the vividness of the illusion is expressed in Logits or log odd units. The higher this Logit score, the more that delay condition constrains participants in developing a vivid illusion. Each of the y-axes on the right provide the probabilities of encountering a specific experience for a person with an average susceptibility to the illusion.

3.3. The Effect of Discrepancies in Appearance

Cole and colleagues describe how they experienced a sense of ownership over the slave robot's arms and hand, despite the obvious discrepancies between human arms and hands and the steel stubby limbs of the robot [8]. For the rubber-hand illusion, several studies have explored the effects of discrepancies between the appearance of a human hand and that of the fake hand. Armel and Ramachandran found that synchronous stimulation of the table top would still elicit the illusion [11]. Their participant's experienced psychological arousal (objectively assessed by recording skin conductance response) when the table-top was "harmed" by pulling a band-aid off the table (note that the experimenters also placed a band-aid on the participant's occluded hand before the start of the experiment). Additionally, they showed that the illusion could be developed even when the fake hand was positioned at an anatomically impossible distance (i.e., 0.91 meters beyond the real hand). Based on these results, the authors conclude that the rubber hand illusion is highly resistant to top-down knowledge about the appearance of one's own body. Yet, although Armel and Ramachandran’s study showed that the rubber hand illusion is relatively robust to manipulations of form or location, their participants rated the subjectively felt strength of the illusion to be much lower under these circumstances, particularly in the tabletop condition. Note that a similar difference between the fake hand and table top condition was found by Haans and colleagues [10]. Tsakiris and Haggard [13] found that people show less proprioceptive drift when the fake hand was placed in an incongruent position (cf. [23,25]), or when the fake hand was replaced by a wooden stick. Participant's in the study of IJsselsteijn and colleagues showed less proprioceptive drift and rated the illusion as less vivid, when looking at a two-dimensional projection of the fake hand rather than the actual object [24]. These findings suggest that bottom-up visuotactile correlations are modulated, top down, by existing body representations (also [26]).[1]

Held and Durlach suggested that a high similarity between the appearance of the slave robot and that of the human body might positively increase self-identification and thus telepresence [1]. In a study by Durlach, Fowlkes and Metevier [27], participants were asked to perform a series of reaching tasks while wearing a head mounted display and a cyber glove, which tracked hand and finger positions and provided tactile feedback. In the low discrepancy condition, the virtual hand, as seen by the participant through his or her head mounted display, had a natural colour and shading, thereby rendering the joints of the fingers clearly visible. In the high discrepancy condition, there was no shading and the virtual hand was rendered completely black. They found that participants reported a higher sense of presence (i.e., the experience of being in a virtual environment), had lower reaction times, and reached the targets faster in the low discrepancy condition, compared to the high discrepancy condition.

3.4. The Effect of Discrepancies in "Feel"

Armel and Ramachandran argue that discrepancies in the nature of expected and actually felt touch may diminish the rubber-hand illusion [11]. They reported, in an anecdotal fashion, that people experienced the rubber-hand illusion more vividly, when the tabletop and the real hand were both touched on the band-aid (i.e., a shared texture). They, therefore, conjectured that people will experience a more vivid illusion when the artificial object is a skin-like textured sheet (i.e., resembling the human skin), instead of a tabletop. This hypothesis was investigated by Haans and colleagues, who did not find a significant difference between the two conditions on either a self-report or a proprioceptive drift measure [10]. However, the vividness with which people experienced the illusion was significantly diminished when the texture of a hand-shaped object did not resemble the human skin (manipulated by putting a white glove over a cosmetic prosthesis). One possible explanation is that people know, in a skill-like fashion (cf. [28]), the difference in "feel" between being touched directly on the skin and while wearing gloves (or a band-aid). Although the authors did not find support for Armel and Ramachandran's hypothesis that a skin-like textured sheet increases the vividness of the illusion, their findings seem to support Armel and Ramachandran's more general claim that discrepancies in the nature of expected and felt touch diminish the illusion. Both discrepancies in visual appearance and discrepancies in the expected feel of the stimulation might negatively affect the rubber-hand illusion. It is important to note, however, that these effects are difficult to separate within the experimental paradigm of the rubber-hand illusion (but see [29] for a variation on the illusion that does not require vision).

4. Discussion

We tend to think of our bodies as relatively stable entities. Yet research on phantom limbs (see, e.g., [30,31]) and experimentally induced bodily illusions, such as the rubber-hand illusion, has shown that our body representations (i.e., the way the body is represented in the brain) are not as hard-wired as everyday experiences make us believe. Instead, this research points toward highly malleable body representations that are shaped through a process of integrating afferent and efferent information, modulated by existing body-representations, and perhaps by the observation of other people's movements as well (i.e., postural empathy [32,33]). Through their interaction with objects and other people, infants learn to distinguish between themselves and the environment by establishing body-specific sensorimotor contingencies [34]. Every action the infant performs (e.g., touching a rattle with his or her hands) is accompanied by corresponding multisensory impressions (e.g., the visual image of the hand moving toward the rattle, or the sensation of pressure when the fingers touch the rattle). In time, the infant learns that some of these patterns of sensorimotor correlations are exclusively associated with the body and hence self-specifying; whenever a person exercises or perceives these sensorimotor correlations, he or she "knows" that the perceived object (e.g., the arm) belongs to the body (also [35]). In the rubber-hand illusion, people attribute the fake hand to the self, because their perception of it matches the body-specific sensorimotor contingencies.

Having highly malleable body representations accommodates a lifetime of development and change, yet it is the relative speed at which body representations can be adapted, that enables us to experience technology, such as the slave robot in a teleoperation system, as a phenomenological extension of the self [7]. One interesting question presents itself regarding the differences between technological artifacts as a teleoperation system and other tools, such as a hammer or the blind's man cane, which do not become a

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[1] Tsakiris and Haggard also found that proprioceptive drift would occur for the middle finger, when both the index and the little fingers were stimulated [13]. The fact that proprioceptive can occur for a non-stimulated finger provides evidence against an exclusively bottom-up explanation as well (also [26]).

phenomenological extension of the self. Although the latter tools are incorporated into the body schema (for an overview, see [36]), users of such tool do not appear to develop an experience of self-attribution as in the rubber-hand illusion. Thus, it seems that we have to make the important distinction between the body schema and the body image (e.g., [37,38]). The body schema can be defined as the unconscious performance of the body and includes a postural model of the body. The body schema allows us, for example, to walk without having to consciously deliberate on every step we make. In contrast, the body image can be defined as our conscious perception of the body, which includes the way we see and feel about our bodies, as well as any conceptual knowledge we have about our bodies. When using tools, the body schema adapts itself to incorporate the tool, thereby unconsciously preparing the body for fluent interaction with that tool. Yet, some tools, such as advanced teleoperation systems, can become part of the body image as well, thereby becoming both a functional and a phenomenological extension of the body. Uncovering the nature of these two different kinds of body representations is helpful in understanding the phenomenon of telepresence, as well as the more general issue of transparency of tools, both physical and virtual.

In the present paper, we have limited ourselves to studies that have used the experimental paradigm of the rubber-hand illusion to investigate under what conditions we can or cannot distinguish between our biological selves and the environment of non-biological tools and props. In the rubber-hand illusion, people are sitting passively behind a table, and movement of the arm or hand is not allowed. In fact, if people do move their arm or finger, the illusion will diminish or break. Yet, motor action and corresponding efferent and afferent information are equally important in self-identification as is shown in several studies (for an overview, see, e.g., [39,40]). Virtual reality and teleoperation technologies will prove to be important tools in investigating how body representations are shaped (see, e.g., [24,41]). Technologies that enable the tracking of body limbs in time and space can, for example, be used to extend the experimental paradigm of the rubber-hand illusion to allow for the possibility of moving the fake hand (see, e.g., [42]).

The use of advanced media technologies, such as teleoperation and virtual reality systems, can have a profound impact on the way in which people experience themselves. Biocca [43] introduced the term self-presence to refer to the effects of media technology on body representations and personal identity (see [44] for a refinement of the term self-presence). In this paper, in which we have focused on a small aspect of self-presence, we have set out to demonstrate that the study of body representations in the brain and the processes underlying telepresence can be meaningfully related to one another. On the one hand, studying self-identification and body representations deepens our understanding of the phenomenon of telepresence. On the other hand, understanding telepresence also informs our intuitions about the nature of body representations and the self, allowing us to validate and extend the insights from philosophical thought experiments, such as those discussed at the outset of this paper.

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