Touch, Tools and Telepresence: Embodiment in Mediated Environments

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ABSTRACT

We tend to think of our body image as fixed. However, human brains appear to support highly negotiable body images. As a result, our brains show a remarkable flexibility in incorporating non-biological elements (tools and technologies) into the body image, provided reliable, real-time intersensory correlations can be established, and artifacts can be plausibly mapped onto an already existing body image representation. A particularly interesting and relevant phenomenon in this respect is a recently reported crossmodal perceptual illusion known as the rubber-hand illusion (RHI). When a person is watching a fake hand being stroked and tapped in precise synchrony with his or her own unseen hand, the person will, within a few minutes of stimulation, start experiencing the fake hand as an actual part of his or her own body. In this paper, we will review recent work on the RHI and argue that such experimental transformation of the intimate ties between body morphology, proprioception and self-perception enhances our fundamental understanding of the phenomenal experience of self. Moreover, it will enable us to significantly improve the design of interactive media, including the design of avatars in virtual environments and digital games, as well as a range of human-like telerobotic devices.

Keywords: telepresence, rubber hand illusion, telerobotics, perception of touch, virtual environments

1. A POOR MAN'S EXTREME MAKEOVER

Let us start by describing a short and informal experiment we have frequently carried out in class and at various conferences, but which also works great for cocktail parties. It goes like this: A presenter starts by asking two volunteers to come to the front of the lecture theatre and each take a seat in one of two chairs which we have positioned exactly behind each other, such that the person in the rearmost chair is looking at the back of the head of the person sitting in the front chair. The presenter then takes position standing to the left side of the people sitting behind each other and asks the person in the rear chair to close the eyes while he takes the participant's left hand, in particular the index finger, gently folding away the rest of the hand. The presenter then proceed to touch the nose of the person sitting in the front chair using this index finger, thereby necessarily stretching the arm of the person sitting in the rear chair. At the same time the presenter use his own index finger (in this case of his right hand) to touch (tap, stroke) the person in the rear chair on the nose at exactly the same position, and with the same pressure and movement. The presenter continues with such a synchronous tapping and stroking motion for about a minute or so, asking the person in the rear seat to meanwhile verbalize what he or she is experiencing.

We have repeated this experiment many times, in many different settings, with always the same outcome: More than half of the participants immediately feel something "weird" is happening, and over two thirds will report, after a few minutes, that they feel as if their nose is significantly elongated, sometimes to the extent of a full arm's length. What is especially surprising about this illusion is the *speed* with which it occurs. Remember that we are talking about our nose here, a part of our body we have been intimately familiar with throughout our life, as the centerpiece, quite literally, of our faces. We look at it each time we pass a mirror or glass window, we touch it regularly – pick it, blow it, stroke it, tap it – and continuously look out onto it, with each eye having its own unique perspective on parts of it. It would seem like a fair assumption to think that whatever body representation the brain would have of the nose, it would be fairly stable and not prone to rapid alterations. However, quite to the contrary, the informal experiment we just described illustrates how malleable or plastic the brain's representation of the body really is.

It will come as no surprise that this illusion has become known as the *Pinocchio illusion*, although it is somewhat different from the Pinocchio illusion as originally described by Lackner[12] who employed vibrations to the tendons in the

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arm muscles, thereby inducing illusory arm movements. When asking blindfolded participants to touch their own noses while stimulating their tendons, they reported that their nose has been elongated by as much as 30 centimeters.

Underlying both Lackner's experiments, as well as our own, is the realization that the representation of the body is a continuously ongoing illusion, dynamically inferred from various simultaneous streams of sensory information[15]. It is determined by a process of continuous, reliable, and real-time intersensory correlation, rather than one of static, hard-wired template matching. In the case of the Pinocchio illusion, correlations between touch and proprioception are at the root of this anomalous perception.

2. RUBBER HANDS: BODILY SELF-IDENTIFICATION AND NON-BIOLOGICAL ARTIFACTS

Evidence is mounting that suggests that human brains are able to support highly and rapidly malleable body images. In line with such observations, our sense of bodily self-identification – the ability to distinguish what's contained within versus what's beyond our familiar biological shell – also appears to be a flexible, temporary categorization and not a fixed property.

A particularly interesting and relevant phenomenon in this respect is a recently reported cross-modal perceptual illusion known as the rubber-hand illusion (RHI)[1, 4, 17]. When a person is watching a fake hand being stroked and tapped in precise synchrony with his or her own unseen hand, the person will, within a few minutes of stimulation, start experiencing the fake hand as an actual part of his or her own body (see Fig. 1A).

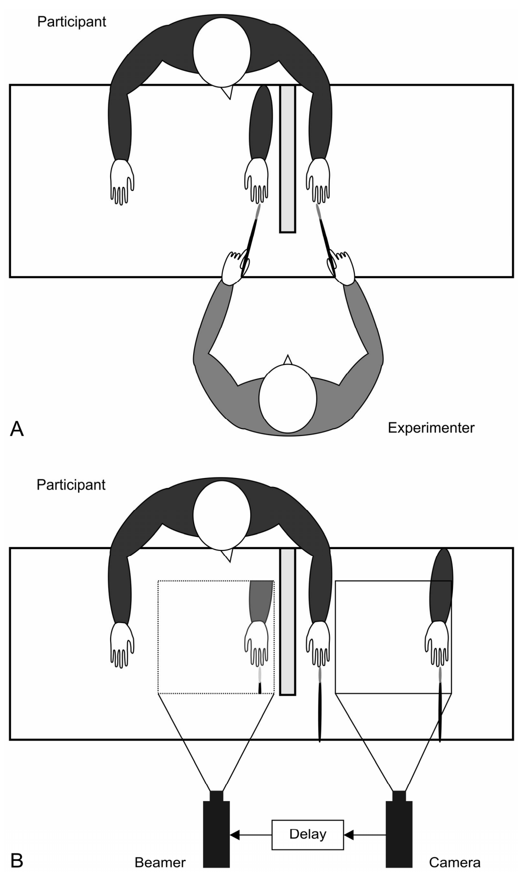

Fig. 1. Set-up of the rubber hand illusion (RHI) experiment. Two conditions are illustrated: The original, unmediated RHI paradigm, as described by Botvinick and Cohen[4] (A) and the video-mediated RHI, as originally described by IJsselsteijn et al.[11], with the possibility of introducing an additional controlled time delay between seen and felt touch (B).

Correlations between visual, tactile and proprioceptive information can be thought of as self-specifying for bodily self-identification, as the brain has learned from a very early age onwards that it can only be the body, and no other object, that can register these specific intersensory correlations[3]. In the RHI, people perceive the fake hand as part of their body because their perception of it matches these body-specific sensorimotor contingencies. If this is no longer the case, for example when participants try to move the fake hand, or when there is a small delay between seen and felt stimulation, the illusion will diminish or break[1, 4, 17].

The strength of the RHI is also considerably diminished when the artificial object is incongruent to the human body, for example when a tabletop[1] or wooden stick[17] is used as the artificial object, or when the fake hand is in an anatomically incorrect orientation[5, 14, 17]. These findings suggest that the strength of the RHI depends not only on matching body-specific sensorimotor contingencies, but also on the correspondence between the artificial object and a cognitive model of what a human body is like (see also de Vignemont, Tsakiris & Haggard[18]).

3. EMBODIMENT IN MEDIATED ENVIRONMENTS

IJsselsteijn, de Kort and Haans[11] demonstrated that the RHI can also be elicited under mediated conditions. They performed an experiment where they investigated this illusion under three conditions: (i) Unmediated condition, replicating the original Botvinick and Cohen[3] paradigm, (ii) virtual reality (VR) condition, where both the fake hand and its stimulation were projected on the table in front of the participant, and (iii) mixed reality (MR) condition, where the fake hand was projected, but its stimulation was unmediated. Dependent measures included self-report (open-ended and questionnaire-based) and drift, that is, the offset between the felt position of the hidden hand and its actual position.

As expected, the unmediated condition produced the strongest illusion, as indicated both by self-report and drift towards the rubber hand. However, also the VR and MR conditions produced the illusion to an extent, thereby providing a basis for research of the bodily self-identification under mediated conditions. For example, using a *projection* of the rubber hand allows for a systematic investigation of the impact of time delay between the visual and the haptic signal on the RHI. Although an ‘asynchronous’ condition is used by most researchers as a control condition which is thought not to elicit the RHI[1, 4, 7, 17], time delay is typically only impressionistically determined (usually between 0,5 and 1 second) and reliable stimulation is dependent on the skills of the experimenter.

Using the mediated RHI (see Fig. 1B), we were able to demonstrate the impact of time delay on the strength of the RHI (see Haans, Kaiser & IJsselsteijn[9]; also Haans & IJsselsteijn[8]). Figure 2 illustrates the results of introducing controlled asynchrony (fully randomized during the experiment) between 0 and 500 ms. Whereas the RHI under a 100 ms delay (delay of video with respect to haptic stimulation) is still comparable to synchronous stimulation, longer delays quickly result in a diminished vividness of the RHI (as is indicated with the probabilities on the y-axes on the right). Indeed, around 500 ms of delay experiencing the illusion becomes highly unlikely.

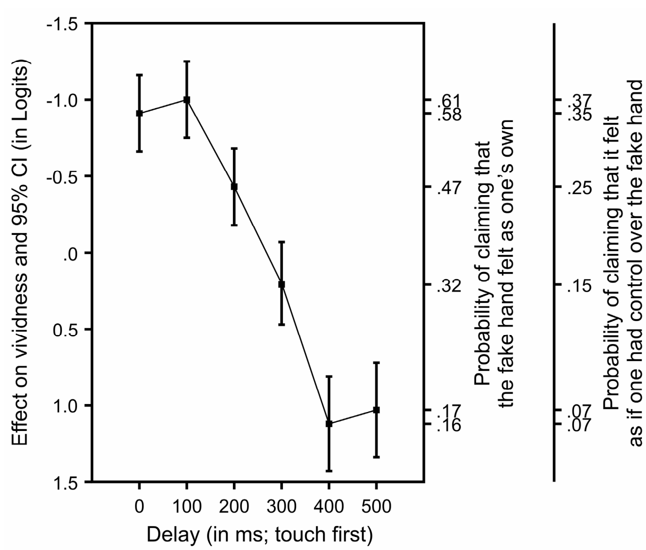

Fig 2. Effects of time delay between seen and felt touch on the subjectively felt strength of the rubber hand illusion.

This paradigm has also been adopted by Sanchez-Vivez & Slater[16] who are investigating the rubber hand illusion using a virtual environment. They report that stimulating a virtual arm (a 3D stereoscopic projection of an arm seemingly coming out of a participant's body) in synchrony with the participant's real arm results in similar feelings of body ownership as originally reported by Botvinick and Cohen[4]. In line with IJsselsteijn et al.[11], recent investigations by Ehrsson[6] and Lenggenhager, Tadi, Metzinger and Blanke[13] have shown that stimulating a video projection of a full body in synchrony with one's physical body can result in an artificially induced 'out-of-body' experience.

4. MEDIATED ENVIRONMENTS AS A TOOL FOR INVESTIGATING BRAIN PLASTICITY AND BODY SELF-PERCEPTION

When we are offered a fully immersive virtual environment that contains a real-time responsive and realistic rendering of our body, mapped onto our bodily movements in minute detail, we expect a significant level of identification with such a virtual body, and consequently, a sense of presence in the virtual space. Similarly, when we control a teleoperation robot, using a master configuration that is mapped in real-time and with high sensory fidelity to a remote slave system, we experience a sense of telepresence, a sense of physically being present and acting at the remote site[10]. Moreover, depending on the mapping and fidelity of haptic feedback, a sense of body ownership may occur, as would be predicted based on the rubber hand illusion findings reviewed so far. Indeed, such observations have been reported. For example, Cole, Sacks and Waterman[5] describe their experience of using a teleoperation system at the Johnson Space Center in Houston:

> "*Making a movement and seeing it effected successfully led to a strong sense of embodiment within the robot arms and the 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! [….] there is a misidentification of the sense of ownership of one's body, this being transferred into a set of steel rods and stubby robotic hands with little visual similarity to human arms*." (p.167)

The fact that such a sense of identification with a virtual body occurs, be it computer-generated or robotic, points towards a highly successful design of the human-machine interface. After all, the ultimate sign of interface transparency when utilizing a technological tool is to experience a tool, quite literally, as an extension of the self. Perhaps more interesting, however, is the fact that the ability to artificially induce the experience of body ownership opens up an entire research agenda on perceived body morphology, bodily self-identification and self-consciousness. Mediated environments (including mirror images, video projections and computer-generated environments) allow for a host of controlled manipulations of factors that potentially influence our sense of body ownership and, consequently, our sense of self. They uniquely enable transformations of body perception, changing perceptual regularities and feedback. In the remainder of this paper, we will discuss some of the research possibilities enabled by the use of mediated environments as tools for investigating brain plasticity and body self-perception..

At a basic perception level, a first research question would be to investigate the required fidelity of the virtual body, that is, the extent to which a full and accurate representation of the participant's body is required to in order to experience ownership. Similarly, the required level of body tracking and match with the participant's proprioception, both in terms of temporal properties as well as spatial detail , is another issue that needs to be empirically determined. Further to this, it would be interesting to determine the effects of dramatic alterations in body perception, for example, remapping of action-perception couplings between existing body parts, adding non-existent body elements (e.g., a tail) under the control of a specific body part (e.g., one's bottom), changes in responsiveness of body parts (e.g., slow motion movements), and so on. Such research would be reminiscent of the way in which visual perception research benefited greatly from controlled transformations of perception, using, e.g., mirror devices or prisms in order to unravel some of the basic perceptual mechanisms and assumptions employed by the brain.

Socially meaningful transformations could include simple body shape alterations, such as body weight or height, or more complicated changes, including changes in perceived race, gender, age, etc. Provided the sensorimotor mappings are convincing enough for participants to identify with their new virtual bodies, interesting social science research may investigate and even influence implicit attitudes concerning person perception and biases in social judgments. Further to this, the impact of social perceptions of others onto our sense of self is potentially significant, and can also be studied systematically under mediated conditions. For example, an important driver of our sense of self will be the social acknowledgement we receive from our environment, varying from simple nods or glances to greetings to full-blown social interactions, including virtual touch.

Research on perceived body morphology, bodily self-identification and self-consciousness traditionally would be dependent on the investigation of anomalies of body perception, such as those found in clinical populations suffering from a variety of body agnosias, neglect syndromes or body dysmorphias. Such patient populations, however, are hard to investigate in large enough numbers (most work in this area is based on case studies), and participants often suffer from brain damage or complicated syndromes that impairs multiple functions at once, and not merely the ones under study. Working with healthy participants that have an experimentally induced transformed perception of self, based on a well-controlled mediated or virtual body, offers a promising way forward for research in self-perception, both for understanding healthy as well as pathological functioning. Understanding anomalous processes of self-perception such as those occurring in body dysmorphias and eating disorders, may eventually lead to improved therapeutic interventions, where both diagnosis and treatment may benefit from the use of virtual bodies with which one can truly identify.

Finally, the study of mediated embodiment holds clear relevance for the development and optimization of mediated environments themselves. Understanding the conditions under which body identification and ownership may or may not occur has implications for the design of virtual environments, teleoperation and mixed reality systems. Notably, in most current virtual environments, much of the time we are like the Invisible Man (or Invisible Woman, for that matter), with only a simple virtual hand to interact with virtual objects, and no body to speak of, let alone appropriate shadows or reflections, haptic feedback, or social acknowledgement as one moves about in the virtual world. We hypothesize that the presence of a believable virtual body, interactively mapped onto our physical body, will likely improve our sense of presence as well as our interaction performance in mediated environments.

5. CONCLUSION

In sum, to paraphrase Frank Biocca[2], media environments are like cyclotrons of the mind: they are a powerful and versatile tool we can use to teach us something fundamental about the structure of perception and the workings of the brain. By experimentally decoupling and transforming the intimate ties between body morphology, proprioception and self-perception, we can study how a seemingly coherent and stable percept can be broken down into its constituent parts and analyzed. This will enhance our fundamental understanding of the phenomenal experience of self, and sheds light onto the intricate brain mechanisms involved in self-representation. The virtual rubber hand illusion is an illustration of the potential of this approach. Applying such fundamental understanding will also enable us to significantly improve the design of interactive media, including the design of avatars in virtual environments and digital games, as well as a range of human-like telerobotic devices.

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