The embodied user : corporeal awareness & media technology

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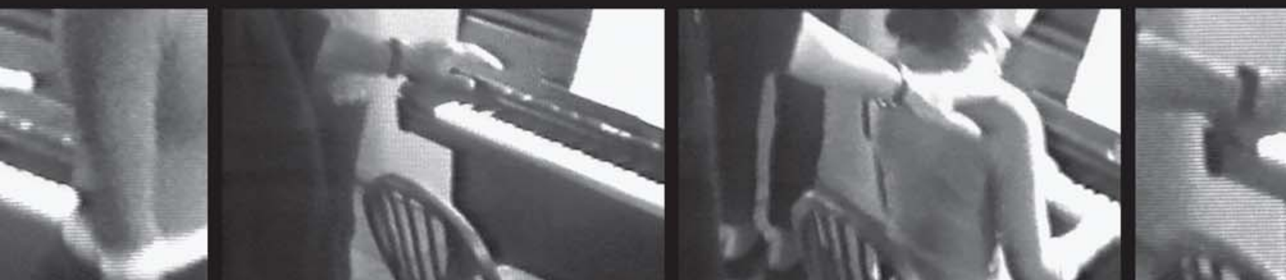
Corporeal Awareness & Media Technology



Antal Haans

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The Embodied User: Corporeal Awareness & Media Technology

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Preface

In the process of writing this thesis, I was reminded of Sir Arthur S. Eddington's (1928) introduction to "the nature of the physical world". In this splendid introduction, Eddington describes how he is surrounded by duplicates of each object in his room: two tables, two chairs, and two pencils. The first of the duplicates is the familiar object: the table, chair, and pencil as one perceives and uses them in everyday life. The second is the object as it is understood and described by the laws of physics: the shadow objects as Eddington liked to call them. The last four years, I found myself surrounded by what can perhaps be described as body duplicates: a familiar body and a shadow body; *a shadow of my own body!*

The first of the duplicates, my familiar body, is the body that I look at in the mirror, and that I see in my dreams sometimes even from the third perspective. This too is the body I am sometimes painfully aware of, for example, after the weekly mountain bike trail with my friends, or after the indoor football matches with the HTI Dream Team. Although my body is subject to both physical (e.g., putting on weight) and psychological (e.g., emotional dispositions) changes, the sense of body ownership remains unchallenged: this familiar body is my body. Indeed, every time we go to sleep, we can rest assured that when we wake up in the morning, we will find ourselves incorporating a body that is not only familiar (at least, as long as you are not waking up as a character in a Kafkaesque tale), but that is unmistakably ours as well. Our familiar bodies are "suffused ... with that peculiar warmth and intimacy that make it come as ours" (James, 1890; p. 242).

Next to the body I have been familiar with for 30 years, there is another body, equally my own, but less familiar and more scientific. In contrast to my familiar body, my shadow body is only present in those moments of more philosophical considerations about the nature of body consciousness and the sense of body ownership. This shadow body is the body, and consciousness of the body, as it is described and explained by biology, neurology and psychology. Given the scientific advancements in these domains, the term shadow body can perhaps best be replaced by Ramachandran's notion of the phantom body: *"Your own body* is a phantom, one that your brain has temporarily constructed purely for convenience" (Ramachandran & Blakeslee, 1999, p. 58). Indeed, as will be described in this thesis, our bodily self is plastic rather than rigid, and can be temporally altered, not only for our amusement in experiencing bodily illusions, but for the purpose of using tools and technologies as well.

This thesis could not have been completed without the kind help of many. I am especially grateful to my supervisors Don Bouwhuis and Wijnand IJsselsteijn. Besides their invaluable input in the research presented in this thesis, they at times pointed out great books and interesting articles, and when necessary, kept me critical towards my own writing. I am also particularly indebted to Florian Kaiser, who has, as always, been a mayor support. I am especially thankful for the precious time he has spent in trying to clarify my thoughts on the measurement of the vividness of the rubber-hand illusion (presented in Chapter 6). I am indebted also to Martin Boschman, who assisted in building and setting up laboratory equipment: Without his assistance, many of the experiments reported in this thesis could not have been conducted. I also would like to thank Loy Rovers for his technical support with the software and hardware for the tactile vest (described in Chapter 8.), and Otto Bock Benelux BV and Jongenengel Orthopedisch Centrum for kindly donating and manufacturing some of the materials used in this thesis. During the past four years, I have had the pleasure to work with many students from the Human-Technology Interaction group, whose assistance in running the various experiments I kindly acknowledge. I especially like to mention Christiaan de Nood, whose graduation project on mediated social touch I co-supervised. Finally, I thank family and friends, especially Beryl, for their endless support and kind ears to jabber to.

Contents

— Chapter 1 —

Introduction

... and our attention will be particularly called to those singular illusion of sense, by which the most perfect organs either cease to perform their functions, or perform them faithlessly; and where the efforts and the creations of the mind predominate over the direct perceptions of external nature. ... [to] *those prodigies of the material world which have received the appellation of* Natural Magic.

—Sir David Brewster

Anyone who believes that there is a "natural" place, where the body is not wedded to technology, may be embracing both technology and self-deception.

—Frank Biocca

Human beings are proficient users of tools and technology. We can acquire the skills necessary to hit a nail accurately with a hammer, or to drive a car safely through a crowded city. A few of us can even learn to play Vivaldi's Le Quattro Stagioni fluently on the violin. At times, our interactions with a technological artifact appear so effortless, that the distinction between the artifact and the body starts to fade. People with a visual impairment, for example, often report to feel their sensations at the tip of their canes rather than their fingers. Likewise, car drivers sometimes claim that the car becomes an extension of their own body; as if their bodily boundaries have somehow shifted toward the outer boundaries of the car (see e.g., Blakeslee & Blakeslee, 2007). Advanced media technologies, such as virtual reality and prosthetic systems, hold the promise of affecting the perception of one's body, or one's body consciousness, in even more profound ways.[1] Consider, for example, the technological domain of teleoperation systems in which the malleable nature of the boundary between the biological body and the technological artifact is currently most evident.

[1] Biocca (1997) introduced the term self-presence to refer to the effects of media technology on the way we think and perceive of our own bodies and ourselves (for a refinement of the term self-presence, see Lee, 2004).

Teleoperation systems allow people to control and manipulate real-world objects from a remote location by means of media technology.[2] Such systems enable humans to work in hazardous (e.g., nuclear plants) or otherwise demanding environments (e.g., space or undersea exploration). Generally, the components of such systems are the human operator who controls the teleoperation station (i.e., the master system), 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. A series of sensors record the operator's movements, the output of which feed the actuators controlling the slave robot. Sensors at the slave robot may 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 (i.e., a head-mounted 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 consist 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., IJsselsteijn, 2004). This, in turn, may result in a phenomenon that in the domain of teleoperation systems is called telepresence: the experience of being there at the remote site (Sheridan, 1992), or the experience of being in the location of the slave robot (Loomis, 1993). Cole, Sacks and Waterman (2000) describe their experience of the phenomenon when they used a teleoperation system at Johnson Space Center in Houston:

"...one sees and controls the robot's moving arms, without receiving any peripheral feedback from them, (but having one's own peripheral proprioceptive [kinesthetic[3]] *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*

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[2] This example is taken from Haans and IJsselsteijn (2007).

[3] We prefer to use the term kinesthesia instead of proprioception to denote the information that is received from the muscle and joint receptors. Following Sherrington (1961), we use proprioception to refer to the sense of position and movement of the body in time and space, which involves sensations from the muscle and joint receptors (i.e., the kinesthetic system), the semicircular canals and otolith organs (i.e., the vestibular system), and the eyes.

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)

Their experience of the phenomenon of telepresence was, however, not limited to a sense of being physically located at the remote site:

"... 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)

Cole and colleagues started to sense the slave robot's arms, which were visible through the head-mounted display, as an actual part of their own body; feeling as if they had ownership over the robot's arms and hands. This process in which the central nervous system categorizes a foreign object as a part of the body, and thus in which a discrimination is made between what is contained within and outside the boundaries of the body, is called self-attribution.[4]

The ease with which foreign objects can be incorporated into the body as a phenomenological extension of the self can be demonstrated by means of a short experiment. For this experiment, two persons and one fake left hand (e.g., a stuffed household glove) are required. The first person, who has the role of participant, takes place in a chair, and places his or her left hand on a table. The second person, who has the role of experimenter, places the left fake hand in front of the participant at a lateral distance of about 30 centimeters from his or her left hand (see Figure 1.1). Next, the experimenter conceals the participant's left hand from view, for example, by placing a wooden barrier between his or her left hand and the fake hand (alternatively, a cardboard box can be placed over the participant's left hand). The participant is asked not to move his or her left hand, and to focus on what he or she is going to feel and see. Using both hands, the experimenter now starts to tap and stroke the fingers of the participant's concealed hand in precise synchrony with the fake hand (preferably by means of two small brushes). After a few minutes of this kind of synchronous tapping and stroking of the fingers of the concealed

[4] Although this aspect of the phenomenon of telepresence has received relatively little attention, Held and Durlach (1991) already pointed toward the relation between self-attribution and telepresence.

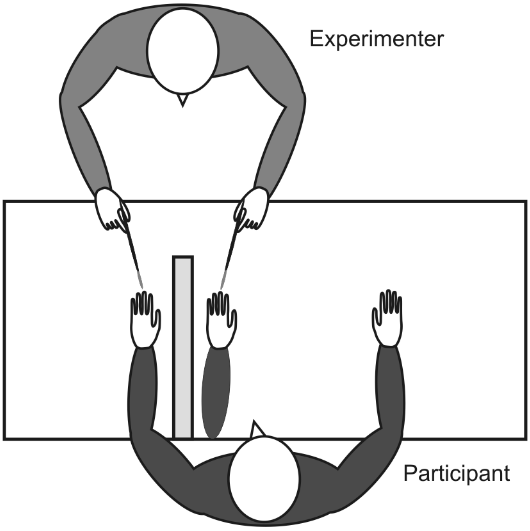

Figure 1.1: Experimental setup for the rubber-hand illusion.

hand and the fake hand, the person in the chair might develop the vivid impression that the fake hand is actually his or her own. This so-called rubber-hand illusion was first described by Botvinick and Cohen (1998). Two aspects of the rubber-hand illusion are remarkable. First, people develop the illusion despite the obvious absurdity of the experimental setup (see also Holmes & Spence, 2006). 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 in developing a strong, or vivid, rubber-hand illusion. A second remarkable aspect of the rubber-hand illusion is the relative speed with which the illusion develops. Some people report to have experienced a sense of ownership toward the fake hand within only a few minutes of multimodal stimulation.

Having highly malleable body representations accommodates a lifetime of development and change, but also enables us to experience technology, such as the slave robot in a teleoperation system, as a phenomenological extension of the self (IJsselsteijn, 2005). Since bodily illusions, such as the rubber-hand illusion, can be induced in the majority of people, they are an excellent tool in the aid of experimental research on body consciousness and related phenomena. The aim of this thesis, then, is twofold:

(a) To determine the personal factors (e.g., the characteristics of an individual's psychological makeup) and situational factors (e.g., the appearance of the foreign object) that constrain or facilitate the development of a vivid rubber-hand illusion.

(b) To determine the degree to which the situational factors that constrain or facilitate self-attribution in the rubber-hand illusion also affect people's experience with media technology, such as the phenomenon of telepresence discussed at the outset of this chapter.

1.1. Outline of This Thesis

In chapter 2, we will describe the theoretical background of our research. At the foundation of this theoretical background lies a conception of the user of technology as an embodied agent: not just a brain, but a biological body.

In chapter 3, we investigate whether the rubber-hand illusion can be elicited under mediated situations in which people are looking at a video projection of the fake hand rather than the actual object. Differences in the strength of the illusion under mediated and unmediated conditions are discussed in terms of the mechanism underlying the rubber-hand illusions, and the potential of using media technology for experimental research on self-attribution and related phenomena.

In Chapter 4, we examine the effect of visual dissimilarities between the foreign object and a human hand on the vividness with which people develop the rubber-hand illusion. In contrast to previous research (e.g., Tsakiris & Haggard, 2005), we explore the effects of shape and texture independently by systematically manipulating these qualities of the foreign object. We will test Armel and Ramachandran's (2003) hypothesis that people will experience a stronger illusion when the foreign object is a skin-like textured sheet instead of a tabletop.

In Chapters 5, we examine the shift in the felt location of the concealed hand that is commonly observed during the rubber-hand illusion. The extent of this so-called proprioceptive drift is often regarded as a corroborative, and more objective, measure of a person's self-reported vividness of the illusion (e.g., Tsakiris & Haggard, 2005). In order to substantiate this claim, we investigate the extent to which the various features of the experimental setup of the rubber-hand illusion, which in themselves are not sufficient to elicit the illusion (e.g., the mere presence of a fake hand), can explain proprioceptive drift.

In addition, we compare a person's proprioceptive drift under these conditions with his or her self-reported vividness of the rubber-hand illusion.

In Chapter 6, we test a model of the vividness of the rubber-illusion in which the probability of reporting a certain level of vividness (e.g., the fake hand feels as one's own) depends on a person's susceptibility for the rubber-hand illusion, the processing demand required to develop that particular level of vividness, and the concrete situational features of the setup in which the illusion is created. In addition, we provide empirical evidence regarding the effect of small asynchronies between seen and felt stimulation (i.e., between 100 and 500 ms), and regarding Armel and Ramachandran's (2003) hypothesis that the strength of the illusion is dependent on the amount of information in the stimulation. Finally, we provide further evidence regarding the relation between proprioceptive drift and the vividness of the rubber-hand illusion.

In Chapter 7, we further test the validity of our susceptibility measure by investigating the relation between susceptibility for the rubber-hand illusion, body image instability, and people's ability to mentally position their hands in an extracorporeal location. In addition, we investigate whether the commonly reported effect of the orientation of the fake hand on the vividness of the illusion is dependent on the anatomical implausibility of that orientation (which indicates that the attribution of foreign objects to the self is constrained by the morphological characteristics of the human body; cf. Tsakiris & Haggard, 2005).

In Chapter 8, we investigate the effect of morphological correct visual feedback (i.e., matched to the human body) on people's experience with media technologies that allow for mediated social touch (i.e., that allow geographically separated people to touch each other by means of haptic or tactile feedback technology; e.g., Haans & IJsselsteijn, 2006). We investigate the extent to which morphological correct visual feedback affects (a) physiological arousal in response to a mediated touch (assessed by means of skin conductance response), (b) the experience of telepresence, and (c) the perceived naturalness of the mediated touches. Results are discussed in terms of the identification with virtual bodies, and the mechanisms underlying self-attribution.

Chapter 9, the epilogue, brings the various chapters of this thesis together, while taking a broader perspective on the field of research on media technologies and corporeal awareness. The main contributions of this thesis and interesting future research directions will be discussed.

— Chapter 2 —

The Embodied User

"Hawen yuda dasibi unaia, *his whole body knows," they say. When I asked him where specifically a wise man had knowledge, they listed his skin, his hands, his ears, his genitals, his liver, and his eyes. "Does his brain have knowledge?" I asked.* "Hamaki *(it doesn't)," they responded*

—Kenneth M. Kensinger

Porcina Schemata *(A hog's morphology)*

Four legs, one snout, a curly tail
Forty-six pork chops, two sixteen-pound hams
Eight thousand grams of shoulder roast
A hundred and eighty bacon strips smoked
For soup, or stew, ten pounds of bones
Four sausages measuring two and half stone
In cans are stored the final parts
Fourteen kilos of brawn and lard

—AH

In recent years, the term embodiment (or being embodied) has become popular in various disciplines of science and technology, including human-computer interaction (e.g., embodied interaction with computers; Dourish, 2001) and cognitive psychology (e.g., embodied cognition; Varela, Thompson & Rosch, 1991). In these instances, the term embodiment is commonly used in the tradition of philosophers like Heidegger, Husserl or Merleau-Ponty: as being an active participant in the world. Embodied cognition, for example, postulates that it is through this participation, which is bounded by the characteristics and possibilities of the human body, that intelligence and the mind itself can be explained. Yet, how exactly are we embodied? According to Metzinger (2006), there are three different levels of being embodied, which he calls, first, second, and third order embodiment. These three orders of embodiment can be explained in terms of the morphology of the body, the body schema, and the body image.[5]

2.1. Morphology

The most obvious way in which human beings are embodied is by means of the human body itself. The human body has certain characteristics, including the type and number of limbs, and the modality and location of sensory receptors, that distinguish it from bodies of other animals, such as pigs, birds, or bats. These morphological characteristics largely determine the animal's behavior. Having wings, for example, is a necessary condition to fly. In other words, the morphological and physiological characteristics of the body both enable and constrain the animal's action possibilities. Scratching your own back when it itches can be annoyingly difficult, because the length and flexibility of the arm, as well as the degrees of freedom of its joints, do not allow you to reach the itching spot easily. At the same time, body morphology determines, to some extent, the quality of the individual animal's experiences. An eye, for example, is a prerequisite for sight. Since all human beings have a highly similar morphology, one can presume that others are capable of having the same or highly similar experiences. In contrast, if one lacks wings and a sense of echolocation, then it is hard to imagine what it would be like to be a bat (Nagel, 1974).

Having a body is the most fundamental way in which an organism can be embodied, and constitutes what Metzinger (2006) calls first order embodiment.[6] An example of a first order embodiment would be a simple Braitenberg vehicle such as depicted in Figure 2.1. This device consists of a mechanical body with wheels and two light sensors as eyes. Each light sensor is connected directly to the motor of the contra-lateral wheel. Since the two light sensors are located at a distance from each other, the automaton's direction of movement is dependent on how much light each sensor registers. If the rightmost sensor receives more light than the leftmost sensor, then the left wheel will spin faster than the

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[5] The term "corporeal awareness" in the title of this thesis is adopted from Critchley (1979) who suggested this single label to replace the often confused terms of body schema and body image. This term is adopted, however, without adopting Critchley's opinion that the body schema and the body image can be described under a single heading.

[6] Clark (2007; 2008) distinguishes between two types of body morphologies: (a) Morphologies which have a biomechanical structure that inherently allows for energy efficient motions, and (b) morphologies without such structures, and that thus require constant motor actuation for movement. Examples of the former include humans, passive dynamic walking robots (e.g., Fallis, 1888), most things on wheels, and airplanes. Examples of the latter include Honda's Asimo robot, and helicopters.

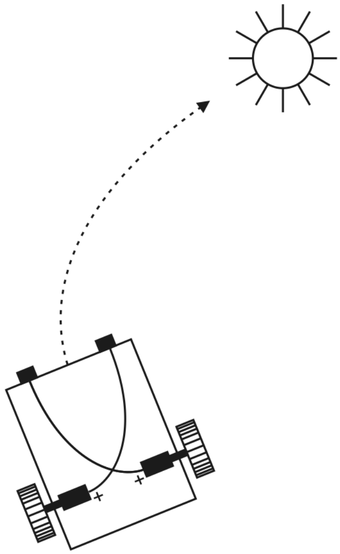

Figure 2.1: A simple Braitenberg vehicle

right wheel. As a result the automaton will orient itself toward the light source. Moreover, the closer the automaton is to a light source, the more light each sensor receives, and thus the higher the speed of movement will be. For an outside observer it might appear as if the automaton has the intention to aggressively attack the light source. Note that this Braitenberg vehicle's action possibilities are rigid rather than plastic: Being first order embodied, the automaton's action possibilities are hard-wired as morphological characteristics of its body. For an organism, or robot, to be second order embodied, it not only requires a body (i.e., a certain morphology), but a dynamic body schema as well.

2.2. Body Schema

Our bodies are in a constant interaction with the environment, yet we generally do not pay much attention to what the body is doing. We can, for example, walk without having to consciously deliberate on every step we make. Consider a simple task as fetching a book from the top shelf of a bookcase. If the bookcase is not too high, then you "simply" extend your arm and grab the book in a single fluent motion. However, even such a simple task involves a complex pattern of muscle contractions which are required for extending the arm, standing on the tips of your toes, keeping balance, and grabbing the book, while at the same adjusting your posture for the weight of the book. It is due to the body schema that we can interact fluently with the environment despite the complexity of human motion. Although the term body schema or body schemata can be traced back to the writings of Bonnier (see Critchley, 1979), the term was popularized by the famous neurologist Henry Head. According to Head and Holmes (1911), the body schema is a postural model of the body which is constantly updated to account for the position and movement of the body and its limbs. Since the body schema is involved in the continuous regulation of posture and movement, Gallagher defines the body schema as the "non-conscious performance of the body" (Gallagher, 1986; p. 548), or as "a nonconscious system ... of motor-sensory capacities that function below the threshold of awareness, and without the necessity of [conscious] perceptual monitoring" (Gallagher, 2005a; p. 234). The body schema necessarily constrains the action possibilities that the morphological characteristics of the body allow: There are many different ways in which we could fetch the book, but only one specific motion is endorsed. Another important aspect of the body schema is that it is dynamic rather than rigid (Gallagher, 2005a). It is due to this dynamic nature of the body schema that one can grab the book with the same effectiveness when, for example, one leg is injured or when holding a stack of books in the other hand. Similarly, the body schema can adjust itself to long term morphological changes, for example, due to growth or the accidental loss of a limb.

The most obvious function of the body schema is to keep track of the relative position of the body and its parts in time and space. According to Head and Holmes (1911) this involves an internal representation of the body, or a postural model of the body, which is constantly updated to account for the position and movement of the body and its limbs. They argue that there may be more than one single body representation, and discuss the possibility of another representation that maps a tactile sensation to a certain part of the body (i.e., a faculty of localization). However, determining the spatial position of body parts and the localization of tactile stimulation are not sufficient for the body schema to function. It requires, amongst others, a mapping of the space immediately around the body (e.g., to determine whether an object is within reach) and appropriate action selection (cf. Maravita, Spence, & Driver, 2003). The body schema can, thus, best be described as a dynamic distributed network of procedures aimed at guiding behavior (cf. Kugel, 1969).[7] Although

[7] Our definition of the body schema resembles closely Kugel's (1969) notion of the body plan: The organization of all sensorimotor structures that prescribes unconscious and automatic human behavior (p. 52).

each individual procedure might serve rather simple tasks, such as determining whether something is happening around a certain part of the body, the network of procedures can subserve complex tasks such as keeping balance or determining whether an object is within reaching space. To an observer (including the owner of a body), it might appear that the body schema functions by means of a coherent whole-body representation (i.e., a homunculus of some sort), but such a representation is not required for the individual procedures to function (Minsky, 1988; Brooks, 1991). This has implications for the discussion on how many body representations there actually are (e.g., de Vignemont, 2007; Schwoebel, Buxbaum, & Coslett, 2004): One may find many different and useful body representations depending on how one functionally groups the individual procedures together. Furthermore, consistent with Gallagher's (1986; 2005b) conclusion that the body is anonymous on the level of the body schema, the network of procedures functions without conscious reference to the body and its limbs as owned by a person. The body schema, thus, requires neither a puppet, nor a puppeteer (and thus no Cartesian puppet-theatre either; cf. Dennett, 1991).

2.2.1. Incorporation of Artifacts into the Body Schema

Head and Holmes (1911) already describe that objects in the environment can be incorporated into the body schema.[8] Their famous examples include the blind man's cane and the feather on a woman's hat. Regarding the latter example, one should understand that in the beginning of the 20th century it was fashionable for women to wear tall feathered hats (think of the famous 1910 painting "the black feather hat" by Gustav Klimt). Head must have observed how elegantly and effortlessly these women passed through small doorways without disturbing the feathered piece of millinery on top of their heads. There is an increasing amount of empirical evidence to support such observations. In this section, three examples of research on the use of tools, such as sticks and rakes, to increase our reaching space (or peripersonal space; e.g., Holmes & Spence, 2004) will be discussed. Yamamoto and Kitazawa (2001a) asked their participants to judge the order in which two tactile stimuli, which were delivered to a finger of the left and right hand, were presented. With the arms uncrossed, people are generally quite proficient in making such temporal order

[8] By defining the body schema as a network of procedures, rather than an internal representation of some sort, it is perhaps incorrect to say that tools are incorporated into the body schema. More correctly formulated, the individual procedures in the distributed network adapt themselves to a tool, thereby allowing for a more fluent interaction with that tool.

judgments. However, people perform significantly worse when they make such judgments with the arms crossed (see also Shore, Spry, & Spence, 2002). Yamamoto and Kitazawa (2001b) also investigated people's performance in making such temporal order judgments when the tactile stimuli were delivered to the tip of two sticks, which were held by the participant in each hand, rather than to the fingers. They found that crossing the sticks had a similar detrimental effect on performance as crossing the arms, indicating that the sticks were incorporated into the body schema as extensions of the arms.

Further evidence is provided by research on bimodal neurons that respond to tactile stimulation of the hand as well as to visual stimuli near the hand (e.g., Iriki, Tanaka, & Iwamura, 1996; see also Maravita & Iriki, 2004). Iriki and colleagues trained Japanese macaques in using a rake to retrieve a piece of food outside of the monkeys' normal reach (i.e., outside of the monkey's peripersonal space). Using single cell recording, they found that the monkey's bimodal neurons would not only respond to stimuli near the hand, but started to respond to stimuli near the rake as well. In other words, while the monkey retrieved pieces of food with the rake, the receptive field of its bimodal neurons had temporarily expanded to include the entire rake. No such expansion of the receptive field was found when the monkeys passively held the rake.

Finally, Berti and Frassinetti (2000) provide evidence of the incorporation of tools into the body schema in an experiment involving a patient P.P. who suffers from left-sided visual neglect after a stroke in the right hemisphere. As such, P.P. cannot attend to, and has no awareness of, the left side of her visual field. For P.P. this deficit is limited to reaching space (i.e., near-space neglect). In other words, although she is unaware of the left most side of her reaching space (or near space), her awareness of far space is unaffected. This dissociation between near and far space in patient P.P. indicates that reaching and non-reaching space is dealt with by the central nervous system in different ways. In their experiment, Berti and Frassinetti asked patient P.P. to perform a series of line bisection tasks, in which she had to indicate the midpoint of a line by means of a laser pointer. Consistent with near space neglect, she would perceive the midpoint of the line to be closer toward the right when the line was located at a distance of 50 cm (and thus within her normal reaching distance), but not when the line was located at a distance of 100 cm (i.e., outside of reach). However, when she had to point toward the midpoint of the line by means of a stick rather than a laser pointer, a displacement toward the right was observed even when the line was located at a distance of 100 cm. This illustrates that when using tools and rakes to touch objects that would otherwise be out of one's reach, the brain actually remaps the space around us to accommodate for the expansion of our reaching space. For patient P.P. this unfortunately included an expansion of her neglect as well.

These examples provide empirical evidence for the often made claim that tools, such as a rake, a hammer, or a violin bow, can become incorporated into the body schema. However, due to its anonymous nature, incorporation into the body schema does not change our perception of these tools into something other than just an object in the environment. Incorporation of tools into the body schema, thus, appears to be mainly functional, allowing for the unconscious preparation of the body for fluent interaction with the tool (see also Gallagher & Cole, 1995).

2.2.2. The Role of the Body Schema in the Perception of Others

The anonymity of the body schema is exemplified not only by the possibility of incorporating tools and artifacts, but by the role of the body schema in observing other people as well. There is increasing evidence to support that some of the procedures of the body schema are involved both in action execution (whether mental or real) and in action observation. Reed and Farah (1995), for example, asked people to judge whether a posture of another person had changed between two photographs taken from different angles, while simultaneously making repetitive movements with their own limbs. They found that a person's accuracy in detecting a change in the position of a particular limb of another person significantly improved when participants moved that same limb at the same time. The authors demonstrated that this facilitation effect is not due to actively matching the limb position of the other person, and that it did not apply to inanimate objects.

Shiffrar and Freyd (1990) showed people two static images of a human character. In one image the character had his or her arm in a different position than the other. When the two static images were presented sequentially, people perceived an apparent motion of the arm (for an example, see Figure 2.2). At temporal rates consistent with the time normally required for a person to make these movements, people perceived biomechanically plausible paths of apparent movement. In contrast, when the two images were presented more rapidly after one another, people perceived the implausible shortest path. This finding demonstrates that the visual system, when given sufficient processing time, constructs a path of apparent motion that satisfies the morphological characteristics of the human body (see also Shiffrar & Freyd, 1993). Interestingly, when the images depicted objects, such as clocks or boxes, participants always experienced the shortest path of movement (i.e.,

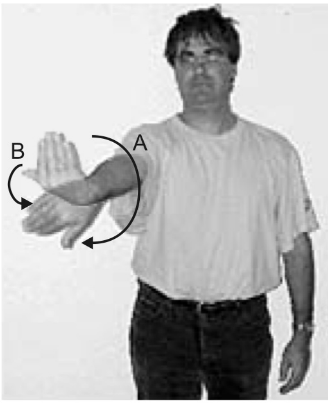

Figure 2.2: The two stimuli of an apparent motion paradigm superimposed. The longest but biomechanically plausible path of apparent motion is indicated with an A. The shortest implausible path is indicated with a B. Picture adapted from Funk, Shiffrar and Brugger (2005).

irrespective of the temporal rate). Funk, Shiffrar and Brugger (2005) demonstrated that the rate-dependency of the perceived path of apparent motion cannot be explained by the fact that we have knowledge about the biomechanical constraints of the human body. They compared two persons born without arms (i.e., aplasic) with normally-limbed persons. Whereas one of the aplasic persons experienced genuine phantoms for both arms, the other did not (for evidence regarding the reality of the aplasic phantom limbs, see Brugger et al., 2000; Brugger & Funk, 2007). For the person with aplasic phantoms, perception of the path of apparent motion was rate-dependent (similar to the normally-limbed controls; see Figure 2.2). In contrast, the person without aplasic phantoms predominantly experienced the shortest, but biomechanically impossible, path of motion. Since both aplasic individuals have knowledge about the biomechanical constrains of normally-limbed others, this study provides evidence for the supporting role of the body schema in the observation of other people.

The recent discovery of the mirror neuron system in monkeys and humans is important in understanding how such a supporting role is implemented in the brain (for a recent review, see Rizzolatti & Craighero, 2004). This class of neurons discharges both when the individual performs a particular action (e.g., grasping) and when it observes that same action being performed by another individual (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996).

In other words, the actions of the other individual are automatically mapped onto one's own motor system as if one is performing the action oneself.[9] Similar mirror-like neural mechanisms are found for the observation of emotions (e.g., disgust; Wicker et al., 2003) and touch (Keysers et al., 2004). Behavioral evidence for the existence of a somatosensory mirror system is, for example, provided by Thomas, Press, and Haggard (2006). The authors investigated whether a visual event on another person's body facilitates tactile perception. Such an effect on the detection of tactile stimuli was found, but only for visual cues presented in the same anatomical position on the other person's body. This indicates that the transformation of visual information regarding locations on another person's body occurs in a somatotopic reference frame. Correspondingly, no effect was found when the cues were presented on a house rather than a human body, providing evidence that the cueing effect is body-specific.

In the scheme of Metzinger (2006), having both a body, whether biological or mechanical, and a body schema is sufficient for second-order embodiment. For third order embodiment, an organism or robot requires not only a body and a body schema, but a body image as well. More specifically, third order embodiment requires the kind of higher-order consciousness that enables humans to hold a concept of their own body over time.

2.3. Body Image

Gallagher (1986; 2005b) has defined the body image as our perceptions of the body, which includes the way we see and experience our bodies, as well as any conceptual knowledge we have about our bodies. In contrast to the body schema, the body image is, in terms of Gallagher (1986; 2005b), not anonymous but owned. The body image can, in our point of view, best be described as a part of the process of consciousness. According to Edelman (2003; 2006) consciousness is the result of neural processes that allow for a large amount of refined discriminations and perceptual categorizations, by combining

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[9] Since not all people that are born without limbs experience phantom limbs, the relation between aplasic phantom experiences and performance on apparent motion tasks points toward a possible role of observing other people in the structuring of the body schema as well (for an overview, see Price, 2006). It has been argued that individual differences in the experience of aplasic phantoms might be related to differential activation of mirror-like neural mechanisms (Brugger et al., 2000, Funk et al., 2005; Brugger & Funk, 2007). Interestingly, several studies have revealed a relation between the activation of neural mirror-like mechanisms and individual differences in self-reported empathy and perspective taking personality characteristics (e.g., Banissy & Ward, 2007; Gazzola, Aziz-Zadeh, & Keysers, 2006; Jabbi, Swart, & Keysers, 2007).

multimodal sensory information, and connecting such sensory information with memory content. These higher-order discriminations are qualia, which are not limited to, for example, "red" or "cold" but include all aspects of subjective experiences: the unitary perceptual scene, moods, and memories alike. If one accepts this formulation of consciousness, then the body image consists of those discriminations, and thus of those qualia, that pertain to the individual's own body (i.e., to those objects that the central nervous system has categorized as being a part of the physical body).

Although we have described the body image as a part of the process of consciousness, not all organisms are necessarily conscious of their body image. According to Edelman (2003; 2006), one can distinguish between two types of consciousness: primary and higher-order consciousness. All organisms that have primary consciousness have a body image. That is, they can make some minimal discrimination between their body and the environment out of all information that is available to them at a certain moment in time. Organisms with only primary consciousness, however, make such discrimination only for that brief period in time that Edelman calls "the remembered present". They lack the higher-order consciousness that enables the linking of the remembered present with a remembered past, and an anticipated future. Organisms with primary consciousness alone lack the capacity to be conscious about having a body image. Similarly, they lack the capability of being self-conscious. Put differently, with primary consciousness alone, an organism will possibly experience one bodily self after the other, without being able to combine these temporary bodily selves into a longer lasting conception of its own body.

How might the high-order body image have evolved, and what is the benefit of having a high-order body image? One interesting hypothesis with respect to the evolutionary development of the high-order body image is given by Povinelli and Cant (1995). According to their hypothesis, it has evolved as a mechanism that enables large-bodied apes to maintain their arboreal lifestyle. Animals that spend most of their lives in trees are faced with a challenging environment: the size, strength and stability of branches and lianas is highly variable, fruit and leaves often grow on the end of thin, easily bendable branches, and individual trees may be separated by considerable distances. This is not much of a problem for small animals who will survive a ten meter fall from the canopy. When our ape ancestors grew bigger, however, their arboreal lifestyle became increasingly challenging. Of course, those individual apes that could make the higher-order discriminations required to plan and perhaps even simulate their movements were more fit to arboreal life, and had an advantage over their contemporaries who did not possess this ability. The higher-order body image, thus, might have evolved from the stubbornness of our ancestors in committing to an arboreal lifestyle. In contrast to our ancestors, most humans do not live in trees. However, a higher-order body image remains important as it enables a wide range of behaviors: planning and learning of complex movements (e.g., learning to play a musical instrument or to play golf), learning by simulating such complex movements before the mind's eye, or managing one's appearance (e.g., a soon-to-be wed woman who puts together a diet or training schedule in order to fit into a wedding dress she has to wear several months later). Each of these tasks requires the higher-order consciousness that enables humans to hold a concept of their own body over time.

In the scheme of Metzinger (2006), only organisms that have a body, a body schema and are conscious of having a body image are third-order embodied. Since this requires higher-order consciousness, only animals that are self-conscious (and, thus, in terms of Metzinger possess a phenomenological self model; see also Metzinger, 2003) are third-order embodied. The traditional test to determine whether an animal is self conscious is the rouge test (Gallup, 1970). For this test, the animal is anesthetized and a patch of skin on the head or ear is marked with rouge (or another odorless dye). After the animal has fully recovered from anesthesia, a mirror is placed in the animal's cage. If the animal, after seeing the marks in the mirror, attempts to remove the marks from its body, then the inference is that the animal recognizes itself in the mirror and, thus, is self-conscious. Currently, only human beings, chimpanzees, bonobos, orang-utans, a single abnormally reared gorilla (Povinelli & Cant, 1995), and perhaps dolphins (Reiss & Marino, 2001), elephants (Plotnik, de Waal, & Reiss, 2006) and magpies (Prior, Schwarz, & Güntürkün, 2008) have passed the rouge test, and can thus be expected to have higher-order body images.

2.3.1. Incorporation of Artifacts into the Body Image

Incorporation of foreign objects into the body image requires that the central nervous system categorizes the object as a part of one's body. A distinction can thus be made between two different kinds of bodily extensions: functional (i.e., incorporation into the body schema) and phenomenological (i.e., incorporation into the body image; cf. Gallagher & Cole, 1995). Functional extensions allow for fluent and proficient interaction with tools, such as a hammer, a car, or a violin. In contrast to a phenomenological extension, functional extensions are not experienced as becoming an actual part of one's own body, but remain to be experienced as objects in the environment instead. In other words, a mere functional extension lacks the kind of self-attribution that, for example, might occur when operating anthropomorphically-designed teleoperation systems. Some tools and technological artifacts, thus, can become incorporated into both the body schema and the body image, thereby becoming both a functional and a phenomenological extension of the body. The benefits of such a double incorporation is perhaps most obvious in the case of mechanical prostheses, where an amputee's attitude toward his or her prosthetic limb depends on both the functionality of the prosthesis (i.e., how well it can be operated), and the extent to which the prosthesis is experienced as a part of the self (Desmond & MacLachlan, 2002).

This incorporation of foreign objects into the body image (i.e., self-attribution) is mainly dependent on the capability of the central nervous system to extract correlations between the various sensory modalities, upon which it reconstructs a meaningful representation of the world (and thus one's body; e.g., Armel & Ramachandran, 2003). There is increasing evidence that infants, through their interaction with objects and other people, learn to distinguish between themselves and the environment by establishing body specific sensorimotor contingencies (Botvinick, 2004; Lackner, 1988; Rochat & Striano, 2000; see also O'Regan, Myin & Noë, 2005). Every event the infant perceives (e.g., the clapping of hands), whether self-inflicted or not, consists of correlated multisensory impressions (e.g., the visual image and sound of clapping hands). In time, the infant learns that some of these patterns of sensorimotor contingencies are exclusively associated with the body, and hence self-specifying. Whenever a person exercises or perceives these sensorimotor contingencies, he or she "knows" (in a skill-like fashion; cf. O'Regan et al., 2005) that the perceived object belongs to the body: When the visual image of clapping hands is accompanied immediately by a tactile sensation in the hands, then by inference it must be your hands that do the clapping.

By altering the patterns of sensorimotor correlations, one can temporally induce perceived bodily alterations in other people. Consider for example, the so-called Pinocchio illusion (e.g., Lackner, 1988; Ramachandran & Hirstein, 1998). To elicit this illusion, two persons take a seat in two chairs 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 (see Figure 2.3). The experimenter takes a position to the right side of the persons sitting in the chairs. Next, the experimenter asks the person in the rearmost chair to close the eyes, and to concentrate on what he or she is going to feel. Subsequently, the experimenter takes a hold of the index finger of right hand of the person sitting in the

A B

Figure 2.3: Experimental setup for the induction of the Pinocchio illusion (Panel A), and a picture of the author inducing the illusion at the Interdisciplinary College in Günne, Germany, March 9 - 16, 2007 (Panel B).

rearmost chair, and uses that finger to gently stroke and tap the nose of the person sitting in the front chair. At the same time, the experimenter uses the index finger of his or her own left hand to stroke and tap the nose of the person sitting in the rearmost chair in precise synchrony with the nose of the person sitting in front. After a few minutes of this kind of synchronous tapping and stroking, the person in the rearmost chair might develop the vivid impression that his or her own nose has considerably elongated.[10]

In the Pinocchio illusion, there is a near perfect correlation between afferent proprioceptive information and the touches felt at the nose and index finger. Moreover, this pattern of multisensory correlations matches the body-specific sensorimotor contingencies normally registered when your nose is stroked with your own index finger. As a result, the central nervous systems cannot do else but deduce that one's nose has elongated to about arm's length. Apparently, it considers the rapid growing of the nose to be more likely than the existence of two perfectly synchronized sources of stimulation. Experimentally induced bodily illusions, such as the Pinocchio illusion, are excellent paradigms in the aid of

[10] There are considerable individual differences in susceptibility to the Pinocchio illusion. Based on our own experiences in trying to induce the illusion, about two thirds of the people will experience an elongation of the nose. Alternatively, some people may experience a lengthening of the fingers of the right hand (see Burrack & Brugger. 2005).

experimental research on body consciousness and related phenomena. The rubber-hand illusion (Botvinick & Cohen, 1998; see also Chapter 1) is another such experimental paradigm, which is particularly suited for investigating the incorporation of tools and technological artifacts into the body image. In the following chapters, we explore this rubber-hand illusion in more detail.

— Chapter 3 —

The Rubber-Hand Illusion in Reality, Virtual Reality, and Mixed Reality[11]

Abstract

In the rubber-hand illusion, which is induced by stroking a person's concealed hand in precise synchrony with a visible fake hand, people sense the fake hand as an actual part of their body. This chapter presents a first study in which the rubber-hand illusion is investigated under mediated conditions. In our experiment, we compared the strength of the illusion under three conditions: (1) an unmediated condition, replicating the original paradigm, (2) a virtual reality condition, where both the fake hand and its stimulation were projected on the table in front of the participant, and (3) a mixed reality condition, where the fake hand was projected, but its stimulation was unmediated. Although we succeeded in eliciting the rubber-hand illusion under mediated conditions, the resulting illusion was less vivid than in the traditional unmediated setup. Results are discussed in terms of the perceptual mechanisms underlying the rubber hand illusion, and the relevance of using media technology in research on self-attribution and other aspects of body consciousness.

By simultaneously stroking a person's concealed hand together with a visible fake one, some persons start to sense the fake hand as an actual part of their own body (Botvinick & Cohen, 1998; see also Chapter 1). This rubber-hand illusion illustrates that a few minutes of the proper kind of multisensory stimulation can radically alter our sense of bodily boundaries, thereby providing evidence for the malleability of the central nervous system in accommodating perceived bodily alterations. Armel and Ramachandran (2003) have shown that when the fake hand is threatened, for example by bending a finger of the fake hand in an anatomically impossible and hence potentially painful manner, people show signs of increased arousal (assessed by means of skin conductance response). This finding has recently been corroborated in a brain imaging study by Ehrsson, Wiech, Weiskopf, Dolan

[11] This chapter is based on IJsselsteijn, de Kort, and Haans (2006).

and Passingham (2007). They showed that threatening the fake hand in the rubber-hand illusion induced activity in brain areas associated with anxiety and interoceptive awareness. The rubber-hand illusion also results in a distortion of proprioception. After experiencing the illusion, participants misperceive the location of their concealed hand toward the direction of the fake hand (i.e., proprioceptive drift; Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005).

3.1. Underlying Mechanisms

Similar to the Pinocchio illusion (see Chapter 2), the rubber-hand illusion depends on the capability of the central nervous system to extract correlations between the various sensory modalities (Armel & Ramachandran, 2003). In the rubber-hand illusion, the seen and felt stimulation co-occurs with such a high probability, that the brain cannot do else but deduce that the fake arm is part of the body. If this is no longer the case, for example when participants try to move the fake hand, or when there is a delay between seen and felt stimulation, the illusion will diminish or break down. Because of such an impeding effect of temporal delay on the vividness of the illusion, asynchronies of 500 to 1000 ms are commonly used as an experimental control condition in which the illusion is thought not to be elicited (e.g., Ehrsson, Spence, & Passingham, 2004; Tsakiris & Haggard, 2005).[12]

In Chapter 1, it was described how Cole and colleagues (2000) experienced a sense of ownership over the slave robot's arms, despite the obvious discrepancies between biological human arms and the iron mechanical limbs of the robot. For the rubber-hand illusion, several studies have explored the effects of discrepancies between the appearance of the fake hand and that of a human hand. Armel and Ramachandran (2003) demonstrated that the illusion could be elicited with the tabletop as the foreign object, which, of course, bears no visual resemblance to a human hand. In their experiment, they removed the fake hand from the table, and stroked the participant's concealed hand in precise synchrony with the tabletop (on the location where the fake hand had been). Their participants experienced psychological arousal (assessed by means of skin conductance response) when the tabletop was "harmed" by pulling a band-aid off the table (the experimenters also placed a band-aid on the participant's occluded hand before the start of the experiment). Based on this

[12] In these studies, time delay is typically only impressionistically determined and dependent on the skills of the experimenter who controls the delay between the stimulation of the real and fake hand manually (i.e., by an offset between the two brush strokes).

finding, they conclude (a) that the rubber-hand illusion is highly resistant to top-down knowledge about the appearance of one's own body, and (b) that reliable correlations of visuotactile events are both necessary and sufficient for self-attribution to occur. However, their participants rated the strength of the rubber-hand illusion to be much lower with the tabletop as compared to a fake hand as the foreign object. Similarly, Tsakiris and Haggard (2005) found that people showed less proprioceptive drift when the fake hand was replaced by a wooden stick. These findings suggest that bottom-up visuotactile correlations are modulated, top down, by a cognitive representation of what the human body is like (Tsakiris & Haggard, 2005; see also de Vignemont, Tsakiris & Haggard, 2006).[13]

3.2. Research Aims

In this chapter, we explore whether the rubber-hand illusion can also be elicited in mediated situations in which people are looking at a video projection of the fake hand rather than the actual object. By comparing a virtual and mixed reality version of the rubber-hand illusion with the traditional (i.e., unmediated) version, we aim to demonstrate that the mechanisms underlying the rubber-hand illusion are also operative in those instances in which the stream of sensory information is mediated by technology (as, for example, in the teleoperation systems described in Chapter 1).

3.3. Experiment

3.3.1. Method

Participants. Our sample was drawn from students and employees of the Eindhoven University of Technology, Eindhoven, the Netherlands. Thirty persons were invited to participate in the experiment. All participants were tested on their ability to experience the rubber-hand illusion several days prior to the actual experiment. Six (20%) out of 30 participants did not experience the illusion and were excluded from the experiment. Of the remaining 24 participants, the mean age was 23.4 (SD = 2.2; range 20 to 32 years); 16 participants were male, and 20 were right handed. All participants received a compensation of € 7.00.

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[13] Tsakiris and Haggard (2005) also found that proprioceptive drift would occur for the middle finger, when both the index and the little fingers were stimulated. The fact that proprioceptive drift can occur for a non-stimulated finger provides evidence against an exclusively bottom-up explanation as well (also de Vignemont et al., 2006).

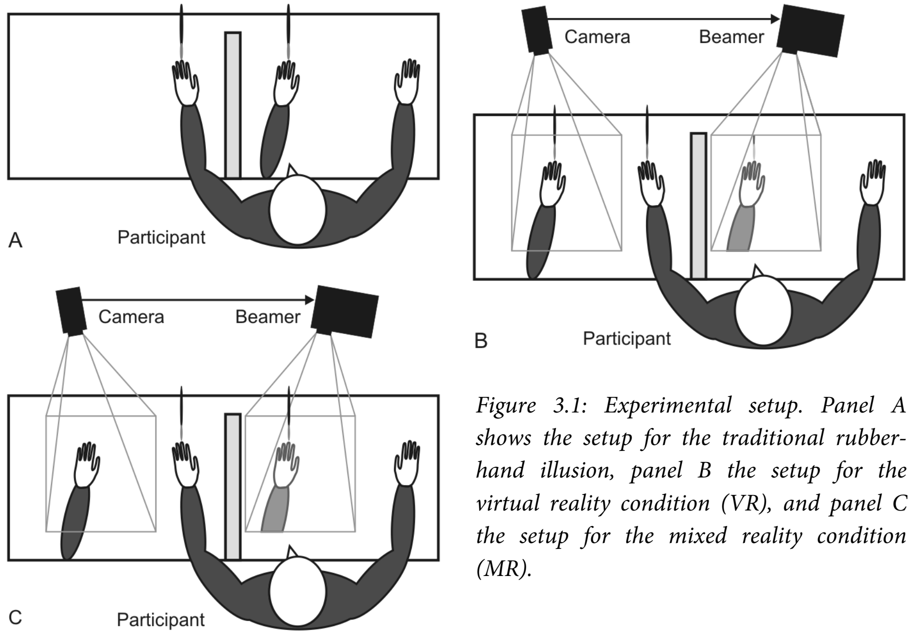

Figure 3.1: Experimental setup. Panel A shows the setup for the traditional rubber-hand illusion, panel B the setup for the virtual reality condition (VR), and panel C the setup for the mixed reality condition (MR).

Design and Apparatus. A within-subject experiment was conducted in which we tried to induce the rubber-hand illusion under three different conditions: (a) a traditional (i.e., unmediated) condition, (b) a virtual reality condition (abbreviated as VR), and (c) a mixed reality condition (MR). The traditional condition was similar to Botvinick and Cohen (1998; see Figure 3.1A). In the VR condition, participants were not looking at the fake hand directly, but were looking at video projection of the fake hand and its stimulation. A standard mini-DV camera, mounted on a tripod, was used to record the stimulation of the fake hand (see Figure 3.1B). The camera output was directly fed to an InFocus LP750 beamer that was mounted on the ceiling and projected the image of the fake hand and its stimulation downwards onto the tabletop surface in front of the participant. Care was taken that the projected hand was of the same size as the fake hand itself, and that its perspective was matching the participant's viewpoint. In the MR condition, the rubber hand was again projected in front of the participant, yet this time the stimulation with the brush was physically applied to the projection of the fake hand rather than to the fake hand itself (see Figure 3.1C). The order of the three conditions was counterbalanced across participants.

Procedure. Participants were asked to take a seat and place their left hand on a table. A pencil mark indicated the exact location at which participants had to place their middle finger. First, the experimenter obtained, for each participant, the base-line (i.e., pre-exposure) difference between actual and felt position of the left hand. For this task, the experimenter asked the participant to close his or her eyes. With eyes closed and keeping their left hand in place on the table, participants were asked to indicate the location of their left hand by moving their right hand in a straight line over the underside of the tabletop to indicate the felt position of the left hand. The differences between actual and felt position were calculated by taking the lateral distance between the middle fingers of the right and the left hand. It was coded with a positive sign when the felt position was biased towards the participant's right-hand side, and with a negative sign when the felt position was biased beyond the left hand's actual position.

Next, the rubber-hand illusion was induced in three 7.5 minute sessions. At the beginning of each session, the participant was asked to place his or her left hand back on the table in the position indicated by the pencil mark. Next, the experimenter either placed the fake hand in front of the participants (in the traditional condition), or projected the fake hand onto the tabletop (in the VR and MR condition). The lateral distance between the participant's left hand and the (projected) fake hand was always 30 cm. Participants were instructed not to move their left hand during the sessions, and to focus their attention on what they saw and felt. Next, the experimenter placed a wooden screen between the participant's left hand and the (projected) fake hand. Finally, the experimenter used two small brushes to stroke and tap the middle and index finger of the participant's left hand, and, simultaneously, congruent positions on the fake hand. Whereas the experimenter stimulated the fake hand in the traditional and VR condition, the projection of the fake hand was stimulated in the MR condition.

After each session, the experimenter obtained the post-exposure difference between actual and felt position of the left hand, and the participant completed a questionnaire. The post-exposure difference between actual and felt position was obtained by means of the same procedure as for the base-line differences.

Measures. Similar to previous studies on the rubber-hand illusion, both self-reports and a proprioceptive drift measure were employed (e.g., Botvinick & Cohen, 1998). The self-reports consisted of a questionnaire containing fixed response items and an open-ended question. The open-ended question asked participants to describe their experiences during

Table 3.1: Items of the self-report measure

	Items
1	It seemed as if I were feeling the touch in the location where I saw the fake hand touched.
2	It seemed as though the touch I felt was caused by the paintbrush touching the fake hand.
3	It felt as if the fake hand were my hand.
4	It felt as if my hand were drifting towards the fake hand.
5	It seemed as if I had more than one left hand or arm.
6	It seemed as if the touch I was feeling came from somewhere between my own hand and the fake hand.
7	It felt as if my hand was turning rubbery.
8	It appeared as if the fake hand were drifting towards my hand.
9	The fake hand began to resemble my hand in form.
10	The fake hand began to resemble my hand in texture.
11	It felt as if my hand was inside the fake hand.

the session in their own words. Whereas the self-reports tap more or less directly into the participants' experiences, proprioceptive drift is considered to be a corroborative behavioral measure of the rubber-hand illusion (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). We also informed participants that they were allowed to comment on their experiences during the sessions. During the actual experiment, we did not further encourage, nor remind, participants to do so. Remarks were transcribed by an experimenter.

The self-report items were adopted from Botvinick and Cohen (1998). Their questionnaire consisted of nine statements describing specific perceptual effects associated with the rubber-hand illusion, such as "I felt the rubber hand was my hand" or "It seemed as though the touch I felt was caused by the paintbrush touching the rubber hand". Several changes were made to this questionnaire. Firstly, all items were translated into Dutch. Secondly, the item "The rubber hand began to resemble my own (real) hand, in terms of shape, skin tone, freckles or some other visual feature" was divided into two separate items, one on the resemblance between the rubber hand and the real hand in terms of shape, the other in terms of texture. Thirdly, one item was added describing a sensation that a number of people reported during the pilot phase of the study: "It felt as if my hand was inside the fake hand". Participants were asked to indicate the extent to which each statement matched their own experiences on a seven-point scale ranging from "not at all" (coded with a 0) to "completely" (coded with a 6). The resulting 11 items are reported in the table 3.1. There were no missing responses.

Proprioceptive drift is conventionally defined as the difference between two differences: the baseline difference between actual and felt hand position (i.e., before exposure to the rubber-illusion) subtracted from the post-exposure difference between actual and felt position (Tsakiris & Haggard, 2005).[14] There were no missing responses.

3.3.2. Results

Self-Reports. Scores on the questionnaire items for the three experimental conditions are shown in Figure 3.2. Similar to previous findings with the same or a comparable sets of items, the first three items were most strongly affirmed and demonstrated the greatest effects of our manipulations (e.g., Botvinick & Cohen, 1998; Ehrsson, 2007; Peled, Ritsner, Hirschmann, Geva & Modai, 2000; for an overview see Holmes & Spence, 2007).[15] With these first three items as dependent variables, we performed a Multivariate Analysis of Variance (MANOVA) with the level of mediation (i.e., the traditional, VR, and MR conditions) as a within-subject factor. Using Wilks' criterion, we found that the combined dependent variables were significantly affected by the level of mediation, with $F(6, 88) = 9.1$, $p < .01$ and partial $\eta^2 = 38.2\%$. Subsequent contrast analyses revealed that participants agreed more strongly with all three items in the traditional (i.e., unmediated) condition compared to the two mediated conditions, with $F(1, 23) \geq 7.5$ and $p \leq .01$. Also, participants agreed more strongly to Items 2 and 3 (see Table 3.1) in the VR compared to the MR condition, with $F(1, 23) \geq 7.4$ and $p \leq .01$. For Item 1 (see Table 3.1), no significant difference was found between the VR and MR condition, with $F(1, 23) = 0.5$ and $p = .47$. The various *p*-values should, however, be interpreted with care, as assumptions of normality, and homogeneity of variance and covariance matrices were not met.

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[14] Other and / or additional baseline measures, such as the difference between actual and felt hand position after five minutes without stimulation, might perhaps be more informative. For now, we adopt Tsakiris and Haggard's definition of proprioceptive drift, but we consider additional baseline measures in Chapter 5.

[15] These three items are commonly regarded as most important in assessing the vividness of the rubber-hand illusion. Some researchers have argued that the remaining items of the questionnaire by Botvinick and Cohen (1998) ask about impressions unrelated to the rubber-hand illusion, and that participants who strongly agree on these items should be removed from the analysis to control for suggestibility and compliance with task demands (e.g., Ehrsson, 2007). In our opinion, such strong claims should be based on sound psychometric analyses of people's self-reported experiences. Such an analysis is reported in Chapter 6. For now, we make no commitment to any of these claims, and analyze the self-reports in multiple ways.

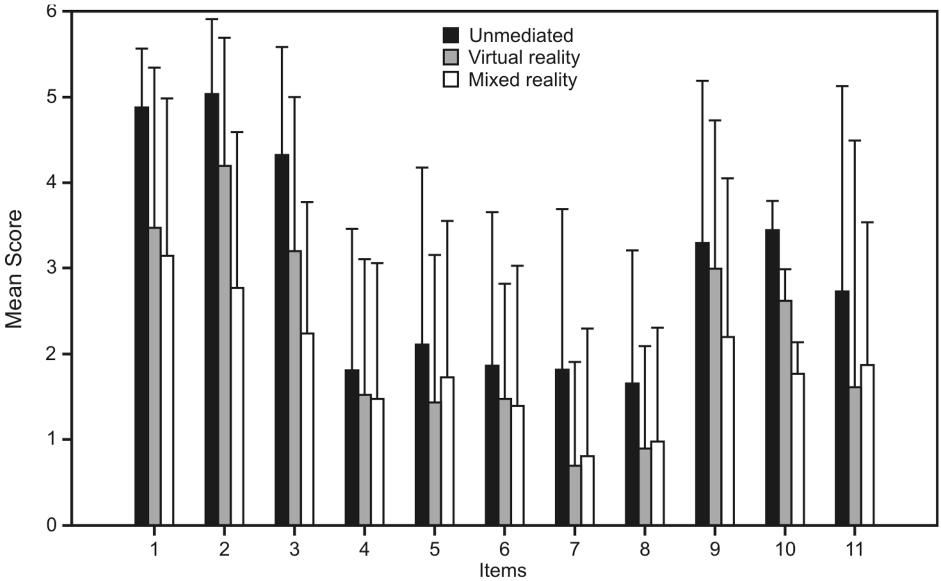

Figure 3.2: Average response and standard deviation for each of the 11 self-report items. See Table 3.1 for a description of the items.

As an alternative, we decided to calculate each person's mean score across all 11 items. The estimated reliability (Cronbach's alpha) of this aggregated self-report measure was $\alpha = .64$ in the traditional, $\alpha = .78$ in the VR, and $\alpha = .83$ in the MR condition. With these mean scores as the dependent variable, we performed a repeated measure Analyses of Variance (ANOVA) with level of mediation as the within-subject factor. This time, assumptions of normality and sphericity were met. As before, we found that the strength of the rubber-hand illusion was significantly affected by the level of mediation, with $F(2, 46) = 27.8$, $p < .01$ and partial $\eta^2 = 54.7\%$ (see Figure 3.3A). Further contrast analyses revealed that people experienced a stronger illusion in the traditional condition compared to the two mediated conditions, with $F(1, 23) > 27.7$, $p \leq .01$. Moreover, people experienced a stronger rubber-hand illusion in the VR as compared to the MR condition, with $F(1, 23) = 5.3$, $p = .03$.

Proprioceptive Drift. With proprioceptive drift as the dependent variable, we performed a repeated measures ANOVA with mediation as a within-subject factor. One participant was identified as an outlier, as his or her standardized drift score in the VR and MR conditions was larger than 3.0. With this participant removed from the analysis, assumptions of normality and sphericity were met. We found a significant effect of

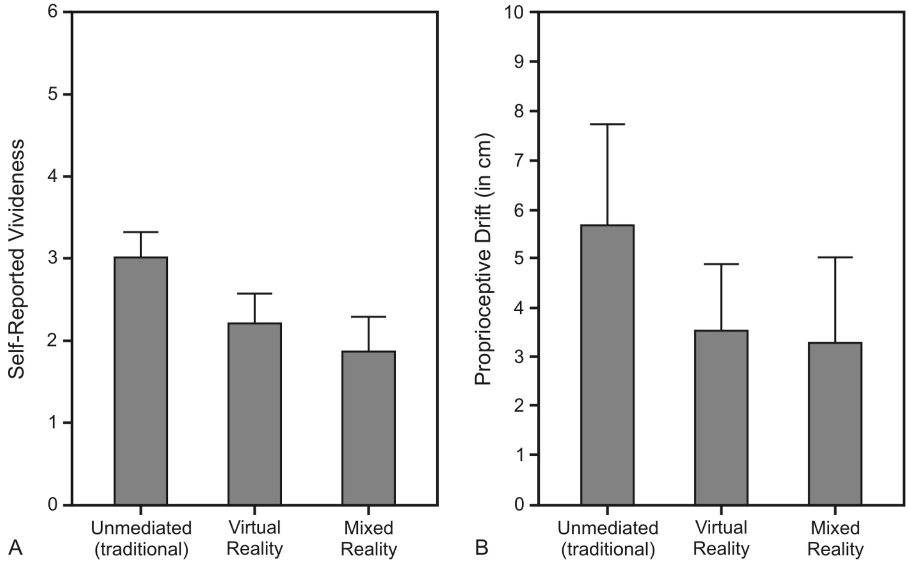

Figure 3.3: Mean self-reported vividness (Panel A) and mean proprioceptive drift (Panel B) for the three experimental conditions. Error bars depict 95% confidence intervals. In the estimation of proprioceptive drift, one outlier was removed.

mediation, with $F(2, 40) = 3.7$, $p = .03$, and partial $\eta^2 = 15.7\%$ (see Figure 3.3B). Contrast analyses revealed that participants showed significantly more drift in the traditional condition compared to the MR condition, with $F(1, 20) = 5.3$ and $p = .03$. The difference in drift between the traditional and the VR condition was found to be marginally significant, with $F(1, 20) = 3.9$, and $p = .06$. No difference was found between the two mediated conditions, with $F(1,20) = .01$, and $p = .75$.

Open-Ended Descriptions. Participants sometimes used descriptions that signaled a sense of bodily ownership of the fake hand: *"The feeling seems to build up the first few minutes and then, all of a sudden, the hand feels like my own. And after a while they [the fake hand and the participant's own hand] start to look the same as well"*, or *"Quickly you have the feeling* [that] *the rubber hand is really your hand, you can really feel it being touched"*. One participant remarked that the illusion was particularly vivid when fingers of the fake hand moved a little as a result of the force applied by the experimenter. In the VR condition, participants sometimes claimed that they felt as if the projection of the fake hand was a projection of their own hand: *"I had a feeling I was looking at a projection of my own hand"*, or *"It quickly appeared as if the projection was my own hand, and my own hand was* *being touched"*. Interestingly, in the MR condition participants sometimes noted that the flat image appeared to obtain volume: *"It felt as if the projection became three-dimensional, just like my own hand"*, or *"The illusion was not strong, but the image appeared to become 3D as time passed"*.

3.4. Discussion

As demonstrated by both our participants' self-reports and a proprioceptive drift measure, we were able to elicit the rubber-hand illusion under mediated conditions, in which people were watching a projection of the fake hand rather than the actual object. However, the resulting vividness with which people experienced the illusion was less in the mediated conditions as compared to the traditional (i.e., unmediated) condition. This finding partially contradicts Armel and Ramachandran's (2003) claim that reliable correlations of visuotactile events are both necessary and sufficient to constitute self-attribution. If this were true, then no difference ought to be found between the mediated and the unmediated conditions. The main difference between the mediated and unmediated conditions was that in both mediated conditions the foreign object was flat rather than three-dimensional. The results, thus, point toward a role of top-down mechanisms that impose restrictions on the appearance of the foreign object, thereby supporting the view that the rubber-hand illusion is affected, top-down, by a cognitive representation of the human body (Tsakiris and Haggard, 2005; see also de Vignemont et al., 2006). Based on our experiment, we can argue that such a top-down cognitive body representation needs to include a specification of the three dimensional shape of the hand as this was the main difference between the mediated and unmediated conditions. This issue needs to be investigated further, for example, by means of stereoscopic imaging.[16]

Although the difference between the VR (in which the fake hand and its stimulation were projected) and the MR condition (in which stimulation was applied to the projection of the fake hand) was not always found to be statistically significant, the VR condition seems to be slightly more capable of eliciting a vivid rubber-hand illusion. This difference between the VR and the MR condition can, however, not be explained by differences in

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[16] Slater, Perez-Marcos, Ehrsson and Sanchez-Vives (2008) have recently induced the rubber-hand illusion in an immersive virtual environment in which, by means of stereoscopic imaging, a virtual arm was attached to people's right shoulder. The authors, however, did not make a direct comparison with either the traditional (i.e., unmediated) setup, or the two-dimensional setup presented in this chapter.

appearance of the foreign object which was similar in the VR and MR condition. A plausible explanation is suggested by the open-ended descriptions. In the VR condition a considerable number of participants had the impression that the projected hand was a video recording of their own concealed hand. None of the participants mentioned this in the MR condition (which would not have made sense since the stimulation was applied to the projected image). In the MR condition, the illusion appears to suffer somewhat from the conflict between the real brush and the virtual hand. This finding points toward the basic challenge of creating seamless perceptual fusion between the real and the virtual in mixed reality. Such a seamless fusion did not seem to occur in our experiment, although some participants mentioned that it appeared as though the two-dimensional image became three-dimensional. Interestingly, this was only mentioned after the MR condition. This specific impression, thus, could be related to the perceptual system solving the contradiction of watching a flat hand being stroked by a three-dimensional brush.

By demonstrating that the rubber hand illusion can be reproduced under mediated conditions, we have shown that the mechanisms underlying the illusion are also operative in mediated situations. This is promising for two reasons. First, to obtain a deeper understanding of the various factors that constrain or facilitate people in developing a vivid illusion, it is necessary to have complete and systematic control over the variables one may want to manipulate. Mediated environments provide such a level of control by combining the ability to systematically tweak relevant variables with high ecological validity, and the precise replication of conditions (Loomis, Blascovich, & Beall, 1999). The setup of the virtual reality version of the rubber-hand illusion could, for example, be extended with a digital delay unit operating on the output of the camera. This would allow for a precise and controlled manipulation of temporal asynchrony between seen and felt stimulation. Second, since the mechanisms underlying the illusion are also operative in mediated situations, research on the rubber-hand illusion can, in turn, provide structure to the design of media technologies that benefit from self-attribution. Determining the various factors that facilitate or constrain self-attribution will aid in development of a set of requirements for such media technologies as the teleoperation systems discussed in the outset of this thesis.

— Chapter 4 —

The Effect of Fake Hand Appearance on the Rubber-Hand Illusion[17]

...equality of appearance is neither necessary nor a sufficient condition of identity. One egg looks just like another egg and still they are not the same: Incubating one would not make the other one hatch. In contrast, the little puppet into which the voodoo priest sticks his needles, only remotely resembles the life victim, and nevertheless the latter is expected to suffer from the procedure.

—Doris Bischof-Köhler

Abstract

In the rubber-hand illusion, people attribute a foreign object to their own body. In this chapter, we investigate the extent to which the rubber-hand illusion is affected by visual discrepancies between the foreign object and a human hand. We tested Armel and Ramachandran's (2003) hypothesis that people will experience a stronger rubber-hand illusion when the foreign object is a skin-like textured sheet instead of a tabletop. We did not find support for their hypothesis, but the strength of the illusion diminished when the texture of a hand-shaped object did not resemble the human skin (manipulated by putting a white glove over the cosmetic prosthesis). We provide an alternative explanation for this finding, based on a skill-based sensorimotor account of perceived body ownership. Such an explanation supports Armel and Ramachandran's more general claim that discrepancies in the nature of expected and felt touch diminish the rubber-hand illusion.

Research on the rubber-hand illusion, such as described in the previous chapter, has provided substantial empirical evidence regarding the mechanisms that underlie self-attribution (i.e., the discrimination between what belongs and does not belong to the body). Research has demonstrated that the perceived boundaries of the body are not hard-wired, but are dynamically inferred through the integration of sensorimotor information. A process which, in turn, is modulated by the morphological characteristics of the human

[17] This chapter is based on Haans, IJsselsteijn, and de Kort (2008).

body. Armel and Ramachandran (2003), for example, demonstrated that the vividness of the rubber-hand illusion is considerably diminished when the illusion is induced with the tabletop as the foreign object, which, of course, bears no visual resemblance to a human hand. Similarly, Tsakiris and Haggard (2005) have shown that the extent to which the illusion occurs is considerable reduced when a wooden stick rather than a human hand is used as the foreign object. These findings demonstrate that reliable correlations between seen and felt touch are not sufficient to elicit a vivid rubber-hand illusion, and suggest that bottom-up visuotactile correlations are modulated, top down, by a cognitive representation of what the human body is like (Tsakiris & Haggard, 2005; see also de Vignemont et al., 2006). This view is supported by our experiment in Chapter 3, which demonstrates that people experience a less vivid rubber-hand illusion when looking at a two-dimensional projection of the fake hand rather than the actual, three-dimensional, fake hand.

In addition to this impeding effect of visual dissimilarities between the foreign object and a human hand, Armel and Ramachandran (2003) have argued that discrepancies in the nature of expected and actually felt touch may also diminish the rubber-hand illusion. They reported, anecdotally, that their participants experienced a stronger illusion 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 rubber-hand illusion when the foreign object is a skin-like textured sheet (i.e., visually resembling the human skin) instead of a tabletop.

4.1. Research Aims and Hypotheses

In this chapter, we further explore the extent to which the rubber hand illusion is affected by discrepancies between the morphology of the foreign object and that of a human hand. In contrast to previous research (e.g., Tsakiris & Haggard, 2005), we explore the effects of dissimilarities in shape and texture independently by systematically manipulating these qualities of the foreign object. With respect to shape, we expect to corroborate existing research which shows that people develop a more vivid rubber-hand illusion when the foreign object resembles a human hand (e.g., Armel & Ramachandran, 2003; Tsakiris & Haggard, 2005). In other words, we expect that hand-shaped objects are more easily attributed to the self than non-hand-shaped objects. The effect of texture has, to our knowledge, not yet been empirically examined. However, a similar effect is to be expected as for shape: People will develop a stronger illusion when the texture of the foreign object resembles the human skin. Specifically, we expect to provide empirical support for Armel and Ramachandran's (2003) hypothesis that a skin-like textured sheet would induce a stronger illusion than a tabletop.

4.2. Experiment

4.2.1. Method

Design. A two (hand vs. no hand shape) by two (natural vs. non-natural skin texture) repeated measures experiment was conducted. For the hand shape with natural texture condition (further to be referred to as the ST condition), a cosmetic prosthesis of a man's left hand was used which was highly realistic in terms of skin texture, color, and shape. For the hand shape with non-natural texture condition (S¬T), a white latex glove was fitted over the prosthesis to modify texture and color, but not shape. For the no hand shape with natural texture condition (¬ST), a flat sheet (size 24 by 13 cm) of the same material as the prosthesis was used (as suggested by Armel & Ramachandran, 2003). Finally, for the no hand shape with non-natural texture condition (¬S¬T), no object was used, thereby leaving only the white tabletop to be stimulated. The ST condition was always in the first session as this condition was used to select only those participants that were susceptible to the traditional version of the illusion. The order of the remaining three conditions was counterbalanced across participants.

Participants. Our sample was drawn from students and employees of the Eindhoven University of Technology, Eindhoven, the Netherlands. Twenty-six persons were invited to participate in the experiment. Three (11.5%) out of 26 participants did not experience the illusion in the ST condition. Of the remaining 23 participants, the mean age was 22.3 (*SD* = 2.2; range 18 to 27 years); 14 participants were male, and 18 were right handed. All participants received a compensation of € 7.00.

Procedure. Participants were asked to take a seat and place their left hand on a table. A pencil mark indicated the exact location at which participants had to place their middle finger. First, the experimenter obtained, for each participant, the base-line (i.e., pre-exposure) difference between actual and felt position of the left hand. In an attempt to increase the accuracy of the estimation, this difference was obtained in a different manner as in the experiment in Chapter 3. First, the experimenter asked the participant to close his or her eyes. Subsequently, the experimenter placed a small platform (30 cm by 80 cm with a

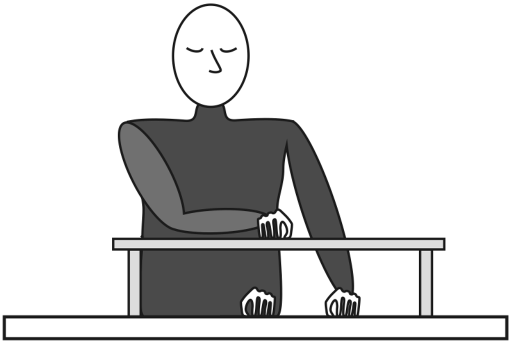

Figure 4.1: Experimental setup for the measurement of proprioceptive drift

height of 24 cm) over the participant's left hand (see Figure 4.1). Next, the experimenter guided the participant's right hand to the right most edge of the platform (from the participant's point of view), and instructed the participant to slide his or her hand over the platform to indicate the felt position of the left hand. The differences between actual and felt position were calculated by taking the lateral distance between the middle fingers of the right and the left hand. It was coded with a positive sign when the felt position was biased towards the participant's right-hand side, and with a negative sign when the felt position was biased beyond the left hand's actual position. The difference between actual and felt position was consecutively assessed three times.

The experimenter removed the platform, and instructed the participant to move his or her hands for a while. Next, the rubber-hand illusion was induced in four five minute sessions. At the beginning of each session, the experimenter placed the foreign object in front of the participant (depending on the experimental condition, a cosmetic prosthesis, a white fake hand, a sheet of skin-like material, or no object was used). The participant was asked to place his or her left hand back on the table in the position indicated by the pencil mark (at a lateral distance of 30 cm from the foreign object), to keep the hand motionless during the session, and to focus his or her attention on what he or she saw and felt (see Figure 3.1A). Next, the experimenter placed a wooden screen between the participant's left hand and the foreign object. Finally, the experimenter used two small brushes to stroke and tap the middle and index finger of the participant's left hand, and, simultaneously, congruent positions on the foreign object. After each session, the experimenter obtained the post-exposure difference between actual and felt position of the left hand, and the participant completed a questionnaire. The post-exposure difference between actual and felt position was obtained by means of the same procedure as for the base-line differences. This time, however, only a single difference was obtained for each participant.

Measures. Similar to the experiment in the Chapter 3, we employed both self-reports and a proprioceptive drift measure. The self-reports, again, consisted of a questionnaire containing fixed response items and an open-ended question. The open-ended question asked participants to describe their experiences during the session in their own words. Whereas the self-reports tap more or less directly into the participants' experiences, proprioceptive drift is considered to be a corroborative behavioral measure of the rubber-hand illusion (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). At the beginning of the experiment, we also informed participants that they were allowed to comment on their experiences during the sessions. During the actual experiment, we did not further encourage, nor remind, participants to do so. Their remarks were transcribed by an experimenter.

The self-report items were adopted from Chapter 3. For the purpose of the present experiment, however, several changes were made. First of all, the statements "The foreign object began to resemble my hand in form" and "The foreign object began to resemble my hand in texture" were excluded as these might potentially be biased in favor of the hand shape and natural texture conditions. Secondly, the statement "It felt as if my hand was turning rubbery" was changed into "It felt as if my hand was turning into the same material as the foreign object". Thirdly, the term "foreign object" in the statements was replaced by the appropriate term for each condition (e.g., "fake hand" or "rubber sheet"). Participants were asked to indicate the extent to which each statement matched their own experiences on a seven-point scale ranging from "not at all" (coded with a 0) to "completely" (coded with a 6). The resulting nine items are reported in Table 4.1. There were no missing responses.

Proprioceptive drift is defined as the difference between two differences: the baseline difference between actual and felt hand position (i.e., before exposure to the rubber-illusion) subtracted from the post-exposure difference between actual and felt position (Tsakiris & Haggard, 2005). Since baseline differences were obtained three times for each participant (Cronbach's $\alpha = .95$), the participant's average baseline difference was used for the calculation of his or her proprioceptive drift. There were no missing responses.

Table 3.1: Items of the self-report measure

	Items
1	It seemed as if I were feeling the touch in the location where I saw the *foreign object* being touched.
2	It seemed as though the touch I felt was caused by the paintbrush touching the *foreign object.*
3	It felt as if the *foreign object* were my hand.
4	It felt as if my hand were drifting towards the *foreign object.*
5	It seemed as if I had more than one left hand or arm.
6	It seemed as if the touch I was feeling came from somewhere between my own hand and the *foreign object.*
7	It felt as if my hand was turning into the same material as the *foreign object.*
8	It appeared as if the *foreign object* were drifting towards my hand.
9	It felt as if my hand was inside the *foreign object.*

Note that the term foreign object *was replaced by the appropriate term for each experimental condition.*

4.2.2. Results

Self-Reports. Scores on the questionnaire items for the four experimental conditions are shown in Figure 4.2. Similar to the experiment in Chapter 3, the first three items were most strongly affirmed and also demonstrated the greatest effects of our manipulations. With these first three items as dependent variables, we performed a two (hand vs. no hand shape) by two (natural vs. non-natural skin texture) repeated measures Multivariate Analysis of Variance (MANOVA). Using Wilks' criterion, we found that the combined dependent variables were significantly affected by Shape, with $F(3, 20) = 28.5$, $p < .01$, and partial $\eta^2 = 81.0\%$, indicating that a hand-shaped object induced a stronger rubber-hand illusion than a non-hand-shaped object. In contrast, we did not find a significant main effect of Texture, with $F(3, 20) = 2.2$, $p = .12$, and partial $\eta^2 = 24.6\%$. The Shape by Texture interaction, however, was found to be significant, with $F(3, 20) = 4.7$, $p = .01$, and partial $\eta^2 = 41.4\%$. Additional simple effect analyses on the combined dependent variables showed that a natural skin texture increased the strength of the rubber-hand illusion for a hand-shaped object, with $F(3, 20) = 7.4$, $p < .01$, and partial $\eta^2 = 52.7\%$, but not for a non-hand-shaped object, with $F(3, 20) < 0.1$, $p = .98$, and partial $\eta2 = 1.0\%$. The various p-values should however be interpreted with care as assumptions of normality, and homogeneity of variance and covariance matrices were not met.

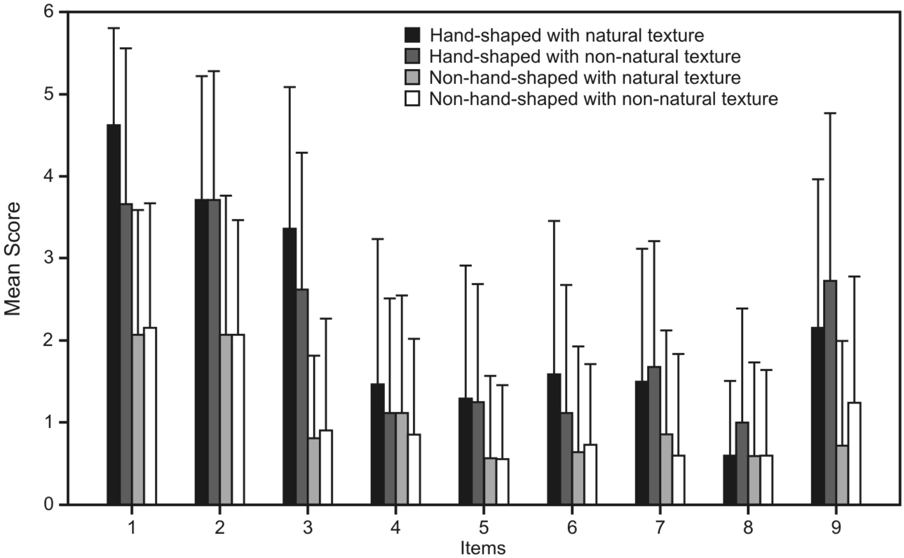

Figure 4.2: Average response and standard deviation for each of the 9 self-report items. See Table 4.1 for a description of the items.

As an alternative, we calculated each person's mean score across all 9 items, and we used those as an aggregated measure of the vividness of the rubber-hand illusion in our analyses. The estimated reliability (Cronbach's alpha) of this aggregated vividness measure was $\alpha = .62$ in the ST, $\alpha = .72$ in the S¬T, $\alpha = .83$ in the ¬ST, and $\alpha = .89$ in the ¬S¬T condition. With these mean scores as the dependent variable, we performed a repeated measure Analyses of Variance (ANOVA) with Shape and Texture as within-subject factors. This time, assumptions of normality and sphericity were met. As before, we found a statistically significant main effect of Shape, with $F(1, 22) = 53.6$, $p < .01$, and partial $\eta^2 = 70.9\%$, but no significant main effect of Texture, with $F(1, 22) = 0.4$, $p = .56$, and partial $\eta^2 = 1.6\%$ (see Figure 4.3A). Although the effect of texture was again larger for a hand-shaped compared to a non-hand shaped object, this time the difference was not found to be statistically significant, with $F(1, 22) = 0.7$, $p = .40$, and partial $\eta^2 = 3.2\%$.

Proprioceptive Drift. Participants showed, on average, a pre-exposure difference between actual and felt position of the left hand of $M = 3.5$ cm with $SE = 0.9$ (i.e., towards the participant's right-hand side). The average post-exposure difference was $M = 7.1$ cm ($SE = 1.0$) after the ST, $M = 7.2$ cm ($SE = 1.3$) after the S¬T, $M = 6.5$ cm ($SE = 0.9$) after the ¬ST, and $M = 7.4$ cm ($SE = 1.4$) after the ¬S¬T condition. We used a series of paired sample

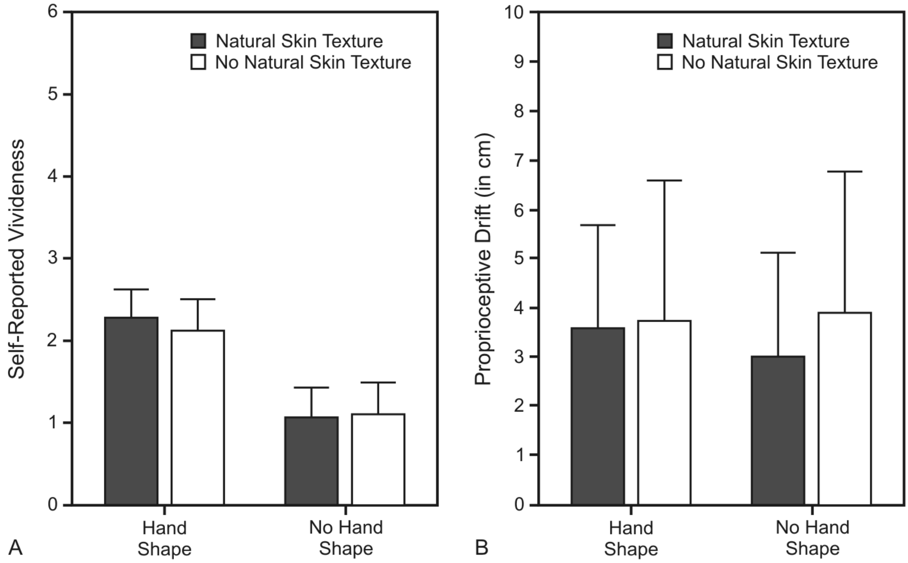

Figure 4.3: Mean self-reported vividness (Panel A) and mean proprioceptive drift (Panel B) for the three experimental conditions. Error bars depict 95% confidence intervals.

t-tests to compare pre- and post-exposure differences. Post-exposure differences were found to be significantly different from pre-exposure differences for all experimental conditions, with $t(22) \geq 2.7$ and $p \leq .02$.

Secondly, we calculated each person's proprioceptive drift (i.e., post minus pre-exposure difference between actual and felt position of the left hand) and performed a repeated measure ANOVA with Shape and Texture as within-subject factors. Assumptions of normality and sphericity were met. None of the effects were found to be significant, with $F(1, 22) \leq 0.8$, $p \geq .38$ and partial $\eta^2 \leq 3.5\%$ (see Figure 4.3B).

Open-Ended Descriptions. Generally, participants made spontaneous remarks like *"this was strange"* or *"something was not right here"*. During the sessions, one participant remarked, *"Sometimes I was not sure whether my hand was still being stimulated by the brush"*. In the S¬T condition, this same participant noticed that the stimulation of his own hand and the fake hand were implausibly similar: *"There were so many small details (e.g., a couple of hairs on the brush that leaped from one finger to the other) that I both saw and felt, which cannot have happened synchronously"*. Interestingly, some participants remarked that the felt stimulation in the S¬T condition did not match their expectations: e.g., *"If I would* *have worn a glove,* [then] *it would have made more sense, as the stimulation of the glove* [on the foreign object] *did not match with what I felt".*

In the ST condition, one participant remarked, *"I was sure that when I would move a finger, I would see the finger of the fake hand move as well".* Such feelings of perceived agency were described by several other participants as well. One male participant, for example, remarked, *"Sometimes it felt as if the fake hand would respond to my movements".* Some of these participants had a similar experience in the S¬T condition.

Our participants differed in the location in which they perceived their left hand to be. In the S¬T condition, some participants had the feeling that their hand was inside the glove. After the ¬ST condition, one female participant wrote, *"It seemed as if my hand was on top of the rubber sheet".* In contrast, another participant experienced her hand to be under the sheet. In the ¬S¬T condition, one participant remarked, "[It seemed] *as if I felt my hand to be underneath the table, feeling the stroking that occurred on the surface".* In that same condition, another participant remarked, "*At one time, I saw a hand shape emerge on the table".* Another participant wrote down a similar experience: *"I saw my hand appear on the table, but as a transparent ghost hand".*

4.3. Discussion

On the self-report measure, we found that a hand-shaped object induced, as expected, a stronger rubber-hand illusion than a non-hand-shaped object (cf. Armel & Ramachandran, 2003; Tsakiris & Haggard, 2005). In contrast, we did not find a significant main effect of texture, but there was a significant shape by texture interaction (at least in the MANOVA analysis on the three items normally considered as most important in assessing the vividness of the illusion; e.g., Ehrsson, 2007; see also Chapter 3). Further analyses showed that a natural skin texture increased the strength of the rubber-hand illusion for a hand-shaped object, but not for a non-hand-shaped object. These findings corroborate the hypothesis that the rubber-hand illusion diminishes when the foreign object does not resemble the human hand, and thus supports the view that the rubber-hand illusion is affected by top-down cognitive information regarding what a human body is like (Tsakiris & Haggard, 2005; de Vignemont et al., 2006; see also Chapter 3). Our experiment, however, does not support Armel and Ramachandran's (2003) hypothesis that a skin-like textured sheet induces a stronger rubber-hand illusion than the tabletop.

Although we did not find support for Armel and Ramachandran’s (2003) hypothesis that people will experience a stronger rubber-hand illusion when the foreign object is a skin-like textured sheet rather than the tabletop, people experienced a stronger illusion when a natural skin-like texture was applied to a fake hand (at least when assessed with the first three item of the questionnaire). In contrast, no such effect of texture was found for the tabletop conditions. In this study, we used a white latex glove to manipulate the color and texture of the fake hand. By doing so, we not only reduced textural similarity, but perhaps inadvertently changed the expected pattern of sensorimotor contingencies as well. During and after the S¬T session, several participants remarked that their tactile sensations did not match those generally perceived while wearing gloves. It is not unlikely that people know (in a skill-like fashion; cf. O’Regan et al., 2005) how their tactile sensations change when they put on gloves. People, for example, might know the difference in "feel" between being touched directly on the skin and while wearing gloves (or a band-aid). To experience the gloved fake hand as a part of the body, the perceived sensorimotor contingencies should match those that normally occur while wearing latex gloves. It might, thus, be that the significant difference between the ST and S¬T conditions on the first three items of the self-report measure is not an effect of visual similarity, but an effect of a change in the admissible pattern of sensorimotor correlations. This would explain why texture had an effect on the hand-shaped objects, but not on the non-hand-shaped objects. Such an explanation supports Armel and Ramachandran’s (2003) more general claim that discrepancies in the nature of expected and felt touch diminish the rubber-hand illusion.[18]

The qualitative data that were gathered during the two experiments show substantial individual differences in the vividness with which people develop the rubber-hand illusion, even when the experimental conditions are similar between participants. Whereas some participants’ rubber-hand illusion is limited to experiencing something strange, others even reported to have had the vivid impression that they could move the foreign object. These

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[18] Unfortunately, the rubber-hand illusion procedure employed in the present study cannot separate the effect of visual similarity from that of knowledge regarding sensorimotor contingencies with respect to tactile sensations. Instead, future studies into this issue might use a somatic version of the rubber-hand illusion (see Ehrsson, Holmes & Passingham, 2005). In this somatic version of the rubber-hand illusion, the experimenter takes hold of the index finger of a person’s right hand and strokes that finger over an foreign object. Simultaneously, the experimenter uses his or her own index finger to stroke the person’s left hand in a synchronous manner. Since the participant is blindfolded, this setup allows an investigation of the effect of tactile discrepancies (i.e., discrepancies in feel) in isolation from visual discrepancies (i.e., discrepancies in appearance).

data point toward an illusion that is not only experienced at different levels of vividness, but that is marked by considerable individual differences as well. To date, only a few studies have investigated these individual differences in the rubber-hand illusion (MacLachlan, Desmond & Horgan, 2003; Mussap & Salton, 2006; for similar studies regarding other experimentally induced body illusions, see Burrack & Brugger, 2005; Juhel & Neiger, 1993). Further research is needed to understand the physiological mechanisms behind, and personality correlates of these individual differences in people's susceptibility to experimentally induced body illusions.

Similar to the experiment in Chapter 3, there was a slight difference in the interpretation of the results when the vividness of the illusion was assessed by means of an aggregated score across all self-reports, and when assessed by means of the first three self-reports only (which are commonly regarded as most important for assessing the illusion; see Chapter 3). In this chapter, the shape by texture interaction was statistically significant when the first three items were considered, but not when all items were considered. In contrast, the difference between the VR and the MR condition in Chapter 3 was statistically significant when all items were included in the analyses, but not when only the first three items were included in the analysis. Further research is, therefore, needed to determine which of the impressions contained within these items can best distinguish between the various levels of vividness of rubber-hand illusion.

Although the proprioceptive drift measure largely corroborated self-reports in Chapter 3, this was clearly not the case in the present experiment. Contrary to our expectations, no differences were found on the proprioceptive drift measure: Participants showed the same amount of proprioceptive drift in all experimental conditions. This is surprising, since Tsakiris and Haggard (2005) found that people showed significantly less proprioceptive drift when a wooden stick was used as the foreign object rather than a cosmetic prosthesis. However, there are several notable differences between our method of measuring proprioceptive drift and the method used by Tsakiris and Haggard. Their participants reported on where their left hand was located, whereas our participants reported on where they felt their left hand was located. Gross and Melzack (1978) prefer the latter method of estimating drift, since some (yet few) people are aware of the difference between felt and actual (i.e., remembered) location of their left hand. Secondly, the two methods differ in how participants made their reports. Whereas the participants of Tsakiris and Haggard made their reports verbally, our participants pointed to the felt location with their other hand. However, when directly comparing the two methods of estimation, Gross, Webb and Melzack (1974) did not find a substantial difference between reports made verbally or by pointing with the other hand. Finally, compared to Tsakiris and Haggard, we only partially counterbalanced the experimental conditions (i.e., each participant did the ST condition first), therefore our proprioceptive drift measurements may have been more vulnerable to carry-over effects. Since the proprioceptive drift measure did not always corroborate the self-report measure, further research is needed to demonstrate the conditions under which proprioceptive drift can be assumed to reliably correspond to the vividness of people's rubber-hand illusion.

In sum, we have corroborated that a hand-shaped foreign object can be more easily attributed to the self than a non-hand-shaped object (e.g., Armel & Ramachandran, 2003; Tsakiris & Haggard, 2005). Our results, thus, support the view that bottom-up visuotactile correlations are modulated, top down, by a cognitive representation of what the human body is like (see also de Vignemont et al., 2006). In contrast, we did not find support for Armel and Ramachandran's (2003) hypothesis that a skin-like textured sheet would allow for a more vivid illusion than a tabletop. Instead, we found that texture might have an effect on a hand-shaped object: The rubber-hand illusion was significantly decreased when the texture of the fake hand did not resemble the human skin. This finding seems to support Armel and Ramachandran's more general claim that discrepancies in the nature of expected and felt touch diminish the rubber-hand illusion.

— Chapter 5 —

Magnitudes of Drift

Abstract

In the rubber-hand illusion, people commonly misperceive the location of their concealed hand toward the direction of the fake hand (so-called proprioceptive drift). To what extent can this perceptual recombination of proprioception be attributed to experiencing the illusion? In this chapter, we investigate the extent to which the various features of the experimental setup of the rubber-hand illusion, which in themselves are not sufficient to elicit the illusion, affect proprioceptive drift. Our experiments corroborate existing research demonstrating that looking at a fake hand or a tabletop for five minutes, in absence of visuotactile stimulation, is sufficient to induce a change in the felt position of an unseen hand. In addition, our experiments indicate that the use of proprioceptive drift as a measure for the strength of the rubber-hand illusion might yield different conclusions than an assessment by means of self-reports. Results are discussed in terms of the validity of proprioceptive drift as a measure of the vividness of the rubber-hand illusion.

In the rubber-hand illusion, people commonly misperceive the location of their concealed hand toward the direction of the fake hand (e.g., Botvinick & Cohen, 1998; see also chapters 3 and 4). In the literature on the rubber-hand illusion, this shift in the felt position of the concealed hand is called proprioceptive drift (e.g., Tsakiris & Haggard, 2005). This proprioceptive drift seems similar to the perceptual recombination of proprioception that is found in prism adaptation studies (for an overview, see Welch, 1986). When seen and actual position of a limb are in conflict, the visually displaced limb is usually felt where it is seen; a phenomenon known as immediate visual capture (Welch & Warren, 1980). 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., Groen & Werkhoven, 1998; Held & Durlach, 1991). Moreover, proprioceptive drift of a concealed hand occurs also when there is no kinesthetic and visual information about hand position, for example, when kinesthetic information is blocked by pressure-cuffs (Gross & Melzack, 1978) or anesthetics (Melzack & Bromage, 1973), or when people are asked not to move their concealed arm for a while (Gross et al., 1974; Wann & Ibrahim, 1992). In such situations, people feel that their concealed hand is located closer to the body midline than it actually is. Moreover, these studies demonstrate that the proprioceptive drift continues over time with felt hand position slowly approaching the chest, thereby apparently following a path that is anatomically possible.

Proprioceptive drift, thus, is not limited to the rubber-hand illusion, but is common in situations in which there is a conflict between kinesthetic and visual information, or in which there is no such sensory information from which arm location can be deduced. The experimental setup in which the rubber-hand illusion is elicited provides a combination of these two factors: People have little kinesthetic and no visual information regarding the location of their left hand for a considerable amount of time (e.g., five minutes), and the location of the visible fake hand is in conflict with actual hand location. Both these factors can contribute to the shift in felt hand position that is commonly observed in research on the rubber-hand illusion, but they are in themselves not sufficient to elicit the rubber-hand illusion. Yet, the extent of proprioceptive drift is commonly regarded as a corroborative measure of the vividness of the rubber-hand illusion (e.g., Tsakiris & Haggard, 2005). The question is: To what extent can proprioceptive drift be attributed to experiencing the illusion?

5.1. Research Aims

In this chapter, two studies are reported in which we examine the perceptual recombination of proprioception that occurs under various conditions related to the setup of rubber-hand illusion. Knowing the various magnitudes with which proprioceptive drift occurs under these conditions is important to assess the effect of the rubber-hand illusion on proprioceptive drift: If experiencing the rubber-hand illusion does increase a person's proprioceptive drift, then drift ought, at least, to be higher in conditions in which people can develop the illusion (i.e., when synchronous stimulation is applied to the participant's concealed hand and the fake hand), compared to those conditions in which they are not expected to develop the illusion (e.g., when no tactile stimulation is applied). Additionally, by comparing proprioceptive drift with people's self-reported vividness of the illusion, we aim to provide empirical support for the often made claim that proprioceptive drift is a corroborative measure of the vividness of the rubber-hand illusion (e.g., Tsakiris & Haggard. 2005).

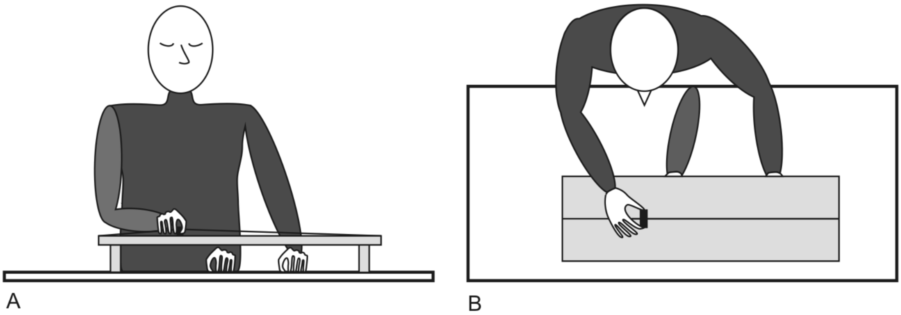

Figure 5.1: The setup for the measurement of proprioceptive in front view (Panel A) and top view (Panel B).

For the two experiments described in this chapter, several changes were made to the platform on which participants had to indicate the felt position of their left hand (cf. Figure 4.1). The table was lowered to nine cm, thereby bringing the platform as closely as possible to the participant's left hand underneath (i.e., without the underside of the table touching the hand; see Figure 5.1). By decreasing the vertical distance between the left hand and the platform on which participants indicate the felt location of their left hand, we aimed to increase the accuracy with which felt hand position could be estimated. For a better assessment of the lateral distance between felt and actual hand position, a string was mounted over the length of the platform to which a small wooden block (4.0 cm by 1.5 cm by 1.5 cm) was attached. By sliding the small wooden block over the platform, participants could indicate the felt position of his or her concealed left hand. For the remainder, the procedure of measuring proprioceptive drift remained similar to previous chapters.

5.2. Experiment 1: Various Magnitudes

5.2.1. Method

Participants. Our sample was drawn from students and employees of the Eindhoven University of Technology, Eindhoven, the Netherlands. Twenty-three persons were invited to participate in the experiment. Several days prior to the actual experiment, all participants were tested on their ability to experience the rubber-hand illusion. Five (22%) out of 23 participants did not experience the illusion and were excluded from the experiment. Of the remaining 18 participants, the mean age was 25.9 (*SD* = 7.5; range 20 to 52 years); 12 were male; 17 were right handed. All participants received € 3.50 as compensation.

Design. A within-subject experiment was conducted in which we assessed the magnitude of people's proprioceptive drift under three different conditions: (a) A "real and fake hand" condition in which the participant's concealed hand was stimulated in precise synchrony with a visible fake hand (i.e., the traditional rubber-hand illusion setup; see Figure 3.1A), (b) a "real hand only" condition in which the participant's concealed hand is stimulated, but not the fake hand, and (c) a "fake hand only" condition in which the fake hand is stimulated, but not the participant's concealed hand. The order of the conditions was counterbalanced across participants.

Procedure. At the beginning of the experiment, participants were asked to take a seat and place their left hand on a table. A pencil mark indicated the exact location at which participants had to place their middle finger. For each participant, the experimenter first obtained the baseline (i.e., pre-exposure) difference between actual and felt position of the left hand. For this, the experimenter asked the participant to close his or her eyes. Second, the experimenter placed the newly designed measurement platform over the participant's left hand (see Figure 5.1). Third, the experimenter guided the participant's right hand to the small block attached to the string that was mounted on the platform, and instructed the participant to slide the block over the platform (starting from the participant's outermost right-hand side) to indicate the felt location of the middle finger of his or her left hand. The differences between actual and felt position were calculated by taking the lateral distance between the wooden block and the index finger of the participant's concealed hand. It was coded with a positive sign when the felt position was biased towards the participant's right-hand side, and with a negative sign when the felt position was biased beyond the left hand's actual position.

After the experimenter removed the platform, participants were asked to move their hands as if conducting an orchestra, while the experimenter placed a fake hand in front of the participant. As a fake hand, a cosmetic prosthesis of a man's left hand was used that was highly realistic in terms of skin texture, color, and shape. The participants were asked to place their left hand back on the table in the position indicated by the pencil mark (at a lateral distance of 30 cm from the fake hand), to keep it motionless during the session, and to focus their attention on what they saw and/or felt. Depending on the experimental condition, the experimenter used paint brushes to stroke the fake hand, the concealed hand, or both in a synchronous manner for five minutes. After each session, the experimenter obtained the post-exposure difference between actual and felt location of the left hand, and the participant completed a questionnaire. The post-exposure difference between actual and felt location was obtained by means of the same procedure as for the pre-exposure difference.

Measures. Similar to the experiments in the previous chapters, we employed both a self-report and a proprioceptive drift measure. *The self-report measure* consisted of a single statement "At some times during the session, it felt as if the fake hand were my hand". Participants were asked to indicate the extent to which this statement matched their own experiences on a seven-point scale ranging from "not at all" (coded with a 0) to "completely" (coded with a 6). There were no missing responses. *Proprioceptive drift* is defined as the difference between two differences: the baseline difference between actual and felt hand position (i.e., before exposure to the rubber-illusion) subtracted from the post-exposure difference between actual and felt position (Tsakiris & Haggard, 2005). Again, there were no missing responses.

5.2.2. Results

Self-Reports. Since our participants' responses to the self-report item were not normally distributed, the non-parametric Friedman test was used to test for differences in self-reported vividness between the three conditions. We found that there was at least one significant difference between the three conditions, with $\chi^2(2, N = 18) = 28.6$, and $p < .01$ (see Figure 5.2A). Further contrast analysis by means of a series of Wilcoxon signed-rank tests revealed that people, as expected, reported the highest vividness of the illusion in the "real and fake hand" condition as compared to the other conditions, with $Z(N = 18) \geq 3.6$, and $p \leq .01$. No difference in self-reported vividness was found between the "real hand only" and "fake hand only" conditions, with $Z(N = 18) = 0.8$, and $p = .41$.

Proprioceptive drift. Participants showed, on average, a pre-exposure difference between actual and felt position of the left hand of $M = 1.0$ cm with $SD = 2.6$ (i.e., towards the participant's right-hand side). The average post-exposure difference was $M = 2.1$ cm ($SD = 2.9$) after the "real hand only" condition, $M = 3.8$ cm ($SD = 5.4$) after the "fake hand only" condition, and $M = 7.5$ cm ($SD = 6.7$) after the "real and fake hand" condition. We used a series of paired sample *t*-tests to compare pre- and post-exposure differences. Post-exposure differences were found to be significantly different from pre-exposure differences for the "fake hand only" and the "real and fake hand" condition, with $t(17) = 4.8$ and $p < .01$, and $t(17) = 2.5$ and $p = .02$, respectively. There was a marginally significant difference between the pre- and post-exposure differences between actual and felt position for the "real hand only" condition, with $t(17) = 1.7$ and $p = .09$.

Secondly, we calculated each person's proprioceptive drift (i.e., post-exposure minus pre-exposure difference between actual and felt position of the left hand; see Figure 5.2B), and performed a repeated measures ANOVA with proprioceptive drift as the dependent variable. Assumptions of normality, and sphericity were met. The repeated measures ANOVA revealed a significant difference between the three conditions, with $F(2,34) = 19.1$, $p < .01$ and partial $\eta^2 = 52.9\%$. Further contrast analyses revealed that, as expected, proprioceptive drift was found to be significantly larger in the "real and fake hand" condition compared to the two other conditions, with $F(1,17) \geq 24.3$, and $p \leq .01$. In contrast to the self-report measure, there was a marginally significant difference in proprioceptive drift between the "real hand only" and "fake hand only" conditions, with $F(1,17) = 4.1$, and $p = .06$.

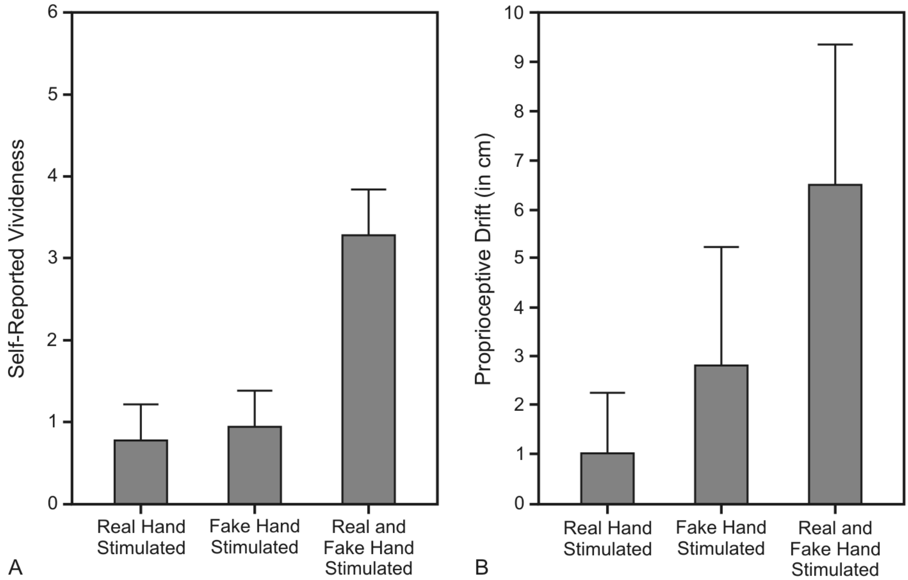

Figure 5.2: Mean self-reported vividness (Panel A) and mean proprioceptive drift (Panel B) for the three experimental conditions of Experiment 1. Error bars depict 95% confidence intervals.

5.2.3. Discussion

As expected, the difference between pre- and post-exposure differences between felt and actual hand location was statistically significant for the "real and fake hand" condition (in which the rubber-hand illusion is expected to occur). The difference between pre- and post-exposure differences was, however, found also to be statistically significant for the "fake hand only" condition. Since people are not expected to develop the rubber-hand illusion without synchronous stimulation of the fake hand and the concealed hand, this difference cannot be due to the experience of the rubber-hand illusion. This difference between and pre- and post-exposure differences can perhaps be explained by the common finding that the perceptual recombination of proprioception increases over time (e.g., Gross & Melzack, 1978; Wann & Ibrahim, 1992; Tsakiris & Haggard, 2005). Yet, the difference between pre- and post-exposure differences between felt and actual hand location was not found to be statistically significant for the "real hand only" condition. In other words, stimulating only the participant's real hand did not change felt hand location, whereas stimulating only the fake hand did. A possible explanation for this finding might be that the stimulation directed the participant's attention toward the hand that is stimulated, thereby resulting in a larger shift in felt position when the fake hand was stimulated, and a smaller shift when the participant's own hand was stimulated. We, therefore, conducted an additional *t*-test to compare the post-exposure differences between felt and actual hand location in these two conditions, but found only a marginally significant difference, with $t(17) = 2.0$ and $p = .06$. Although an attention-based explanation sounds plausible, there is little published evidence that supports such an effect of attention on the perceptual recombination of proprioception. Gross and colleagues (1974), for example, did not find a difference in felt hand position between a group of participants that received tactile stimulation to the concealed hand and a group that did not. In contrast, Wann and Ibrahim (1992) did find a significant effect of attention on the perceptual recombination of proprioception, but this effect was in the opposite direction. That is, when attention was directed away from the concealed hand, by having participants performing a tracking task with their other hand, they observed a lesser shift in felt location of the concealed than when participants were specifically asked to concentrate on the location of their concealed hand.

Proprioceptive drift (i.e., the baseline difference between actual and felt hand position subtracted from the post-exposure difference) was found to be significantly larger in the "real and fake hand" condition, compared to the conditions in which either only the fake hand, or only the real hand were stimulated. In contrast, only a marginally significant difference in proprioceptive drift was found between the "fake hand only" and the "real hand only" conditions. A similar pattern of differences between the experimental conditions was found on the self-report measure. As expected, our participants reported the most vivid rubber-hand illusion when their concealed hand and the fake hand were stimulated in precise synchrony. Similar to the proprioceptive drift measure, the difference in self-reported vividness of the illusion between the "fake hand only" and the "real hand only" conditions was not found to be significant. Our experiment thus illustrates that the perceptual recombination of proprioception during the induction of the illusion can be explained by factors other than the experience of the illusion, but that the proprioceptive drift measure might still adequately distinguish between experimental conditions in which people can and cannot develop the illusion.

Several interesting questions, however, were not addressed in this experiment. What would be the magnitude of proprioceptive drift resulting from a five-minute exposure to a fake hand (i.e., without stimulation), and how would this drift compare to the drift normally observed after the rubber-hand illusion has been induced. These questions will be addressed in a second experiment.

5.3. Experiment 2: More Magnitudes

5.3.1. Method

Participants. Our sample was drawn from the students and employees of the Eindhoven University of Technology, Eindhoven, the Netherlands. Thirty-two persons were invited to participate in the experiment. Several days prior to the actual experiment, all participants were tested on their ability to experience the rubber-hand illusion. Eight (25%) out of 32 participants did not experience the illusion and were excluded from the experiment. Of the remaining 24 participants, the mean age was 27.7 (SD = 1.4; range 24 to 30 years); 20 participants were male; 22 were right handed. All participants received € 5.00 as compensation.

Design. A two (fake hand vs. tabletop) by two (stimulation vs. no stimulation) within-subject experiment was conducted. The "fake hand with stimulation" condition was similar to the traditional rubber-hand illusion setup in which the participant's concealed hand is stroked, by means of two brushes, in precise synchrony with a visible fake hand (Botvinick & Cohen, 1998; see Figure 3.1A). In the "fake hand without stimulation" condition, a fake hand was again placed in front of the participant, but neither the fake hand nor the participant's concealed hand were stroked. In the "tabletop with stimulation condition", there was no fake hand in front of the participant. Instead, the experimenter stroked the participant's concealed hand in synchrony with corresponding locations on the tabletop (similar to the ¬S¬T condition in the experiment in Chapter 4). Finally, in the "tabletop without stimulation" condition, the experimenter neither stroked the participant's concealed hand, nor the tabletop. The order of the conditions was counterbalanced across participants.

Procedure. At the beginning of the experiment, the experimenter obtained, for each participant, the baseline (i.e., pre-exposure) difference between actual and felt position of the left hand. This was done in a similar manner as in Experiment 1. After the measurement of baseline drift, participants were asked to move their hands as if conducting an orchestra. Meanwhile, the experimenter, depending on the experimental condition, either placed a fake hand in front of the participant, or continued without the fake hand. Next, the participants were asked to place their left hand back on the table in the position indicated by the pencil mark (at a lateral distance of 30 cm from the fake hand or the corresponding location on the tabletop) and to keep it motionless during the session. In the conditions with stimulation, the experimenter stimulated the participant's concealed hand, and the fake hand or tabletop for five minutes in a synchronous manner. In the conditions without stimulation, the participant sat and stared at the fake hand or tabletop for five minutes. After each session, the experimenter obtained the post-exposure difference between actual and felt position of the left hand, and the participant completed a questionnaire.

Measures. Similar to Experiment 1, we employed both a self-report and a proprioceptive drift measure. *The self-report measure* consisted of a single statement "At some times during the session, it felt as if the foreign object was a part of my body." The term "foreign object" was replaced by the appropriate term for each condition (i.e., fake hand, or tabletop). Participants were asked to indicate the extent to which this statement matched their own experiences on a seven-point scale ranging from "not at all" (coded with a 0) to "completely" (coded with a 6). There were no missing responses. *Proprioceptive drift* is defined as the difference between two differences: the baseline difference between actual and felt hand position (i.e., before exposure to the rubber-illusion) subtracted from the post-exposure difference between actual and felt position (Tsakiris & Haggard, 2005). Again, there were no missing responses.

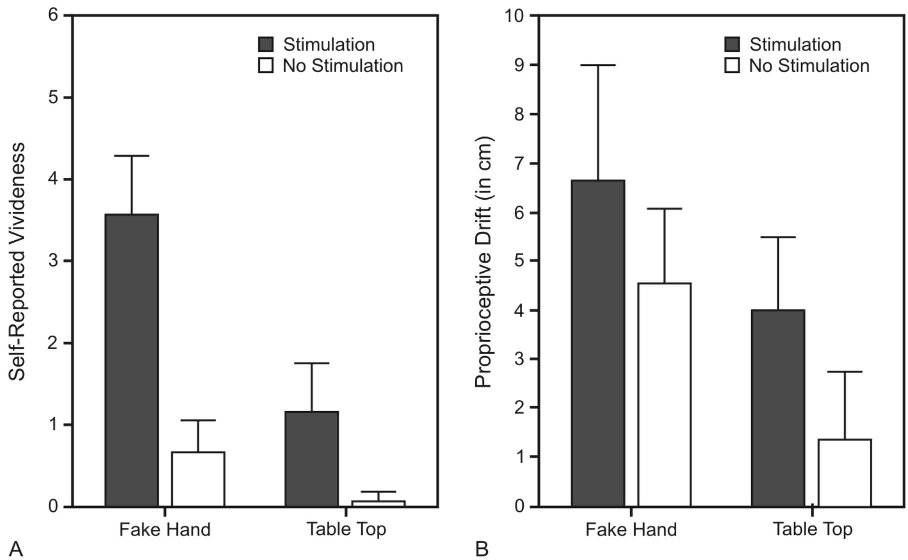

Figure 5.3: Mean self-reported vividness (Panel A) and mean proprioceptive drift (Panel B) for the four experimental conditions of Experiment 2. Error bars depict 95% confidence intervals.

5.3.2. Results

Self-Reports. Since our participants' responses to the self-report item were not normally distributed, the non-parametric Friedman test was used to test for differences in self-reported vividness between the four conditions. We found that there was at least one significant difference between the four conditions, with $\chi^2(3, N = 24) = 50.3$, and $p < .01$ (see Figure 5.3A). Additional pair-wise comparisons by means of a series of Wilcoxon signed-rank tests revealed that people, as expected, experienced a more vivid illusion in the "hand shape with stimulation conditions" than in all other conditions, with $Z(N = 24) \geq 3.8$, and $p \leq .01$. There was no difference between the "tabletop with stimulation" and the "fake hand without stimulation" condition, with $Z(N = 24) = 1.5$, and $p = .12$. Finally, people reported a less vivid illusion in the "tabletop without stimulation condition" than in any other condition, with $Z(N = 24) \geq 3.0$, and $p \leq .01$.

Additionally, we performed a two (hand vs. tabletop) by two (stimulation vs. no stimulation) repeated measures ANOVA with participants' responses to the self-report measure as the dependent variable. The main effect of the mere presence of a fake hand on the table, with $F(1, 23) = 43.6$, $p < .01$, and partial $\eta^2 = 65.5\%$, and the main effect of synchronous stimulation of the participant's concealed hand and the foreign object, with $F(1, 23) = 74.8$, $p < .01$, and partial $\eta^2 = 76.5\%$, were found to be significant. In addition, there was a statistically significant interaction effect, with $F(1, 23) = 19.1$, $p < .01$, and partial $\eta^2 = 45.3\%$. Further contrast analysis revealed that the facilitating effect of synchronous stimulation was larger when stimulation was applied to the fake hand, with $F(1, 23) = 76.0$, $p < .01$, and partial $\eta^2 = 76.8\%$, than when it was applied to the tabletop, with $F(1, 23) = 14.1$, $p < .01$, and partial $\eta^2 = 38.1\%$. The estimated *p*-values and effect sizes should, however, be interpreted with care, as assumptions of normality and sphericity were not met.

Proprioceptive Drift. Participants showed, on average, a pre-exposure difference between actual and felt position of the left hand of $M = 1.5$ cm with $SD = 2.6$ (i.e., towards the participant's right-hand side). The average post-exposure difference was $M = 8.1$ cm ($SD = 5.7$) after the fake hand with stimulation, $M = 6.1$ cm ($SD = 0.9$) after the fake hand without stimulation, $M = 5.5$ cm ($SD = 0.7$) after the tabletop with stimulation, and $M = 2.9$ cm ($SD = 0.6$) after the tabletop without stimulation condition. We used a series of paired sample *t*-tests to compare pre- and post-exposure differences. Post-exposure differences were found to be significantly different from pre-exposure differences for all experimental conditions, with $t(23) \geq 2.1$ and $p \leq .04$.

Secondly, we calculated each person's proprioceptive drift (i.e., post- minus pre-exposure difference between actual and felt position of the left hand; see Figure 5.3B), and performed a two (hand vs. tabletop) by two (stimulation vs. no stimulation) repeated measures ANOVA with proprioceptive drift as the dependent variable. Assumptions of normality and sphericity were met. Two participants were identified as an outlier, as their standardized drift scores were larger or smaller than three times the standard deviation. Since the removal of these outliers did not affect the interpretation of the results, we report the analyses with all data included. We found that proprioceptive drift significantly increased with mere exposure to a fake hand, with $F(1,23) = 27.1$, $p < .01$, and partial $\eta^2 = 54.1\%$. In addition, the main effect of stimulation was found to be significant with, $F(1,23) = 13.0$, $p < .01$ and partial $\eta^2 = 36.1\%$. As expected, our participants showed more proprioceptive drift when their concealed hands were stroked in precise synchrony with the fake hand or the tabletop. In contrast to self-report measure, the hand by stimulation interaction was not found to be significant, with $F(1,23) = 0.2$, $p = .63$ and partial $\eta^2 = 1.0\%$.

5.3.3. Discussion

There was a statistically significant difference between pre- and post-exposure differences between actual and felt hand location for all experimental conditions. Looking at the tabletop for five minutes (i.e., without any tactile stimulation), for example, was found to increase the difference between seen and felt stimulation to a statistically significant extent. Since no illusory sense of ownership over the tabletop is expected to be elicited in such a situation, this finding can be explained only as the result of having little kinesthetic and no visual feedback about hand location for five minutes (cf., e.g., Gross & Melzack, 1978; Wann & Ibrahim, 1992). This finding corroborates Experiment 1 in demonstrating that the perceptual recombination of proprioception during the induction of the rubber-hand illusion can be explained, partially, by factors other than the experience of the illusion.

Further analyses of the proprioceptive drift measure (i.e., the baseline difference between actual and felt hand position subtracted from the post-exposure difference) revealed a significant main effect of synchronous stimulation, and a significant main effect of the presence of a fake hand. In the experiment in Chapter 4, the extent to which proprioceptive drift occurred was not affected by the visual dissimilarities between the foreign object and a human hand: Using a the tabletop rather than a fake hand as the foreign object did not affect proprioceptive drift. In the present experiment proprioceptive drift was found to be larger for the fake hand with stimulation condition as compared to the tabletop with stimulation condition. Interestingly, however, mere exposure to a fake hand for five minutes (i.e., without stimulation) resulted in a similar proprioceptive drift as trying to induce the illusion with the tabletop. Since we cannot expect that people will develop the illusion without synchronous stimulation (see also Holmes, Snijders, & Spence, 2006), we must conclude either that we could not elicit the rubber-hand illusion in the "tabletop with stimulation" condition, or that proprioceptive drift is not a valid measure for the strength or vividness of the illusion.

If we compare people's proprioceptive drift with their self-reported vividness of the illusion, then we find that proprioceptive drift, as in the previous experiment, was largest in the condition in which participants developed the most vivid rubber-hand illusion: When the participant's own hand was stimulated in precise synchrony with a visible fake hand. Consistent with the view that bottom-up visuotactile correlations are modulated, top down, by a cognitive representation of what the human body is like (Tsakiris & Haggard, 2005; de Vignemont et al., 2006; see also Chapters 3 and 4), the effect of synchronous stimulation on the self-reported vividness of the illusion was found to be larger for a hand-shaped foreign object as compared to the tabletop. In contrast, we did not find a significant hand by stimulation interaction effect on proprioceptive drift. The self-report and the proprioceptive drift measures thus yield different conclusions with respect to the effect of experimental manipulations. Our experiment, thus, does not support the claim that proprioceptive drift is a valid corroborative measure of the vividness with which people experience the illusion (e.g., Tsakiris & Haggard, 2005).

5.4. General Discussion

In this chapter, we investigated the commonly made claim that proprioceptive drift is a corroborative measure of the vividness with which people experience the rubber-hand illusion. This proprioceptive drift is usually defined as the difference between two differences: the baseline difference between actual and felt hand position (i.e., before exposure to the rubber-illusion) subtracted from the post-exposure difference between actual and felt position (Tsakiris & Haggard, 2005). In two experiments, we examined the extent to which changes in the felt location of the concealed hand occur under conditions that are related to the setup of the rubber-hand illusion, but which in themselves are not sufficient to elicit the illusion. As we would expect from prior research (e.g., Gross et al., 1974; Wann & Ibrahim, 1992), we found that several of such conditions had a statistically significant effect on felt hand location, such as the mere exposure to a fake hand. We demonstrated, for example, that looking at the tabletop for five minutes (i.e., without any tactile stimulation) is in itself sufficient for a statistically significant difference between pre- and post-exposure differences between actual and felt hand location. Since no illusory sense of ownership over the tabletop is expected to be elicited in such a situation, this finding does not support the often made claim that proprioceptive drift is a corroborative measure of the vividness of the rubber-hand illusion. In support of this conclusion, Experiment 2 demonstrates that the use of proprioceptive drift to assess the extent of the illusion might yield different conclusions than an assessment by means of self-reports.

A similar conclusion is made by Holmes and colleagues (2006). In their experiments, the participant's left hand was concealed from sight by aligning a mirror with the body midline. Reflected in this mirror, the participants could either see their own right hand, a fake right hand, or a wooden block (i.e., the foreign objects). When the concealed left hand and the foreign object were placed at unequal distances from the mirror, visual information was in conflict with actual hand position. Their participants performed a series of reaching task in which they had to touch a target (reflected in the mirror) with their concealed left hand. Holmes and colleagues found that the reflection of a fake hand in the mirror resulted in a similar amount of misreaching as a reflection of the participant's own right hand. Looking at a reflection of the wooden block resulted in significantly less reaching bias. According to the authors, this suggests that the brain areas involved in integrating proprioceptive and visual information might have access to very rudimentary visual information only (e.g., basic shape and size information). More importantly, their results support our own finding that mere exposure to a fake hand increases proprioceptive bias without necessarily experiencing the rubber-hand illusion (note that there was no tactile stimulation in the experiment by Holmes and colleagues).

There were two notable limitations to the present experiments. First, we measured the extent of the perceptual recombination of proprioception by means of the difference between two differences: the baseline difference between actual and felt hand position (i.e., before exposure to the rubber-illusion) subtracted from the post-exposure difference between actual and felt position (Tsakiris & Haggard, 2005). Although this so-called proprioceptive drift is the most commonly used method, Tsakiris and Haggard (2005) have suggested an alternative method of assessing the extent of perceptual recombination of proprioception in the rubber-hand illusion. This so-called proprioceptive shift is defined as the proprioceptive drift observed after asynchronous stimulation of the concealed hand and the fake hand subtracted from the proprioceptive drift observed after synchronous stimulation. This proprioceptive shift, thus, corresponds to the effect of synchronous stimulation on proprioceptive drift. The question remains whether this proprioceptive shift measure corresponds better with the strength or vividness with which people develop the rubber-hand illusion.

Second, our self-report measure consisted of a single item asking people to indicate the degree to which they felt that the foreign object was their own (Experiment 1) or a part of their body (Experiment 2). Single item measures are more sensitive to measurement error than aggregated measures (e.g., Anastasi, 1988). In other words, they have predictably poor reliabilities. Unfortunately, the experimental setup did not allow the inclusion of the two other items commonly used in research on the rubber-hand illusion (i.e., "it seemed as if I were feeling the touch in the location where I saw the foreign object being touched" and "it seemed as though the touch I felt was caused by the paintbrush touching the foreign object"; e.g., Botvinick & Cohen, 1998; Holmes & Spence, 2007; see also chapters 3 and 4).

Despite these limitations, our experiments provide little empirical support for the often made claim that proprioceptive drift is a corroborative measure of the vividness with which people develop the rubber-hand illusion (e.g., Tsakiris & Haggard, 2005). Yet, the perceptual recombination of proprioception might be still be a prerequisite for developing a vivid illusion (i.e., as a mechanism underlying self-attribution; see also Holmes et al., 2006). If such a relation indeed exists, then future research should be able to demonstrate a significant, but probably small, correlation between proprioceptive drift and the vividness of the rubber-hand illusion. Estimating a reliable such correlation not only requires a larger sample of participants than used in the experiments presented in this chapter, but also a valid and reliable measure for assessing the individual differences in the vividness with which people experience the illusion.

— Chapter 6 —

Quantifying the Rubber-Hand Illusion[19]

Hier, wie in der Naturwissenschaft, bewährt sich die Richtigkeit des von Hegel in seiner "Logik" entdeckten Gesetzes, daß bloß quantitative Verändrungen auf einem gewissen Punkt in qualitative Unterschiede umschlagen.

—Karl H. Marx

Abstract

What determines the vividness of the rubber-hand illusion? We anticipate the probability that a person experiences a certain level of vividness (e.g., a sense of ownership) to depend on that person's susceptibility for the illusion, the processing demand behind that level of vividness, and the concrete impediments of the situation (e.g., the degree of asynchrony in the stimulation). Our newly developed self-report measure turned out to be reliable in its capability to predict vividness experiences, and to assess individual differences in people's susceptibility for the illusion ($rel \geq .83$). Regarding validity, we corroborated a small, but significant, correlation between individual susceptibility and proprioceptive drift (r = .26). Additionally, we confirmed that asynchrony significantly impeded the development of vivid experiences.

People differ considerably in their descriptions of what the rubber-hand illusion feels like. Some people, for example, claim that they sense the fake hand to be part of their body (Botvinick & Cohen, 1998), and others that they even feel they could move and use the fake hand (see Chapter 4). Still others appear to be relatively insensitive to the illusion, as the descriptions of their experiences are limited to impressions of strangeness and confusion. This apparent variability in responses in reports about the illusion points toward substantive interpersonal differences in how vividly people experience the rubber-hand illusion. The question is: What determines the vividness with which people experience the

[19] This chapter is based on Haans, Kaiser, IJsselsteijn, and Bouwhuis (2009).

illusion? And, at the same time, are self-reported experiences valid indicators of a person's susceptibility for the rubber-hand illusion?

In this chapter, we test a conception of the rubber-hand illusion, in which the probability of reporting a certain level of vividness (e.g., the fake hand feels as one's own) depends on three factors: (a) a person's susceptibility for the rubber-hand illusion, (b) the processing demand required to develop that particular level of vividness, and (c) the concrete situational features of the setup in which the illusion is created.

6.1. Phenomenology of the Rubber-Hand Illusion

In the rubber-hand illusion, people often mention that things seem *"confusing"* or *"did not make sense"* (Armel & Ramachandran, 2003; see also chapters 3 and 4). Sometimes, they report that it feels as if the fake hand belonged to them (Botvinick & Cohen, 1998). One participant in Botvinick and Cohen's study, for example, stated: *"I found myself looking at the dummy hand thinking it was actually my own"* (p. 756). Several participants in the experiment in Chapter 4 even reported a sense of agency over the fake hand, which is illustrated by the following remark: *"Sometimes it felt as if the fake hand would respond to my movements"*. For one participant in the experiment in Chapter 3, the concealed and the fake hand started to look the same. Similar distortions in the perceived appearance of the fake hand, and/or in the participant's own hand have been reported by Ramachandran and colleagues (Armel & Ramachandran, 2003; Ramachandran & Hirstein, 1998).

More systematically, Botvinick and Cohen (1998) asked their participants to deny or confirm the occurrence of nine specific impressions (e.g., it felt as if the fake hand was my own). Comparing the various studies that have used this instrument, it becomes apparent that there is a consistent order in the impressions with respect to how often they are encountered (e.g., chapters 3 and 4; Ehrsson et al., 2004; Peled et al., 2000; see also Holmes & Spence, 2007). The two most frequently acknowledged impressions relate to the location of the felt touch (e.g., feeling the touch in the location where one sees the rubber hand being touched). The third most frequently encountered impression is a sense of ownership toward the fake hand. Rarer are distortions in the perceived appearance of the fake hand, while the most infrequent of the nine impressions is a perceived motion of the concealed arm toward the fake hand.

Taken together, the various experiential reports point toward some substantial interpersonal differences in how vivid people experience the rubber-hand illusion. A person who, after several minutes of stimulation, only senses something strange, cannot be said to have experienced an intensive and vivid rubber-hand illusion. In contrast, another person, who reports feelings of ownership, agency, and perhaps even distortions in the perceived appearance of the fake hand, has developed quite a vivid illusion. The question is: Can we anticipate whether or not a person will develop a certain impression? In other words, can we determine a person's level of vividness at which the rubber-hand illusion is experienced?

6.2. Determinants of Vividness

6.2.1. Susceptibility for the Rubber-Hand Illusion

Individual differences in people's susceptibility are likely in the rubber-hand illusion (MacLachlan et al., 2003; Mussap & Salton, 2006) as they are also common with other bodily illusions (e.g., Burrack & Brugger, 2005; Juhel & Neiger, 1993). Such differences could derive from differential information processing capabilities, or from differences in people's psychological makeup. People could, for example, differ in how efficiently and accurately they receive and process information from different sensory modalities upon which a meaningful representation of the world is reconstructed, including a person's body image (e.g., Armel & Ramachandran, 2003; Botvinick & Cohen, 1998). As Mussap and Salton (2006) have argued, it is also possible that people differ in the "tenacity" of their body image (as is, for example, reflected in the frequency of spontaneous body image alterations; Burrack & Brugger, 2005). The more stable a person's body image, the less likely it is susceptible to change due to novel sensorimotor information.

6.2.2. Processing Demands and Vividness.

Some impressions related to the rubber-hand illusion (e.g., the experience of strangeness) are more frequently encountered than others (e.g., a sense of ownership toward the fake hand). Consequently, it seems plausible to suspect that the various impressions are differentially demanding to develop. Experiences of strangeness, for example, require presumably comparatively little cognitive and sensorimotor processing, as it is probably sufficient that the contradiction in the sensory information is registered (cf. Armel & Ramachandran, 2003). The impression that one's tactile sensations originate from the fake hand is probably more demanding to create, as such impressions require that seen and felt sensation are combined into a single percept. Even more difficult to develop are those impressions that involve a recalibration of the mental representation of one's own body, such as ownership (e.g., the feeling as if the fake hand is part of one's body) and agency (i.e., the feeling as if one could use the fake hand). A full-blown rubber-hand illusion, which also entails the impression that one's own hand or the fake hand changes its appearance, is probably the most difficult one to develop. Expectedly, the more vivid the rubber-hand illusion is, the more demanding the processing behind. In other words, we suspect that the different impressions related to the vividness of the rubber-hand illusion can be ordered with respect to how much processing "effort" they require. At the same time, we anticipate that these processing requirements are the same for everyone (note that—ceteris paribus—such a functional equivalence assumption of individual information processing forms basically the backbone of all cognitive psychology). Thus, to experience the rubber-hand illusion at a certain level of vividness, each person has to meet the processing requirements needed to develop that particular experience. This would imply that the subjective phenomena related to the illusion are comparable for different persons. Conversely, this implies that people can be objectively compared with respect to the level of vividness at which they experience the illusion.

6.2.3. Vividness Impediments in the Situation.

By manipulating the situational features with which the rubber-hand illusion is induced (i.e., the experimental setup), one can obstruct the development of a full-blown rubber-hand illusion, and, thus, the ease with which one develops certain experiences. If the real hand and the fake one appear less similar, then the processing demand required to develop a vivid illusion is probably increased. Similarly, temporal asynchrony between seen and felt stimulation effectively reduces the vividness of the illusion (Armel & Ramachandran, 2003; Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). By contrast, the development of the illusion can be facilitated if one increases the amount of information in the stimulation. The more complex and erratic the stimulation pattern (yet still synchronous and simultaneous), the more vivid the illusion becomes. Anecdotal evidence for such situation-specific facilitation/obstruction effects can be found in Armel and Ramachandran (2003).

6.3. Predicting the Vividness of the Rubber-Hand Illusion

To describe mathematically the expected relationships between individual susceptibility, processing demand, and the obstructions imposed by the situation, we adopt the many-facet Rasch model (for details, see Linacre, 1994; also Bond & Fox, 2007):

$$\ln\left(\frac{p(x_{njl})}{1-p(x_{njl})}\right)=\theta_n-(\delta_j+\lambda_l)$$

In this model, the probability that person *n* reports to perceive a certain impression *j* (e.g., the fake hand feels as *n*'s own) is governed by three factors: *n*'s susceptibility for the illusion (θ_n), the specific processing demand required to develop that impression *j* (δ_j), and the obstructions imposed by a suboptimal setup *l* (λ_l). The model involves three predictions which can be translated into three specific hypotheses.

6.4. Experiment 1: A First Model Test

Our first hypothesis states that people can be reliably differentiated with respect to susceptibility for the rubber-hand illusion. A person who claims to have encountered only the least vivid experience (e.g., in the conventional setup, see Figure 3.1A) is probably not highly susceptible for the illusion. By contrast, if a person encounters, under comparable conditions, even the most vivid experiences, then he or she is presumably rather susceptible. Subsequently, we expect that the demand required to develop each of the various impressions is the same for everyone. Our second hypothesis, thus, states that there is an invariant order that reflects increasing processing demands required when developing progressively vivid rubber-hand illusions. This invariant order is assumed to reflect the processing requirements behind progressively vivid rubber-hand illusions. Necessarily, such a vividness-related invariant order of experiences implies also that the rubber-hand illusion is marked by more or less universal subjective phenomena.

In the first experiment presented in this chapter, we model each of 22 impressions conventionally related to the rubber-hand illusion as a function of individual susceptibility (calculated from the number of affirmative responses) and of the processing demand behind each experience (calculated from the total number of participants affirming to have experienced that impression). A successful model test will, on the one hand, corroborate that individuals can be differentiated with regard to susceptibility for the rubber-hand illusion. On the other hand, it will confirm an invariant order of the 22 experiences and, thus, the anticipated universal differences with respect to processing demand. Additionally, we will investigate the relationship between a person's susceptibility for the rubber-hand illusion, as assessed by the self-report measure, and the extent of his or her proprioceptive drift. A correlation between susceptibility and proprioceptive drift is to be expected, as the perceptual recombination of proprioception might be a prerequisite for the rubber-hand illusion to occur (Holmes et al., 2006; see also Chapter 5).

The third hypothesis states that features of the experimental setup obstruct or facilitate the development of a full-blown rubber-hand illusion. In a second experiment (following this first one), we will extend our model test by manipulating two features of the experimental setup: the extent of asynchrony between seen and felt stimulation, and the amount of information in the stimulation. In this first experiment, however, no features of the situation are manipulated. Therefore, the level of vividness at which a person experiences the rubber-hand illusion (e.g., the fake hand felt as my own) is dependent only on individual susceptibility and the processing demand behind that particular level of vividness

6.4.1 Methods

Participants. Our sample of participants was drawn from students and employees of the Eindhoven University of Technology, Eindhoven, The Netherlands. One hundred and twenty-seven persons participated in this experiment, 100 (79%) of which were male. Their mean age was 24.7 (SD = 6.5; range 19 to 65); 73% of our participants were right handed and 14% were ambidextrous (according to the Dutch handedness scale; van Strien, 1992). All participants received coffee and cake as a compensation.

Procedure. Participants were seated in a chair with their left hand on a table in front. A pencil mark indicated the exact location at which participants had to place their middle finger. First, the experimenter obtained, for each participant, the base-line (i.e., pre-exposure) difference between actual and felt location of the left hand. For this, the experimenter asked the participants to close their eyes. Then, a small platform (25 cm by 80 cm with a height of 9 cm) was placed over the participant's left hand (cf. Figure 5.1). A string was mounted over the length of the platform to which a wooden block (4 cm by 1.5 cm by 1.5 cm) was attached. Next, the experimenter guided the participant's right hand to this block, and instructed the participant to slide the block over the platform (starting from the participant's outermost right-hand side) to indicate the felt position of his/her middle finger of the left hand. The difference between actual and felt position was consecutively assessed three times. It was coded with a positive sign when the felt position was biased towards the participant's right-hand side, and with a negative sign when the felt position was biased beyond the left hand's actual position.

After the platform was removed, participants were asked to move their hands as if conducting an orchestra, while the experimenter placed a fake hand in front of them. As a fake hand, a cosmetic prosthesis of a man's left hand was used that was realistic in terms of skin texture, color, and shape. With each participant, the rubber-hand illusion was then conventionally induced in a single five minute trial (cf. Botvinick & Cohen, 1998). For this, participants were asked to place their left hand back on the table in the position indicated by the pencil mark (at a lateral distance of 30 cm from the fake hand) and to keep it motionless (see Figure 3.1A). Next, the experimenter placed a wooden screen between the participant's left hand and the fake hand. Subsequently, the experimenter stroked and tapped the middle and index fingers of both hands, simultaneously and in synchrony, by means of two brushes.

After the induction of the illusion, participants were instructed to continue to keep their left hand motionless on the table. Subsequently, the experimenter obtained, for each participant, the post-exposure difference between actual and felt location of the left hand, using the same procedure as before. Again three estimates were obtained for each individual. Finally, the participants were asked to fill out a questionnaire.

Measures. The extent to which participants experienced the illusion was assessed by means of 22 self-report items and a conventional proprioceptive drift measure (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005).

The 22 self-report items consisted of statements, such as "It felt as if the fake hand was part of my own body". Participants were asked to indicate whether they agreed or disagreed with these statements on a 5-point response scale, labeled "disagree", "slightly disagree", "neutral", "slightly agree", and "agree". Thirteen of these items were adopted from previously used instruments (e.g., Botvinick & Cohen, 1998; see also Chapters 3, 4, and 5), and nine were constructed specifically for this study. Several of the new items were, independently, also proposed by Mussap and Salton (2006), as well as by Longo, Schüür, Kammers, Tsakiris and Haggard (2008). For a complete list of the 22 items see Table 6.1. For all participants and across all 22 items, there were only two missing responses (< 0.1%).

Proprioceptive drift is defined as the difference of two differences: the baseline difference (i.e., before exposure to the rubber-illusion) subtracted from the post-exposure difference between actual and felt position of a participant's left hand (e.g., Tsakiris & Haggard, 2005).

Table 6.1: Processing demand (δ), mean square fit statistic (MS), and the probability of consent for an averagely susceptible person (p) in experiments 1 and 2.

		Experiment 1			Experiment 2		
	Impressions	*σ*	*MS*	*p*	*σ*	*MS*	*p*
1	Sometimes, it appeared as if the fake hand moved to my left hand side.	4.43	1.11	.01	3.84	1.10	.05
2	Sometimes, it felt as if my left hand moved towards my right hand side.	2.89	1.18	.03	2.20	0.80	.15
3	Sometimes, the shape of the fake hand appeared to change.	2.82	0.85	.03	1.06	0.88	.29
4	Sometimes, it felt as if my left hand turned rubbery.	2.29	1.23	.05	1.36	1.27	.25
5	Sometimes, it felt as if the shape of my left hand started to change.	2.16	1.05	.06	2.56	1.02	.12
6	Sometimes, the skin properties of the fake hand (i.e., color or texture) appeared to change.	1.40	0.98	.11	0.45	0.82	.38
7	Sometimes, it felt as if I had more than one left hand.	1.36	1.28	.12	2.59	1.26	.12
8	When a finger of the fake hand moved, I sometimes felt the finger of my left hand moving as well.	1.09	1.08	.15	0.43	1.24	.39
9	Sometimes, it appeared as if the touch I felt originated from somewhere between my own hand and the fake hand.	0.80	0.94	.19	1.53	0.92	.22
10	Sometimes, the fake hand **began** to match my own hand in appearance.	0.44	0.90	.25	-0.67	1.12	.58
11	Sometimes, it felt as if my left hand was inside the fake hand.	0.25	0.87	.29	1.43	0.72	.24
12	Sometimes, it felt as if my left hand and the fake hand were on the same location on the table.	-0.21	0.90	.39	0.61	0.90	.36
13	Sometimes, it felt as if I had complete control over the fake hand: I could have moved the fake hand if I wanted to.	-0.28	0.98	.41	0.64	0.80	.35
14	Sometimes, it felt as if the fake hand was part of my own body.	-0.76	0.78	.53	0.41	0.81	.39
15	Sometimes, I became confused about what I saw and felt.	-1.29	0.92	.65	-2.37	1.48	.82
16	Sometimes, it appeared as if I felt the touch on my side of the wooden screen (i.e., on the side of the fake hand).	-1.29	0.95	.65	-0.13	1.11	.48
17	Sometimes, it felt as if the fake hand was my own hand.	-2.09	0.69	.81	-0.71	0.68	.58
18	Sometimes, it appeared as if I felt the touch on the location where I saw the fake hand being touched.	-2.22	1.02	.83	-1.98	1.06	.78

Continued

		experiment 1			experiment 2		
	Impressions	*σ*	*MS*	*p*	*σ*	*MS*	*p*
19	*I **continuously** felt as if the touches on my fingers and the touches on the fake hand were caused by two different brushes.*	-2.54	1.08	.87	-3.08	1.03	.88
20	Sometimes, it felt as if the touches on my fingers were caused by the brush touching the fake hand.	-3.01	1.07	.91	-2.74	.72	.85
21	*I did **not** experience anything odd.*	-3.08	1.05	.92	-4.99	1.09	.97
22	*I **continuously** noticed clear differences between the touches I saw on the fake hand, and the touches I felt.*	-3.15	1.09	.92	-2.47	1.05	.83

Note that the items are translated from their original Dutch version. Impressions are ordered according to processing demand (δ) as estimated in Experiment 1 in this chapter. All processing demands are in the metric of Experiment 1 of this chapter. Items in italic *are negatively worded. They were reversed in their coding before they were analyzed. Words in **bold** were emphasized in the questionnaire. For Experiment 1, p represents the probability of an affirmative response for an averagely susceptible person. For Experiment 2, p represents the probability of affirmation for an averagely susceptible person in the synchronous (i.e., 0 ms delay) and information-rich (i.e., stroking) condition.*

Since the baseline and the post-exposure difference were each assessed three times, three proprioceptive drift estimates were calculated for each participant.[20] The average of these three estimates was used in our analyses. The reliability (Cronbach's alpha) of the three estimates of proprioceptive drift was $\alpha = .89$.

6.4.2. Results

The results are presented in four sections. In the first three sections, we describe the calibration of the 22 impressions, and test our two hypotheses, the one regarding the invariant order of these 22 experiences and the other regarding reliable individual differences in susceptibility for the illusion. In the fourth section, we explore the relation between the vividness of a person's rubber-hand illusion and the extent of his or her proprioceptive drift.

[20] These three proprioceptive estimates were calculated by subtracting the first pre-exposure difference from the first post-exposure difference, the second pre-exposure difference from the second post-exposure difference, and the third pre-exposure difference from the third post-exposure difference. There were no statistically significant differences between these three estimates of proprioceptive drift, with $F(2, 125) = 1.2$, $p = .31$, and partial $\eta^2 = .02$.

Scale Calibration. Because the subjective use of response categories can make answers more arbitrary and less reliable (cf. Kaiser & Wilson, 2000), we recoded the individual responses to the 22 vividness impressions into a less measurement error-sensitive dichotomous format. For this purpose "disagree" and "slightly disagree" were collapsed into a single category "refute", and "slightly agree" and "agree" into "assert". Neutral responses were treated as missing values, as these are expectedly picked when a participant can neither agree nor disagree with an impression, or is otherwise indecisive (cf. Raaijmakers et al., 2000).[21] A total of 207 "neutral" responses were treated as missing values (i.e., 7.4% of the data). A Rasch model test was performed using the Facets software (Linacre, 2006). The Facets software employs a joint maximum likelihood procedure for estimating each participant's susceptibility (calculated from the number of affirmative responses) and for estimating the processing demand behind each of the 22 impressions (calculated from the total number of participants who affirmed having experienced that impression). The units of these estimates are called logits, or log odds units (i.e., the natural logarithm of the odds that one agrees to a certain impression statement).

Vividness and Processing Demands. The 22 impressions and the estimated processing demand required to develop each of them are reported in Table 6.1. The processing demands were estimated with a reliability of .98. The appropriateness of the Rasch model is reflected by several fit statistics. All but two of the items fit the idea of an invariant item order with mean square values (*MS*) ≤ 1.20 (see Table 6.1): "It felt as if my left hand turned rubbery" (Item 4; *MS* = 1.23) and "It felt as if I had more than one left hand" (Item 7; *MS* = 1.28). Mean square values refer to the weighted average of squared standardized residuals, in which each residual is weighted by its variance (e.g., Bond & Fox, 2007). MS-values of, for example, 1.20 stand for a 20% excess in variation between the observed responses and the model's predictions. As a guideline, mean square values up to 1.20 are considered good even for high-stake tests, and mean square values below 1.30 are considered acceptable (Bond & Fox,2007; Wright & Linacre, 1994). Thus, the fit statistics for the 22 impression items look quite reasonable. This is also reflected in the overall item fit statistics: the mean of mean squares [*M*(*MS*)] = 1.00, standard deviation of mean squares

[21] The susceptibility estimates were not substantially affected by our coding procedure. This becomes obvious in the correlations between various susceptibility scores. They are high $r \geq .91$ irrespective of the type of coding that we used; whether we coded "neutral" also as "assert", or whether we employed the original 5-point response format.

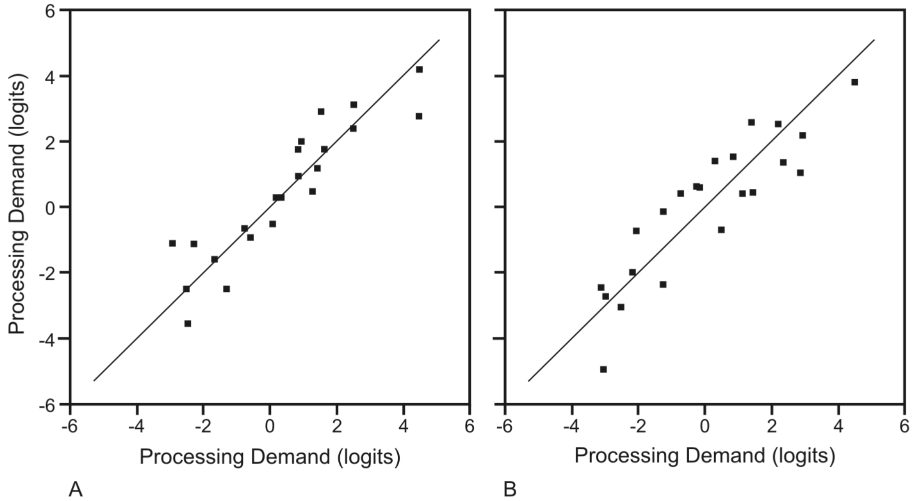

Figure 6.1: Invariance of vividness-related processing demands. These panels depict the processing demands behind each of the 22 impressions, as estimated for different (sub)samples. Panel (A) compares the estimates for highly (y axis) and poorly susceptible people (x axis) in Study 1, and Panel (B) compares the estimates for Study 2 (y axis) and Study 1 (x axis).

[*SD*(*MS*)] = 0.14, mean of t-values [*M*(*t*)] = -0.15, standard deviation of *t*-values [*SD*(*t*)] = 1.01. Ideally, *M*(*MS*) should be 1.0. For *SD*(*MS*) no general reference value can be given. The *t*-values are standardized fit statistics and represent the statistical significance of the mean squares statistics (e.g., Bond & Fox, 2007). Ideally, *M*(*t*) should be 0, and *SD*(*t*) should be 1.0. From these statistics it can be concluded that our model prediction matches the data, thereby supporting our hypothesis that the order of the various impressions are the same for everyone.

Additionally, we compared the processing demands as estimated for two extreme groups: people with a low and people with a high susceptibility for the rubber-hand illusion. For this purpose, we split our sample in half according to the estimated susceptibility scores, and estimated the processing demands for each group in separate analyses. The two estimates of the processing demand related with each vividness impression were found to be significantly correlated with $r = .92$, and $p < .01$ ($r_{corr} = .97$; see Figure 6.1A). This finding corroborates our hypothesis of an invariant order of the various impressions, which is expected to reflect the increasing processing demand required when developing a progressively vivid rubber-hand illusion.

Differentially Susceptible Individuals. The individual susceptibilities for the rubber-hand illusion were estimated with a reliability of .83. The average susceptibility was M = -.65 logits (SD = 1.63; range -5.86 to 3.75). For only 8 (6.3%) of the 127 participants, the model prediction did not fit the data, indicated by a significant t-value of $t \geq 1.96$. The overall fit statistics for the participants were found to be $M(MS)$ = 0.96, $SD(MS)$ = 0.44, $M(t)$ = -0.14, $SD(t)$ = 1.24. From these statistics, it can also be concluded that the rubber-hand illusion is marked by a more or less universal phenomenology. At the same time, the statistics confirm our hypothesis that people can be reliably differentiated with regard to their susceptibility.

Empirically, the Rasch model explained 54.9% of the variance in the observed data (for computational details, see Linacre, 2003). Because the Rasch model estimates probabilities for discrete events (i.e., whether a certain person claims to have encountered a certain impression or not), substantial quantization variance is to be expected. If the Rasch model would fit perfectly, then still 46.4% of the overall variance would be quantization variance (i.e., predicted unexplained variance), and only 53.6% is explained by individual susceptibility and processing demand. The observed (i.e., empirical) proportion of unexplained variance (i.e., 45.1%) is highly similar to the proportion of quantization variance that would have been observed when the model fitted the data perfectly, thereby providing additional support for the appropriateness of the Rasch model. In addition, we performed a principal component analyses on the standardized residuals (i.e., the data not explained by our model) to explore the possibility for another unaccounted factor in the data (Linacre, 1998). As an additional factor would only result in a trivial increase of 4.4% in the proportion of explained variance, we conclude that our set of 22 items taps into a single factor only.

Susceptibility and Proprioceptive Drift. We found a small to moderate, but significant, correlation between a person's susceptibility for the illusion and the extent of his or her proprioceptive drift (r = .26, p < .01). Even after correction for measurement error attenuation (cf. Charles, 2005), the correlation remained moderate r_{corr} = .30, indicating an overlap in variance of about 9.0%. As expected, proprioceptive drift increases with individual susceptibility and vice versa.

6.4.3. Discussion

With a sample of 127 participants, we were successful in modeling people's self-reported experiences related to the vividness of the rubber-hand illusion based on estimates about people's susceptibility for the illusion and on estimates about the anticipated processing demand behind a specific experience. With respect to the individual differences in people's susceptibility for the illusion, we found people to be separable with a reliability of .83. With respect to the phenomenology of the rubber-hand illusion, we found an invariant order in people's self-reported experiences. This order, we believe, reflects the processing demand behind the respective impressions. As expected, the processing demand behind each vividness impression is the same for different persons, which is evidenced by the invariance of the item order. This finding was additionally supported with a high correlation (r_{corr} = .97) between the processing demands estimated for highly and poorly susceptible individuals (see Figure 6.1A). In other words, regardless of a person's susceptibility for the illusion, the processing requirements behind the rubber-hand illusion are the same for everyone.

Moreover, we found a small to moderate, but significant, correlation between a person's susceptibility for the rubber-hand illusion and the extent of a person's proprioceptive drift (r_{corr} = .30). With an overlap in variance of only 9.0%, predicting the extent of people's rubber-hand illusion from their proprioceptive drifts becomes rather inaccurate. As a measure of the vividness with which people experience the rubber-hand illusion, proprioceptive drift, thus, demonstrates poor validity. However, the small to moderate correlation between individual susceptibility and proprioceptive drift supports the view that the perceptual recombination of proprioception is a mechanism behind self-attribution in the rubber-hand illusion (cf. Holmes et al., 2006; see also Chapter 5).

6.5. Experiment 2: Extending the Model

In a second experiment, we extended our model test by manipulating two features of the experimental setup: the extent of asynchrony between seen and felt stimulation and the information-richness in the stimulation. Asynchronies of 500 ms and more are an effective means to obstruct the vividness of the rubber-hand illusion. They are commonly used as experimental control conditions in which the illusion is meant to be suppressed (e.g., Armel & Ramachandran, 2003; Botvinick & Cohen, 1998; Ehrsson et al., 2004; Tsakiris & Haggard, 2005). The reflection of such an impeding effect due to temporal asynchrony would give credit to the validity of our model. In addition, we investigate the effect of relatively small asynchronies on the vividness of the illusion (i.e., between 100 and 500 ms). We expect increasing delays to progressively obstruct the vividness with which people develop the illusion. With regard to the information-richness in the stimulation, we expect to empirically confirm Armel and Ramachandran's (2003) hypothesis that a more complex and erratic (and thus information-rich) stimulation pattern amplifies the vividness with which people experience the illusion. In contrast to experiment 1 of this chapter, the level of vividness at which people experience the rubber-hand illusion is determined, not only by individual susceptibility and processing demand, but by the constraints imposed by the features of the particular experimental setup as well.

6.5.1. Method

Participants. Our sample of participants was again drawn from students and employees of the Eindhoven University of Technology, Eindhoven, The Netherlands. Twenty-four persons were invited to participate in this experiment, 18 (75%) of which were male and all were sensitive to the rubber-hand illusion (which was assessed a few days prior to the actual experiment). Their mean age was 21.8 (*SD* = 2.4; range 18 to 28); 83% of the participants were right handed and 13% were ambidextrous (as based on the Dutch Handedness scale; van Strien, 1992). All participants received € 7.00 as a compensation.

Experimental Design. A six (0, 100, 200, 300, 400, and 500 ms of asynchrony between felt and seen stimulation) by two (low vs. high information in the stimulation) within-subject design was implemented. The amount of information in the stimulation was varied by either shortly stroking (rich in information) or tapping (poor in information) the participant's left hand and the fake hand. We used an incomplete design to reduce the number of trials per participant. The six delay conditions were employed with each participant only once. As a result, each person participated in only 6 of the 12 possible experimental conditions. The presentation order of the delays was randomly assigned to the participants. At the same time, we controlled that each delay condition was presented equally often in the first trial of each session. Whether a participant would receive strokes or taps during a certain delay condition was determined by means of a rotated-judgment plan (for more details, see Schumacker, 1999).

Procedure. The rubber-hand illusion was elicited in six trials. To enable a reliable delay between seen and felt stimulation, a technologically mediated implementation of the rubber-hand illusion was used (for technical details, see Chapter 3). In this procedure, participants are not looking at the fake hand directly, but at a video projection of the fake

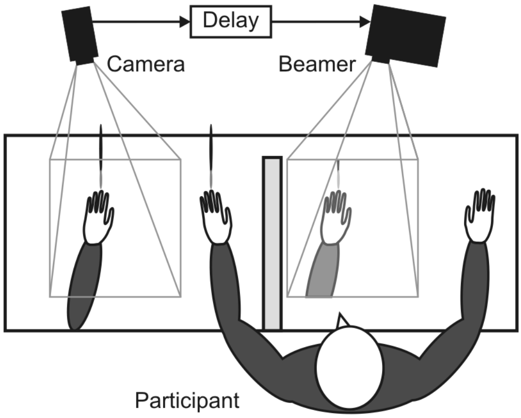

Figure 6.2: Experimental setup for Experiment 2 of this chapter.

hand (see Figure 6.2). The projection of the fake hand and its stimulation was delayed by means of an Evertz7700 delay unit placed between the camera and the beamer. Instead of controlling the delay between the stimulation of the real and fake hand manually (i.e., by an offset between the two brush strokes), this setup allowed the experimenter to synchronously apply stimulation to the participant's left hand and the fake hand. This procedure had two advantages. First, synchronous stimulations are easier to perform and more accurate than asynchronous ones. Second, the experimenter was blind with respect to the degree of asynchrony in each trial. To assure a constant interval between subsequent strokes or taps, the experimenter used a headset through which a tone was played at a one second interval. After each trial, participants completed a questionnaire.

Measures. The extent to which participants experienced the rubber-hand illusion under the various experimental conditions was assessed with the same 22 impression items as in Experiment 1 of this chapter. We processed these items in the same manner as described in Experiment 1. This time, 379 "neutral" responses were treated as missing values (i.e., 12.0% of the responses).

6.5.2. Results

The results are presented in three sections. In the first two sections, we describe another calibration of the 22 experiences commonly reported with the rubber-hand illusion, and we confirm our previous findings regarding the invariant order of these impressions and regarding reliable individual differences in people's susceptibility for the rubber-hand illusion. In the third section, we test the anticipated obstruction effects imposed by a suboptimal setup. As in Experiment 1, we used the Facets software (Linacre, 2006) for these model tests.

Processing Demands and Vividness. The 22 impressions and the estimated processing demand required to develop each of them are reported in Table 6.1. The processing demands were estimated with a reliability of .96. As in Experiment 1 of this chapter, Items 4 (MS = 1.27) and 7 (MS = 1.26) only acceptably fitted our model with mean square values below 1.30. This time, Item 8 "When a finger of the fake hand moved, I sometimes felt the finger of my left hand moving as well" (MS = 1.24) also was found to have only an acceptable fit. One item (Item 15 "I became confused about what I saw and felt") did not even acceptably fit our model (MS = 1.48). These items are either poor indicators of the vividness of the illusion or problematic in their formulation. Overall, the fit statistics for the 22 items are still reasonable with $M(MS)$ = 0.99, $SD(MS)$ = 0.21, $M(t)$ = 0.07, and $SD(t)$ = 1.58. In addition, we correlated the two estimates of the processing demand related with each vividness impression from Experiments 1 and 2 (see Figure 6.1B). This correlation was found to be significant, with r = .89, and p < .01 (r_{corr} = .92), thereby corroborating our hypothesis of an invariant order of the various impressions.

Differentially Susceptible Individuals. The individual differences in susceptibility for the rubber-hand illusion were estimated with a reliability of .97. The average susceptibility was M = -1.31 logits (SD = 1.70; range -4.09 to 4.01). This time, for only 2 (8.3%) out of 24 participants the model prediction did not fit the data, indicated by significant t-values of t > 1.96. The overall fit statistics for all participants combined were again reasonable with $M(MS)$ = 0.98, $SD(MS)$ = 0.23, $M(t)$ = -0.07, and $SD(t)$ = 1.49.

Situational Impediments. The estimated levels of impediment for 0 ms (-.91 with SE = .13), 100 ms (-1.00 with SE = .13), 200 ms (-.43 with SE = .13), 300 ms (.20 with SE = .14), 400 ms (1.12 with SE = .16), and 500 ms (1.03 with SE = .16) delay between seen and felt stimulation are shown in Figure 6.3. The levels of impediment were estimated with a reliability of .97. The different delay conditions had a significant effect on the self-reported vividness of the illusion, with $\chi^2(5, N = 24) = 210.5$, p < .01. The higher the estimated impediment in Figure 6.3, the more difficult it is to develop a vivid illusion. Whereas the vividness of the illusion under a 100 ms delay is still comparable to synchronous

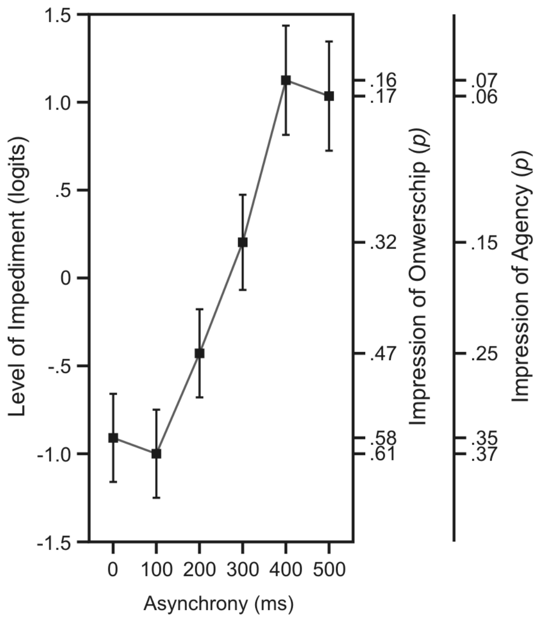

Figure 6.3: Impediment levels to the vividness of the rubber-hand illusion as a function of temporal asynchrony. Error bars depict 95%-confidence intervals. The two y-axes at the right give the probability of an average susceptible person in the high information condition claiming that "the fake hand felt as my own" (ownership; Item 17 in Table 6.1) and "that it felt as if I had complete control over the fake hand" (agency; Item 13 in Table 6.1) as a function of delay.

stimulation, longer delays result in a diminished rubber-hand illusion in terms of the vividness. For example, an average person has about 61% chance of developing a sense of ownership toward the fake hand (i.e., Item 17 in Table 6.1), when the delay between seen and felt simulation is 100 ms or less (in the information-rich condition; see Figure 6.3). By contrast, a 400 ms delay reduces this chance to 16%. Developing the illusion at a more vivid level with, for example, a sense of agency becomes even more unlikely when the extent of asynchrony increases. Hereby, the average person has about 37% chance of developing a sense of agency (i.e., Item 13 in Table 6.1) when the delay is 100 ms or less, this chance is only 6% with delays of 400 ms or more (in the information-rich condition). Asynchrony can thus be seen as an impediment that increases the processing demand for the vividness of the rubber-hand illusion. Based on fit statistics, we can also conclude that the extent of impediment can be accurately estimated (all six estimates resulted in mean square values below 1.20).

The impeding effect of the two levels of information in the stimulation were estimated at .24 (*SE* = .08) and -.24 (*SE* = .08) for the information-poor (i.e., tapping) and information rich-stimulation (i.e., stroking) respectively. The levels of impediment were estimated with a reliability of .88. The information-richness of the setup was found to significantly affect the vividness of the rubber-hand illusion: $\chi^2(1, N = 24) = 17.2$, and $p < .01$). Compared to tapping the fingers of the participant's left hand and the fake hand (poor in information), stroking the fingers (high in information) facilitated the development of a vivid illusion. An average person, for example, has a 12% higher chance of developing a sense of ownership over the fake hand (i.e., Item 17 in Table 1) in the stroking compared to the tapping condition (with no delay between seen and felt stimulation). Again, the fit statistics for these estimates were acceptable, with mean square values below 1.20. The interaction between asynchrony and information-richness was found to be non-significant: $\chi^2(5, N = 24) = 4.0$, and $p = .55$.

6.5.3. Discussion

With a sample of only 24 participants, we were able to largely replicate the findings of Experiment 1 of this chapter. We were successful in modeling people's self-reported experiences related to the rubber-hand illusion based on estimates of people's susceptibility for the illusion, estimates of the anticipated processing demand behind a specific impression, and estimates of the situational impediment. With respect to the individual differences in people's susceptibility for the illusion, we found people to be separable with a reliability of .97. As predicted, the subjective phenomena related to the vividness of the rubber-hand illusion are comparable for different persons as well, which is evidenced by the invariance of the item order. This finding was additionally supported by a high correlation ($r_{corr} = .92$) between the demand estimates of Experiments 1 and 2 (see Figure 6.1B). In other words, even when people look at a two-dimensional projection of the fake hand, the subjective phenomena related to the vividness of the rubber-hand illusion remain comparable to that of the traditional unmediated setup.

For only 1 out of the 22 impressions (Item 15 in Table 6.1: "I became confused about what I saw and felt") participants' responses did not fit our model acceptably, indicating that the impression described in this item is either a comparatively poor indicator of the rubber-hand illusion, or that the item was problematic in its phrasing. It could also be that the asynchrony between seen and felt stimulation, in itself, causes impressions of confusion in our participants. In other words, participants' responses might not only reflect their vividness-related experience, but also their confusion caused by the chosen setup to delay felt stimulation.

Regarding the validity of our extended model, we found that it became more and more difficult for our participants to experience a vivid rubber-hand illusion with increased asynchrony between seen and felt stimulation (cf. Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). Similarly, relatively low amounts of information contained in the stimulation of the participant's concealed hand and the fake hand (i.e., tapping rather than stroking the fingers) obstructed the development of the illusion. Alternatively formulated, we found that the development of a vivid illusion can be facilitated by increasing the information-richness in the stimulation; that is, when the stimulation of the real and fake hand is done in a more complex and erratic (and thus information rich) fashion (cf. Armel & Ramachandran, 2003).

6.6. General Discussion

In two experiments, we were able to predict the probability that a person experiences the rubber-hand illusion at a certain level of vividness based on a person's susceptibility for the illusion, the processing demand that is required for a particular experience, and the suppression/constraints imposed by the situation. In our model tests, we have demonstrated that the vividness impressions related to the illusion (e.g., the fake hand felt as my own) are invariably ordered with respect to the frequency of occurrence. This invariant order is assumed to reflect the processing requirements behind the different experiences. As such, these experiences and processes are comparable for different persons: Regardless of a person's susceptibility for the illusion, each person has to meet the processing requirements needed to develop the illusion at a certain level of vividness. Such an invariant order implies also that the rubber-hand illusion is marked by more or less universal subjective phenomena. We can, thus, speak of *the* rubber-hand illusion in a similar manner as we speak of, for example, *the* Müller-Lyer illusion. This is a non-trivial finding as such invariance is required for an objective scaling of individual susceptibility and situational impediment on the basis of self-reported experiences.

The existence of large differences in the ease with which the various vividness-related impressions can be developed poses a problem for scaling methods based on conventional factor analysis (e.g., Longo et al., 2008; also Longo, Schüür, Kammers, Tsakiris, & Haggard, 2009). Large differences in item difficulty may give rise to spurious vividness dimensions (so-called difficulty factors; e.g., Gorsuch, 1997). Indeed, our analysis indicates that the 22 vividness impressions tap into a single dimension only.

By means of this unidimensional vividness measure, we were able to reliably differentiate people with respect to their susceptibility for the illusion (*rel* ≥ .83). Regarding the validity of our vividness model, the proposed model has proven useful in describing the effects of suboptimal situational conditions on the vividness with which people can develop the illusion. As expected, we found an impeding effect of asynchrony between seen and felt stimulation (cf. Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). Specifically, our data suggest that the vividness of the illusion under a 100 ms delay is still comparable to synchronous stimulation, but that longer delays result in a less vivid rubber-hand illusion (see Figure 6.3; a similar finding is recently reported by Shimada, Fukuda, & Hiraki, 2009). Also, tapping the fingers of the fake hand (the information-poor setup), compared to stroking (the information-rich setup), was found to hinder the development of the illusion. We thus found empirical support for Armel and Ramachandran's (2003) hypothesis that the development of a vivid rubber-hand illusion can be facilitated by providing more complex and erratic—and thus information rich—visuotactile stimulation.

We found a small to moderate correlation between a person's susceptibility for the rubber-hand illusion and the extent of his or her proprioceptive drift, with an overlap in variance of 9.0%. This small to moderate drift-susceptibility correlation implies that proprioceptive drift has poor validity as a measure of the vividness with which people experience the rubber-hand illusion (thereby corroborating the experiments presented in Chapter 5). However, the small to moderate correlation with proprioceptive drift supports the view that the perceptual recombination of proprioception is a mechanism behind self-attribution in the rubber-hand illusion (cf. Holmes et al., 2006).

There were several notable limitations to the present experiments. First of all, we did not randomize the order of the self-report items in our questionnaires. This might have affected our participants' responses in a structured manner, thereby strengthening the presumed invariance in the order of the impressions. Therefore, we will test, in the next chapter, whether the invariance hypothesis is still supported when the 22 self-report items are presented to participants in a randomized order. Secondly, an alternative explanation for the invariant item order, rather than the hypothesized universality of the underlying processing demands, is that people can read off the order from the content of the questionnaire (e.g., due to the increasing oddness of the described impressions). A third limitation of the present paper is that we have provided little evidence to support the validity of our susceptibility measure. In the next chapter, therefore, we further investigate the capabilities and characteristics that make up the individual's susceptibility for the rubber-hand illusion.

Despite these limitations, our model seems promising in various respects. It explains individual differences in reports about experiences related with the rubber-hand illusion. And it can be used as a starting point to explore the mental origins of the differences in individual susceptibility, or to explore the specific processing requirements behind increasingly vivid illusions. In particular, the proposed model and its specific implementation as a many-facet Rasch model advances theorizing about the rubber-hand illusion as it becomes a more quantitative and objective endeavor.

— Chapter 7 —

Validating Susceptibility

Abstract

What makes an individual more or less susceptible for the rubber-hand illusion? In this chapter, we investigate the relation between susceptibility for the rubber-hand illusion, body image instability, and people's ability to mentally position their hands in extracorporeal locations. With respect to body image instability, we corroborated a small, but significant, correlation between susceptibility and body image aberration scores (*rho* = .24). With respect to mental own hand transformations, we found a small, but significant, correlation between susceptibility and responses times to a speeded left and right hands identification task (*rho* ≤ -.24). In addition, we demonstrated that the extent of anatomical implausibility of the fake hand's position constrains the development of a vivid rubber-hand illusion. Taken together, our experiment suggests that people who are more attuned to engage in mental own hand transformations are also better equipped to meet the demands imposed by the position of the fake hand. At the same time, the experiment provides empirical evidence for the construct validity of our susceptibility measure.

The experience of a vivid rubber-hand illusion, or at least a claim thereof, is dependent not only on the features of the experimental setup, but on the characteristics of the individual as well. Research on the rubber-hand illusion has provided substantial empirical evidence regarding the features of the situation that constrain or facilitate the illusion, such as the extent of temporal asynchrony between seen and felt touch (i.e., Armel & Ramachandran, 2003; Botvinick & Cohen, 1998; see also Chapter 6), or the extent to which the foreign object resembles a human hand (i.e., Tsakiris & Haggard, 2005; see also Chapters 3 & 4). In contrast, there has been little empirical research into the characteristics of the individual that make one person to report having encountered even the most vivid impressions (including, for example, a sense of agency), while another person, under the same experimental conditions, reports to have encountered no such experiences (for exceptions, see, e.g., MacLachlan et al., 2003; Mussap & Salton, 2006;). Questions are: What makes an individual more or less susceptible to the rubber-hand illusion? And, at the same time, is the self-report measure presented in the previous chapter a valid measure of susceptibility?

To address these questions, we investigate the relation between susceptibility for the rubber-hand illusion (as assessed by means of the 22-item self-report measure introduced in Chapter 6), and two aspects of the individual's psychological make-up: body image instability, and the ability to mentally simulate one's hand to be in an extracorporeal location (i.e., mental own hand transformations). In addition, we further investigate the extent to which the anatomical implausibility of the position and orientation of the fake hand is a situational impediment in developing a vivid illusion.

7.1. Body Image Instability

Burrack and Brugger (2005) investigated whether people who are more prone to experience body image disturbances in everyday life (such as experiencing a temporary elongation of the limbs) are also more susceptible to experimentally induced bodily illusion. Such aberrant body experiences point toward a less stable body image. A relation between body image instability and susceptibility for experimentally induced bodily illusion is to be expected, because less stable body images are more likely to change due to novel sensorimotor information (Mussap & Salton, 2006; see also Chapter 6). Indeed, Burrack and Brugger found that people with a less stable body image (measured with the Body Image Aberration scale; Chapman, Chapman, & Raulin, 1978) are more susceptible to tendon vibration induced illusory arm movements and nose elongations (often called the Pinocchio illusion, Lackner, 1988; see also Chapter 2). For the rubber-hand illusion, individual differences in susceptibility have also been linked to the tenacity with which people identify with their own bodies. People that tend to experience their own bodies as an entity that is clearly differentiated from objects in the environment were found to experience less vivid rubber-hand illusions (MacLachlan et al., 2003). Since the body image is commonly presumed to play a role in developing eating disorders and other types of unhealthy body changing behaviors, Mussap and Salton (2006) investigated whether the individual differences in people's susceptibility for the rubber-hand illusion could aid in predicting such behavior. They found that people who were more susceptible to the rubber-hand illusion were also more inclined to engage in bulimic (e.g., copiously eating) or body enhancing behaviors (e.g., taking food supplements, such as vitamins, protein drinks, or diet pills).

7.2. Fake Hand Position as a Situational Impediment

Traditionally the rubber-hand illusion is induced with the fake hand positioned on the table in such a way as to extend naturally from the participant's shoulder (and thus with the fingers pointing away from the participant; Botvinick & Cohen, 1998; see also Figure 7.1A). Tsakiris and Haggard (2005) demonstrated that rotating a left fake hand anticlockwise by 90 degrees, and thus with the fingers of the fake hand pointing towards the participant's left hand side (see Figure 7.1C), significantly reduced the extent to which the rubber-hand illusion occurred. A similar effect is reported by Ehrsson and colleagues (2004) for a 180 degrees rotation of the fake hand (thus with the fingers pointing toward the participant). The development of a vivid rubber-hand illusion is also constrained by the distance between the fake hand and the participant's concealed hand. Armel and Ramachandran (2003) investigated the effect of positioning the fake hand in a distal location. By placing the fake hand 91 cm away from its traditional position (and away from the participant's body), the self-reported vividness of the rubber-hand illusion had significantly reduced. Lloyd (2007) investigated the impeding effect of the lateral distance between the participant's concealed hand and the fake hand on the extent to which he or she developed the impression that the felt touch was caused by the experimenter stimulating the fake hand. Lloyd found that it became significantly demanding for people to develop such an impression when the lateral distance between the participant's concealed hand and the fake hand was 27.5 cm or more. Moreover, increasing the lateral distance between fake hand and the participant's concealed hand significantly increased the time required for people to develop the rubber-hand illusion.

Taken together, these studies indicate that it is more demanding for the central nervous system to develop a vivid rubber-hand illusion when the fake hand's location and orientation are different from the participant's concealed hand (for similar findings on the effect of observing a fake hand on the localization of touch, tactile extension, and the perceptual recombination of proprioception, see, e.g., Austen, Soto-Faraco, Enss, & Kingstone, 2004; Farné, Pavani, Meneghello, & Làvadas, 2000; Pavani, Spence & Driver, 2000). In terms of our model of the vividness of the illusion presented in Chapter 6, we can, thus, state that the orientation and position of the fake hand operate as a situational impediment of the vividness of the illusion. However, one question remains to be answered: What aspect of the position of the fake hand constrains the vividness of the illusion the most? Does the level of impediment depend merely on the degree in which the location and orientation of the fake hand are different from that of the participant's concealed hand? Or is the level of impediment dependent also on the anatomical awkwardness of the fake hand's position (i.e., on the extent to which it is impossible, anatomically, for the participant to place his or her own hand in the fake hand's position; cf. Armel & Ramachandran, 2003)? To our knowledge, this question has not yet been adequately addressed.

Demonstrating that the anatomical awkwardness of the fake hand's position affects the vividness of the rubber-hand illusion would provide further empirical evidence regarding the importance of morphological congruence between the foreign object and a human hand, and thus for the view that the integration of seen and felt touch is modulated, top down, by a cognitive representation of what the human body is like (Tsakiris & Haggard, 2005; de Vignemont et al., 2006; also Chapters 3 & 4).

7.3. Mental Own Hand Transformations and Susceptibility

Since the orientation and position of the fake hand is a situational impediment of the vividness of the illusion, one interesting question presents itself: Is a person that is more attuned to mentally position his or her own hand in an extracorporeal position also better equipped to meet the demands imposed by the location and orientation of the fake hand? In other words, is there a relation between individual susceptibility and the ability to engage in the mental imagery of motor tasks? Individual differences in the ability to simulate motor tasks are often tested by a speeded left and right hands identification task (e.g., Cooper & Shepard, 1975). In this task people are shown a series of left and right hands depicted in various orientations, and are asked to make a speeded decision regarding the laterality of the depicted hands. Research suggests that people, in order to solve this task, mentally place their own hand in the position of the depicted hand before deciding whether a left of right hand is depicted. First, response times are dependent on the orientation of the depicted hands. People, for example, respond faster to hands that are depicted with fingers pointing upward, than to hands with fingers pointing downward (which require a longer, and a anatomically awkward, trajectory of mental movement; e.g., Cooper & Shepard, 1975; Parsons, 1987; Sekiyama, 1982). Secondly, response times are related to the time it requires to make the same movements with one's actual hand (Parsons, 1994). Thirdly, right-handed people respond faster to stimuli that depict right hands than to stimuli depicting left hands (Nico, Daprati, Rigal, Parsons, & Sirigu, 2004). Finally, neuroimaging studies have demonstrated an involvement of the motor system when people decide on the laterality of the depicted hands (e.g., Bonda, Petrides, Frey, & Evans, 1995; Parsons et al., 1995; Parsons, Gabrieli, Phelps, & Gazzaniga, 1998). Research on the speeded identification of left and right hands is, thus, consistent with the view that the body-schema plays a role in both motor imagery and the observation of people and their body parts (see Chapter 2).

The ability to mentally move one's own hands into a certain position in extracorporeal space might, then, play a role in the rubber-hand illusion as well. In the experimental setup of the rubber-hand illusion, people are watching a fake left hand that is placed on the table in a position that is incongruent with their own concealed left hand (see Figure 7.1). We expect that the fake hand is more easily attributed to the self, when people mentally place their concealed hand in the position of the fake hand. In other words, we expect a relation between motor imagery abilities (or the ability to engage in mental own hand transformations) and susceptibility for the rubber-hand illusion.

7.4. Experiment

7.4.1. Research Aim and Hypotheses

The aim of this experiment is threefold: (a) to investigate the relation between body image instability and individual susceptibility for the rubber-hand illusion, (b) to investigate the relation between individual susceptibility for the rubber-hand illusion and the ability to mentally simulate one's own hand to be in an extracorporeal location, and (c) to determine the effect of the anatomical awkwardness of the position and orientation of fake hand on the vividness with which people can develop the illusion.

With respect to body image instability, we expect to corroborate existing research which shows that people with less stable body images are more susceptibility to experimentally induced bodily illusions (Burrack & Brugger, 2005; MacLachlan et al., 2003). More specifically, we hypothesize a positive relation between a person's self-reported frequency of body image disturbances in daily life and his or her susceptibility for the rubber-hand illusion. Demonstrating such a relation would provide supporting evidence for the construct validity our susceptibility measure developed in Chapter 6.

With respect to mental imagery of motor tasks, we expect that mentally positioning one's own hand in the position and orientation of the fake hand will facilitate the attribution of the fake hand to the self. In other words, we hypothesize a relation between individual susceptibility for the rubber-hand illusion and the ability to engage in mental own hand transformations. If such a relation exists, then we expect to find a negative correlation between a person's susceptibility for the rubber-hand illusion and his or her response times in a speeded left and right hands identification task.

Finally, to determine the effect of the anatomical awkwardness of the fake hand's position and orientation, three different orientations of the fake left hand will be compared. (a) A congruent and anatomically plausible orientation, in which the fingers of the fake left hand point away from the participant's body. In this case, the fake hand's orientation (but not position) is congruent with the participant's concealed hand, and it is possible anatomically for people to place their own left hand in the position and orientation of the fake hand. (b) An incongruent but anatomically plausible orientation, in which the fingers of the fake left hand point to the participant's right hand side. In this case, the orientation of the fake hand is different from the participant's concealed hand, but it is still anatomically possible for the people to place their own hand in the position and orientation of the fake hand. (c) An incongruent and anatomically awkward orientation, in which the fingers of the fake left hand point to the participant's left hand side. In this case, the fake hand is not only orientated differently from the participant's concealed hand, but it is also impossible, anatomically, for a person to place his or her left hand in the position and orientation of the fake hand. In both incongruent conditions, the real and fake hand are rotated by the same amount although in opposite directions. If anatomical plausibility is not important in attributing a fake hand to the self, both incongruent conditions will equally constrain the development of a vivid rubber-hand illusion. In contrast, if anatomical plausibility is important, then the incongruent and anatomically awkward orientation will have a larger impeding effect than the incongruent but anatomically plausible orientation.

7.4.2. Method

Participants. Our sample was drawn from the participant database of the J.F. Schouten School at Eindhoven University of Technology, Eindhoven, the Netherlands. Seventy-one persons were invited to participate in the experiment. The mean age was 23.4 (SD = 6.0; range 17 to 56); 55 (77.5%) of participants were male; 58 (81.7%) of the participants were right handed, and 7 (9.9%) were ambidextrous (as based on the Dutch handedness scale; van Strien, 1992).

Experimental Design. A three condition (0°, 90°, -90° rotation of fake hand) repeated-measures experiment was conducted. In the 0° condition, the participant's concealed left hand was stroked in precise synchrony with a visible fake left hand, which was

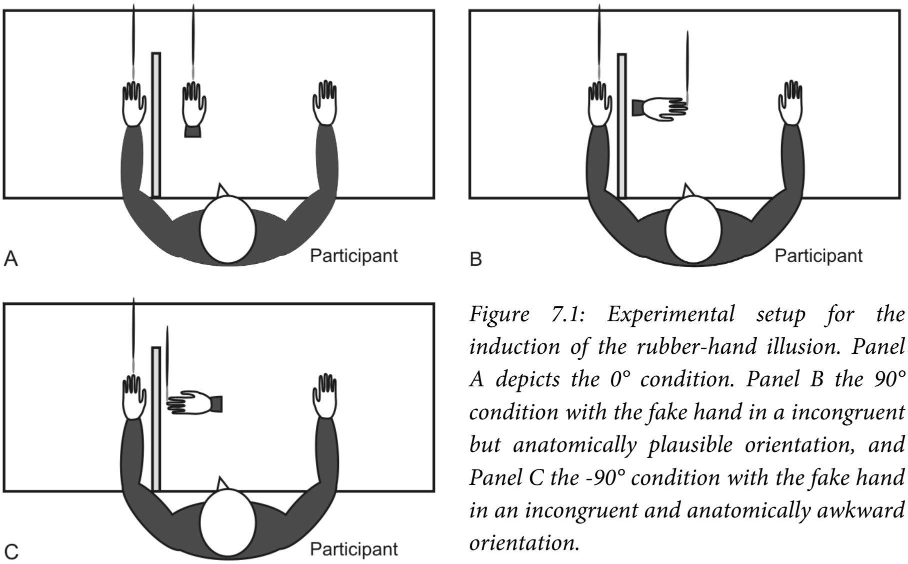

Figure 7.1: Experimental setup for the induction of the rubber-hand illusion. Panel A depicts the 0° condition. Panel B the 90° condition with the fake hand in a incongruent but anatomically plausible orientation, and Panel C the -90° condition with the fake hand in an incongruent and anatomically awkward orientation.

conventionally positioned with the fingers pointing away from the participant (see Botvinick & Cohen, 1998; Figure 7.1A). In the 90° condition, the fake left hand was rotated clockwise with 90 degrees around its midpoint, thus with the fingers of the fake hand pointing to the right (from the participants perspective; see Figure 7.1B). As a result of this rotation, the fake hand was in an incongruent position with respect to the participant's own concealed hand, yet the position of the fake hand was anatomically plausible. In the -90° condition, the fake hand was rotated anticlockwise with 90 degrees, thus with the fingers of the fake hand pointing to the left (i.e., similar to Tsakiris & Haggard, 2005; see Figure 7.1C). In contrast to the 90° condition, this rotation resulted in a position of the fake hand that is both incongruent with the position of the participant's own hand and anatomically awkward. The three conditions were counterbalanced across participants.

Procedure. The study was divided in two sessions. In one session, we elicited the rubber-hand illusion in the three experimental conditions described above. In the other session, participants completed a body image instability questionnaire and a speeded left and right hand identification task. The order of these two sessions was counterbalanced across participants.

For the induction of the rubber-hand illusion, participants were asked to place their left hand on the table and to keep it motionless during the session (see Figure 7.1). A pencil mark indicated the exact location at which participants had to place their middle finger. Next, the experimenter placed a fake hand on the table. Depending on the experimental condition, the fake hand was placed with the fingers pointing away from the participant (0° condition; see Figure 7.1A), pointing to the participant's right hand side (90° condition; see Figure 7.1B), or pointing to the participant's left hand side (-90° condition; see Figure 7.1C). As a fake hand, a cosmetic prosthesis of a man's left hand was used that was highly realistic in terms of skin texture, color, and shape. In the 0° condition, the lateral distance between the fake hand and the participant's concealed hand was 30 cm. Next, the experimenter placed a wooden screen between the participant's left hand and the fake hand, and asked the participant to concentrate on what he or she see saw and felt. Subsequently, the experimenter, by means of two brushes, stroked and tapped the middle and index fingers of the participant's concealed hand and the fake hand for five minutes. To assure a constant interval between subsequent strokes or taps, the experimenter wore a headphone through which a tone was played at a 1.5 second interval. At each tone, the experimenter stimulated a finger of the participant's concealed hand and, synchronously and in the same manner, the corresponding finger of the fake hand. After each experimental condition, the participants completed a questionnaire using a laptop computer.

In the other experimental session, participants were asked to take a seat behind a laptop computer. The participant completed a body image instability questionnaire (the Body Image Aberration scale by Chapman et al., 1978) and a speeded right and left hand identification task (similar to, e.g., Cooper & Shepard, 1975; Parsons, 1994). Each participant completed the Body Image Aberration questionnaire first.

Measures. In this study, we employed two self-report measures: one regarding spontaneously occurring changes in body perception, the other regarding the vividness-related impressions during the rubber-hand illusion. In addition, we employed a response time measure to assess a person's ability in making mental own hand transformations.
Self-reported vividness of the rubber-hand illusion was assessed by means of the 22 self-report items developed in the previous chapter. These items consisted of statements regarding a particular vividness impression, such as "It felt as if the fake hand was part of my own body" (see Table 7.1). Participants were asked to indicate whether they agreed or disagreed with these statements on a 5-point response scale, labeled "disagree", "slightly disagree", "neutral", "slightly agree", and "agree". In contrast to the previous studies with

Table 7.1: Processing demand (δ), mean square fit statistic (MS), and the probability of consent for an averagely susceptible person in the 0 º condition (p).

		Experiment 2		
	Impressions	*σ*	*MS*	*p*
1	Sometimes, it appeared as if the fake hand moved to my left hand side.	4.53	1.05	.02
2	Sometimes, it felt as if my left hand moved towards my right hand side.	3.04	1.04	.05
3	Sometimes, the shape of the fake hand appeared to change.	1.66	0.88	.14
4	Sometimes, it felt as if my left hand turned rubbery.	2.41	1.12	.08
5	Sometimes, it felt as if the shape of my left hand started to change.	1.66	1.09	.14
6	Sometimes, the skin properties of the fake hand (i.e., color or texture) appeared to change.	1.66	1.00	.14
7	Sometimes, it felt as if I had more than one left hand.	1.82	1.04	.13
8	When a finger of the fake hand moved, I sometimes felt the finger of my left hand moving as well.	1.26	1.11	.19
9	Sometimes, it appeared as if the touch I felt originated from somewhere between my own hand and the fake hand.	0.63	1.22	.27
10	Sometimes, the fake hand **began** to match my own hand in appearance.	-0.08	1.01	.39
11	Sometimes, it felt as if my left hand was inside the fake hand.	-0.27	0.77	.43
12	Sometimes, it felt as if my left hand and the fake hand were on the same location on the table.	-0.15	0.88	.41
13	Sometimes, it felt as if I had complete control over the fake hand: I could have moved the fake hand if I wanted to.	0.85	0.95	.24
14	Sometimes, it felt as if the fake hand was part of my own body.	-0.37	0.74	.45
15	Sometimes, I became confused about what I saw and felt.	-1.40	1.30	.64
16	Sometimes, it appeared as if I felt the touch on my side of the wooden screen (i.e., on the side of the fake hand).	-1.15	0.82	.60
17	Sometimes, it felt as if the fake hand was my own hand.	-1.23	0.68	.61
18	Sometimes, it appeared as if I felt the touch on the location where I saw the fake hand being touched.	-2.10	0.85	.76
19	*I **continuously** felt as if the touches on my fingers and the touches on the fake hand were caused by two different brushes.*	-3.25	0.95	.88
20	Sometimes, it felt as if the touches on my fingers were caused by the brush touching the fake hand.	-3.04	0.86	.87

Continued

	Impressions	Experiment 2		
		σ	*MS*	*p*
21	*I did **not** experience anything odd.*	-2.73	1.24	.84
22	*I **continuously** noticed clear differences between the touches I saw on the fake hand, and the touches I felt.*	-3.70	1.16	.92

The items are translated from their original Dutch version. Impressions are ordered according to processing demand (δ) as estimated in Experiment 1 in chapter 6. Processing demands (δ) are in the metric of Experiment 1 in Chapter 6. Items in italic *are negatively worded. They were reversed in their coding before they were analyzed. Words in **bold** were emphasized in the questionnaire. p represents the probability of an affirmative response for an averagely susceptible person in the 0 º rotation condition (i.e., with fingers of the fake hand pointing away from the participant)*

these self-reports (i.e., Experiment 1 & 2 in Chapter 6), the statements were presented to the participant on a laptop computer, one by one, in a random order. There were no missing responses.

Body image instability was assessed by means of self-reported frequency of spontaneously occurring changes in body perception. For this purpose, we used the Dutch translation (Hardy, 2001) of the 28-item Body Image Aberration questionnaire developed by Chapman and colleagues (1978). This questionnaire consists of statements like "I have sometimes had the feeling that one of my arms or legs is disconnected from the rest of my body" or "I sometimes have had the feeling that some parts of my body are not attached to the same person". Participants were asked to indicate whether or not they agreed with each of these statements by means of a dichotomous response format, labeled "true" and "false". A person's Body Image Aberration score is calculated by taking the sum of the "true" responses. The reliability of the Image Aberration measure (Cronbach's alpha) was α = .74. There were no missing responses.

For the Mental Own Hand Transformation test (MOHT-test), participants were asked to make speeded right-left judgments. The stimuli were adapted from Cooper and Shepard (1975; also Parsons, 1987; 1994) and consisted of colored computer generated images of either a left or a right human hand (see Figure 7.2). The hands were presented to the participant with either the fingers pointing toward the top or the bottom of the screen, yielding four unique stimuli (fingers up or down vs. left or right hand). Participants were instructed to mentally place their own hand in the position of the displayed hand, before determining whether the displayed hand was a left or right hand. Participants were instructed to perform the task as quickly and accurately as possible.

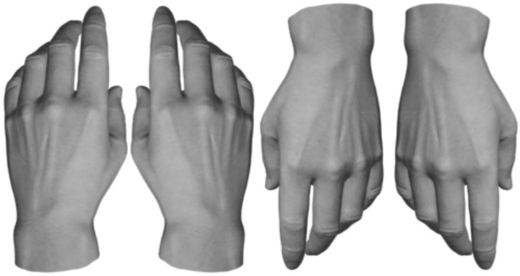

Figure 7.2: Stimuli for the Mental Own Hand Transformation test (MOHT-test). The original colored graphics are here depicted in grayscale.

The stimuli were presented to the participant on a computer screen until the participant made his or her response. After a response was made, a fixation marker was displayed on the computer screen for 1000 ms, after which the next stimulus was displayed. The E-Prime 2.1 software package (Psychology Software Tools, Pittsburgh, PA) was used for presenting the stimuli and for recording response times. All stimuli were presented 30 times in a randomized order in two separate blocks. Participants made their responses through a PST Serial Response Box (Psychology Software Tools, Pittsburgh, PA) by means of two buttons. The left button was always used for making "left" responses, and the right button for "right" responses. In one block, participants were instructed to make their responses with the left hand. In the other block, participants were instructed to make their responses with the right hand. The order of the two blocks was counterbalanced across participants. We used a participant's average response time for correct responses in the analyses.

7.4.3. Results

The results are presented in seven sections. In the first three sections, we confirm the previous calibration of our 22 vividness impressions (see experiment 1 & 2 in Chapter 6) and corroborate prior tests regarding the invariant order of these impressions' processing demands, and the individual differences in people's susceptibility for the rubber-hand illusion. In the fourth section, we test the predicted effect of the anatomical awkwardness of the fake hand's position on the vividness of the rubber-hand illusion. In the final three sections, we describe the relation between individual susceptibility for the rubber-hand illusion, body image instability, and mental own hand transformation abilities.

Scale Calibration. Similar to Chapter 6, we recoded the individual responses to the 22 items of the self-report measure into a dichotomous format (cf. Kaiser & Wilson, 2000). For this purpose "disagree" and "slightly disagree" were collapsed into a single category "refute", and "slightly agree" and "agree" into "assert". Neutral responses were treated as missing values, as these are expectedly picked when a participant can neither agree nor disagree with a statement, or is otherwise indecisive (cf. Raaijmakers et al., 2000). By doing so, 323 (6.9%) of the responses were coded as missing values. Similar to Chapter 6, we adopt the many-facet Rasch model to estimate individual susceptibility, the processing demand behind each impression, and the level of impediment of the three orientations of the fake hand (for details, see Linacre, 1994; also Bond & Fox, 2007):

$$\ln\left(\frac{\mathrm{p}(x_{njl})}{1-\mathrm{p}(x_{njl})}\right)=\theta_n-(\delta_j+\lambda_l)$$

In this model, the probability that person *n* reports to perceive a certain impression *j* (e.g., the fake hand feels as *n*'s own) is governed by three factors: *n*'s susceptibility for the illusion (θ_n), the specific processing demand required to develop impression *j* (δ_j), and the obstructions imposed by the particular orientation of the fake hand *l* (λ_l). A Rasch model test was performed using the Facets software (Linacre, 2006). The Facets software employs a joint maximum likelihood estimation procedure. The units of these estimates are called logits, or log odds units (i.e., the natural logarithm of the odds that one agrees to a certain impression statement).

Vividness and Processing Demands. The 22 impressions and the estimated processing demand required to develop them are reported in Table 7.1. The processing demands were estimated with a reliability of .98. The appropriateness of the Rasch model is reflected by several fit statistics. All but 3 of the items fit the scale with mean square values (*MS*) ≤ 1.20: "It (at least sometimes) appeared as if the touch I felt originated from somewhere between my own hand and the fake hand" (Item 9 in Table 7.1; *MS* = 1.22), "I (at least sometimes) became confused about what I saw and felt" (Item 15 in Table 7.1; *MS* = 1.30), and "I did not experience anything odd" (Item 21 in Table 7.1; *MS* = 1.24). Mean square values refer to the weighted average of squared standardized residuals, in which each residual is weighted by its variance (e.g., Bond & Fox, 2007). *MS*-values of, for example, 1.20 stand for a 20%

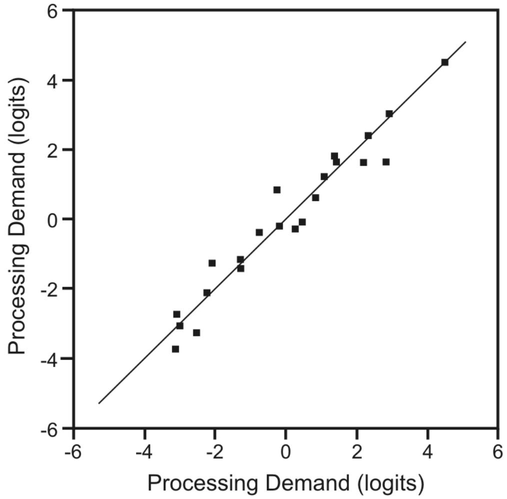

Figure 7.3: Invariance of vividness-related processing demands, as evidenced by the relation between the estimates for Experiment 1 in Chapter 6 (x axis) and the present experiment (y axis).

excess in variation between the observed responses and the model's predictions. As a guideline, mean square values up to 1.20 are considered good even for high-stake tests, and mean square values below 1.30 are considered acceptable (Bond & Fox, 2007; Wright & Linacre, 1994). Thus, the fit statistics for the 22 impression items look quite reasonable. This is also reflected in the overall item fit statistics: the mean of mean squares [*M*(*MS*)] = 0.99, standard deviation of mean squares [*SD*(*MS*)] = 0.16, mean of *t*-values [*M*(*t*)] = -0.27, standard deviation of *t*-values [*SD*(*t*)] = 1.83. Ideally, *M*(*MS*) should be 1.0. For *SD*(*MS*) no general reference value can be given. The *t*-values are standardized fit statistics and represent the statistical significance of the mean squares statistics (e.g., Bond & Fox, 2007). Ideally, *M*(*t*) should be 0 and *SD*(*t*) should be 1.0. Similar to our prior findings with the same 22 vividness impressions (see Chapter 6), only item 15 was found to have a *MS* ≥ 1.30 (cf. Table 6.1). Moreover, the estimated processing demand behind each vividness impression correlated significantly with those estimated in Study 1 in Chapter 6 ($r = .97$, $p < .01$; $r_{corr} = .99$; see Figure 7.3). This high correlation corroborates our findings in Chapter 6, showing that the processing demands behind the different levels of vividness of the rubber-hand illusions can be presumed fairly identical for different persons. This, in turn, implies that the vividness of the illusion is marked by more or less universal subjective phenomena.

Individual Susceptibility. The individual differences in susceptibility for the rubber-hand illusion were estimated with a reliability of .94. The average susceptibility was M = -1.30 logits (*SD* = 1.65; range -5.33 to 2.42). For only two (2.8%) of the 71 participants, the model prediction did not fit the data, indicated by a significant *t*-value of $t \geq 1.96$. The overall fit statistics for all participants were found to be reasonable, with $M(MS) = .98$, $SD(MS) = .23$, $M(t) = -.15$, $SD(t) = 1.24$.

Additionally, we tested whether participants experienced the rubber-hand illusion at a different level of vividness when the illusion was induced in the first as compared to the second session (i.e., before or after the participant completed the Body Image Aberration scale and the MOHT-test). No difference in susceptibility was found, with $t(69) = 1.1$, and $p = .29$, indicating that the order of the two experimental sessions did not affect the self-reported vividness of the rubber-hand illusion.

Impediment Effect of Hand Orientation. The estimated levels of impediment for the -90° (.36 with *SE* = .08), 0° (-.08 with *SE* = .08), and -90° condition (-.28 with *SE* = .07) are shown in Figure 7.4. The levels of impediment were estimated with a reliability of .92. The fit statistics for these estimates were acceptable, with mean square values below 1.20. The different orientations of the fake hand had a significant effect on the self-reported vividness of the illusion: $\chi^2(2, N = 71) = 36.3$, $p < .01$. As can be seen in Figure 7.4, it was more difficult to experience a vivid illusion when the fake hand was rotated anticlockwise toward an anatomically awkward position (i.e., the -90° condition), as compared to the two other conditions. Whereas an average person, according to our model's predictions, has a 44 percent chance of developing a sense of ownership in the 0° condition, this probability was only 33 percent in -90° condition (as assessed with Item 17 in Table 7.1). Surprisingly, the 90° condition was as effective (and perhaps even more effective) as the 0° condition in facilitating the development of a vivid illusion: An averagely susceptible person had a 49% to develop a sense of ownership in the 90° condition, and a 44% to develop such an impression in the -90° condition.

Body Image Instability and Susceptibility. The average Body Image Aberration score was *M* = 4.4 with *SD* = 3.5. Body Image Aberration scores were not normally distributed. One participant was identified as an outlier, as his or her standardized body aberration score was higher than 4.0. Since the exclusion of this outlier did not affect the interpretation of the results, we will report on the analyses with all 71 participants included. Using the nonparametric Mann-Whitney U test, we did not find a statistically significant difference in

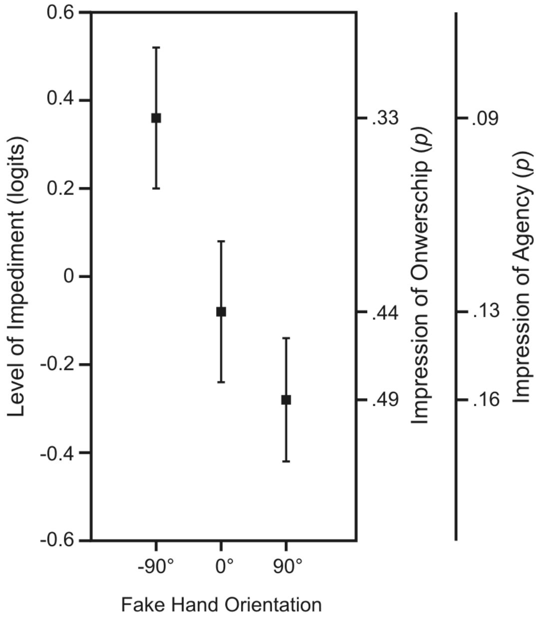

Figure 7.4: Level of impediment to the vividness of the rubber-hand illusion as a function of fake hand orientation. The y-axes on the right give the probability of an average susceptible person claiming that "the fake hand felt as my own" (ownership; Item 17 in Table 7.1) and "that it felt as if I had complete control over the fake hand" (agency; Item 13 in Table 7.1) as a function of the orientation of the fake hand.

Body Image Aberration between participants that completed the scale before as compared to after the induction of the rubber-hand illusion, with $Z(N = 71) = 0.7$ and $p = .51$. The order of the two experimental sessions, thus, did not affect the self-reported frequency of aberrant body experiences in daily life. Secondly, we examined the relation between a person's susceptibility for the rubber-hand illusion and his or her Body Image Aberration score using the nonparametric Spearman's rho correlation. As expected, body image aberration scores were positively related to susceptibility, with *rho* = .24 and $p = .048$.

Mental Own Hand Transformations and Susceptibility. In the MOHT-test, the average percentage of correct responses was $M = 94.6\%$ ($SD = 6.5\%$) for hand stimuli with fingers pointing upwards, and $M = 92.7\%$ ($SD = 10.0\%$) for hand stimuli with fingers pointing downwards. The number of correct responses was not normally distributed. Two participants were identified as outliers, with standardized scores below -4. Since excluding these outliers did not change the interpretation of the results, we will report on the analyses with all 71 participants included. We used the nonparametric Wilcoxon signed-rank test to investigate whether people were more accurate in making left-right judgments for hands with fingers pointing upwards than for hands with fingers pointing downwards. We did not find a significant difference between the two types of stimuli, with $Z(N = 71) = 1.3$, and $p = .20$.

As with accuracy, response times to hands with fingers pointing upward and to hands with fingers pointing downward were not normally distributed. One participant was identified as an outlier with standardized scores above 4 for both stimuli. Since excluding this outlier did not change the interpretation of the results, we report on the analyses with all 71 participants included. As expected from prior research with the MOHT-test (e.g., Cooper & Shepard, 1975; Parsons, 1987; 1994), our participants responded faster to hands that were presented with fingers pointing upward, with M = 1358 ms (*SE* = 175 ms), than to hands with fingers pointing downward, with $M = 1878$ ms ($SE = 186$ ms). This difference was found to be statistically significant, with $Z(N = 71) = 7.3$, and $p < .01$ (using the Wilcoxon signed-rank test). Secondly, we tested for speed-accuracy trade-off by calculating Spearman's rho between a person's accuracy and his or her response time (e.g., Pachella, 1974). We found a significant negative correlation for stimuli with finger pointing upward, with rho = -.58 and p < .01, but not for stimuli with fingers pointing downward, with *rho* = -.20 and $p = .10$. In other words, people who are slower in making left-right judgments are also less accurate. Thirdly, we tested whether participants that completed the MOHT-test after the induction of the rubber-hand illusion had different response times than participants that completed the test before the induction of the illusion. Using the nonparametric Mann-Whitney U test, we did not find significant differences in response times between these two groups for either the fingers upward or finger downward stimuli, with $Z(N = 71) \leq 0.8$ and $p \geq .43$. In other words, the order of the two experimental sessions did not affect response times.

Finally, we investigated the relation between a person's susceptibility for the rubber-hand illusion and his or her response times on the MOHT-test. For hands with fingers pointing upward, the correlation between susceptibility and response time was found to be significant, with *rho* = -.24 and $p = .046$. Similarly, we found a significant correlation between susceptibility and response time for stimuli with fingers pointing downward, with *rho* = -.27 and $p = .02$. These correlations indicate that people who are faster in making left or right hand discrimination (and thus, by inference, are better in performing mental own hand transformations) are also more susceptible to the rubber-hand illusion. In contrast, no significant correlations were found between a person's susceptibility and his or her accuracy in identifying left and rights hands for either the fingers upward or the fingers downward stimuli, with *rho* ≤ .03 and *p* ≥ 0.79.

Body Image Instability and Mental Own Hand Transformations. Additionally, we investigated the relation between a person's score on the Body Image Aberration scale and his or her performance on the MOHT-test. No significant correlation with Body Image Aberration scores were found for response times to either the stimuli with fingers pointing upwards, with *rho* = -.10 and *p* = .42, or the stimuli with fingers pointing downward, with *rho* = -.15 and *p* = .20. Similarly, a person's Body Image Aberration score was not found to be related to his or her accuracy in identifying left and rights hands for either the fingers upward or the fingers downward stimuli, with *rho* = -.11, *p* = .36, and *rho* = .07,*p* = .59, respectively.

7.5. Discussion

With a sample of 71 participants, we were, again, successful in predicting people's self-reported vividness of the rubber-hand illusion based on estimates about people's susceptibility for the illusion, the anticipated processing demands of a specific vividness experience, and the situational impediments of the experimental setup. We found a significant correlation between the processing demands behind the different levels of vividness of the rubber-hand estimated in this experiment and those estimated in Experiment 1 in Chapter 6 (r_{corr} = .99; see Figure 7.3). This near perfect correlation corroborates that the invariance in the order of the impressions with respect to their approval probabilities is due to the universality of the illusion's processing requirements.

In addition, we have provided empirical evidence regarding the construct validity of our susceptibility measure by corroborating a small to moderate, but significant correlation with the frequency of aberrant body experiences in daily life (as assessed by the Body Image Aberration scale; Chapman et al., 1978). This finding supports existing research that points toward a relation between body image instability and susceptibility to experimentally induced bodily illusion: Less stable body images are more likely to be vulnerable to change due to novel sensorimotor information (e.g., Burrack & Brugger, 2005; MacLachlan et al., 2003; Mussap & Salton, 2006; see also Chapter 6).

With regard to the fake hand's position as a situational impediment, we found that it was significantly more difficult for our participant's to develop a vivid illusion in the incongruent and anatomically awkward condition (i.e., the -90° condition) compared to the incongruent and anatomically plausible condition (i.e., the 90° condition; see Figure 7.4). In both these incongruent conditions, the difference between the orientation of the participant concealed hand and that of the fake hand was the same (i.e., the fake hand was always rotated by 90 degrees, but in different directions). Therefore, the significant differences between the 90° and -90° orientation condition reveals that the anatomical plausibility of the fake hand's position is important for inducing a vivid rubber-hand illusion. To our surprise, the incongruent but anatomically plausible condition (i.e., the 90° condition) was as effective (and perhaps even more effective) in inducing a vivid rubber-hand illusion as the 0° condition. This is an unexpected finding, as the position of the fake hand was more incongruent with that of the participant's concealed hand in the 90° as compared to the 0° condition. One possible explanation is that the position of the fake hand in the 90° condition somewhat matches the position to which felt hand position naturally shifts when the individual does not have visual or kinesthetic information about arm position (i.e., toward the body's midline and the person's chest; e.g., Gross & Melzack, 1978; see also Chapter 5). This might, perhaps, have facilitated the development of a vivid illusion in the 90° condition. Further experimentation is required to test this explanation. Taken together, the observed effects of the orientation of the fake hand on the vividness of the illusion suggest that visuotactile integration in the rubber-hand illusion is modulated by the anatomical plausibility of the fake hand's orientation (i.e., whether the orientation makes sense from an egocentric perspective; cf. Saxe, Jamal, & Powell, 2006).

We found a significant relation between a participant's response times in the MOHT-test and his or her susceptibility for the rubber-hand illusion. As expected, we found that more susceptible persons had shorter response times in deciding whether a left or right hand was depicted. Such a negative relation with susceptibility was found both for hands with the fingers pointing upward and for hands with the fingers pointing downward. This finding illustrates that people who are better in mental own hand transformations are also better equipped to meet the processing demands required to develop a vivid rubber-hand illusion. Although further research is required to uncover the nature of this relation, we expect that some people automatically (i.e., involuntarily) engage in the mental positioning of the concealed hand in the location of the fake hand, thereby facilitating self-attribution. Such an explanation seems reasonable given the role of the body schema (defined in Chapter 2 as a distributed network of procedures aimed at guiding behavior) in the observation of other people and their body parts (see Chapter 2). Also possible is that motor imagery and developing a vivid rubber-hand illusion share the same underlying neural mechanisms (see also Kitada, Naito, & Matsumura, 2002).

Body Aberration scores were found not to be related to response times on the speeded left and right hand identification task (i.e., the MOHT-test). In other words, body image instability did not affect a person's ability to engage in mental own hand transformation. In contrast, mental transformations that involve the whole body, rather than just the hand, are impaired by the instability of the body image (Arzy, Mohr, Michel, & Blanke, 2007; Mohr, Blanke, & Brugger, 2006). In these studies, participants were asked to make speeded judgments about whether a marker was attached to the left or right hand of a series of depicted human figures (see also Blanke et al., 2005; for an earlier version of such task, see Gordon, 1934). The stimuli were orientated in one of two ways: either with the face toward (front-facing figures), or away from the participant (back-facing figures). Participants generally responded faster to back-facing figures than to front-facing figures, suggesting that participants, before making a left or right response, situated their own body in the position of the depicted human figure (i.e., engaged in mental own body transformations). Response times to both front- and back-facing figures were found to correlate positively with people's scores on the perceptual aberration scale (i.e., the body aberration scale extended with seven items not related to the body; Chapman et al., 1978). Body image instability, thus, affects the ability to engage in mental transformations of the whole body, but not the ability to engage in mental transformations of a hand. One possible explanation for this apparent contradiction is that own body transformations involve visuospatial perspective taking, which requires a spatial unity between body and self. Using transcranial magnetic stimulation, Blanke and colleagues (2005) demonstrated that impaired performance on the own body transformation task is linked to deficient activation in the temporoparietal junction (TPJ). The TPJ is assumed to be involved in mediating the spatial unity between self and body. Dysfunction of the TPJ has, for example, been related to the occurrence of out-of-body experiences in which people are looking at their own body from an extracorporeal perspective (for an overview, see Lenggenhager, Smith, & Blanke, 2006). Blanke, Ortigue, Landis, and Seeck (2002), for example, demonstrated that out-of-body experiences could be induced in a neurological patient by electrical stimulation of the TPJ. In contrast to mental transformations that involve the whole body, mental transformations of a hand do not require visuospatial perspective taking. Body Image Aberration scores might therefore correlate with the former but not with the latter type of mental motor imagery. Visuospatial perspective taking is also not required for developing a vivid rubber-hand illusion (Schwabe & Blanke, 2007). The positive relation between Body Image Aberration scores and individual susceptibility for the rubber-hand illusion can, thus, not be explained by an increased impairment of the spatial unity between body and self, but by the body image being more vulnerable to change due to novel sensorimotor information. Unfortunately, as a measure of body image instability, the body (or perceptual) aberration scale by Chapman and colleagues (1978) does not differentiate the various causes behind body image disturbances in everyday life (i.e., impaired spatial unity between body and self, or vulnerability to change due to novel sensorimotor information). Interesting future research, then, might explore ways of differentiating people with respect to the mechanisms behind their aberrant body experiences.

There were two notable limitations to the experiment reported in this chapter. First, our participants completed the Body Image Aberration scale and the MOHT-test either immediately before or immediately after the induction of the rubber-hand illusion. Because of the short period of time between the administrations of the various tests, a participant's performance on one test might have influenced his or her performance on another test. However, the order in which the participants completed the various tasks was found not to have a significant effect on any of the reported tests. Second, by rotating the fake hand around its midpoint, we did not keep the lateral distance between the stimulation of the participant concealed hand and that of the fake hand constant across the three conditions. Whereas the distance between the two points of stimulation was 30 cm in the 0° condition, this distance was increased and decreased by about 5 cm in the 90° and -90° conditions, respectively. Based on the results of Lloyd (2007), we can expect that the lateral distance between the points of stimulation will affect the vividness with which people experience the illusion. However, such an effect would be in the opposite direction than the effect of the orientation of the fake hand described in this chapter. For example, the lateral distance between the points of stimulation is larger in the anatomically plausible condition (i.e., the 90° condition) as compared to the anatomically awkward condition (i.e., the -90° condition). This difference would, thus, be expected to impede the development of a vivid illusion in the anatomical plausible as compared to the awkward condition. Put differently, had we kept the lateral distance the same for all conditions (e.g., by rotating the fake hand around the point of stimulation), the estimated impeding effect of hand orientation might have been more pronounced.

Despite these limitations, we have provided empirical evidence regarding two aspects of the individual's psychological makeup that make him or her more susceptible to the rubber-hand illusion: body image instability, and the ability to engage in mental imagery of motor tasks. By doings so, we further demonstrated the construct validity of our self-report measure of susceptibility for the rubber-hand illusion. Moreover, we have provided empirical evidence that the anatomical awkwardness of the position and orientation of the fake hand constrains the development of a vivid rubber-hand illusion. This, in turn, provides further evidence for the view that the integration of seen and felt touch is modulated by a cognitive representation of what the human body is like.

— Chapter 8 —

Self-Attribution and Telepresence[22]

From behind the screen where I hid,
I advance personally, solely to you.
Camerado! This is no book,
Who touches this, touches a man,
(Is it night? Are we here alone?)
—Walt Whitman

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.
—George M. Stratton

Abstract

In this chapter, we investigate the relation between self-attribution (i.e., the discrimination between what is contained within and outside the boundaries of the body) and the phenomenon of telepresence (i.e., the experience of "being there" in a remote/mediated environment). For this purpose, mediated social touch (i.e., interpersonal touch over a distance by means of a tactile display) was combined with visual feedback, allowing a person to see, and feel, the touch acts being performed on either a morphologically congruent (a sensor equipped mannequin) or a morphologically incongruent input medium (a touch screen). Research on the rubber-hand illusion predicts that the mannequin input medium will be more easily attributed to the self than the touch screen. As a result, the experience of telepresence is expected to increase with the mannequin input medium. Our experiment demonstrates that morphologically correct visual feedback affects (a) physiological arousal in response to a mediated touch (assessed by means of skin conductance response), (b) the self-reported experience of telepresence, and (c) the self-reported perceived naturalness of the mediated touches. Our experiment, however, suggests that other mechanisms than self-attribution might be involved.

[22] Part of this chapter is discussed in Haans and IJsselsteijn (2009b).

We tend to think of our bodies as relatively stable entities. Yet research on experimentally induced bodily illusions, such as the rubber-hand illusion discussed in the previous chapters, demonstrates that the perceived boundaries of the body are not hard-wired, but are dynamically inferred through the integration of sensorimotor information. This process in which the central nervous system discriminates between what is contained within and outside the boundaries of the body is called self-attribution. Having highly malleable body boundaries accommodates a lifetime of development and change, yet it is the relative speed at which these boundaries can be adapted, that enables us to incorporate media technology into the body image as a phenomenological extension of the self (IJsselsteijn, 2005). Media technologies, such as the anthropomorphically-designed teleoperation systems discussed in Chapter 1, can at times become so transparent that the human operator "forgets" the technology, and starts to feel and act as if the technology is not there (e.g., IJsselsteijn, 2004). In Chapter 1, we described Cole and colleagues' (2000) experiences with such a teleoperation system at Johnson Space Center in Houston. With this system, they could control the arms and hands of a robot located at a remote site (i.e., the slave robot). They had also a three-dimensional view on the remote site by means of a stereoscopic display (i.e., a head-mounted display) connected to two cameras attached to the slave robot's head. While tying knots, and transferring tools from one hand of the robot to the other, Cole and colleagues developed the vivid impression that they were physically located at the remote site. This phenomenon is called telepresence: the experience of being there at the remote site (Sheridan, 1992), or the experience of being in the location of the slave robot (Loomis, 1993). However, beside the impression of "being there", Cole and colleagues (2000) also encountered the impression that the slave robot's arms, which were visible through the head-mounted display, were actually their own. In other words, their central nervous systems came to categorize the slave robot's arms as belonging to the body.

Although it has received relatively little attention to date, Held and Durlach (1991) already pointed toward the relation between self-attribution and telepresence. They argued that the experience of telepresence in a teleoperation system is expected to diminish or break down, when the slave robot's arms are not attributed to the self. In this chapter, we further investigate the relation between self-attribution and the phenomenon of telepresence. For this purpose we introduce the technological domain of mediated social touch which allows geographically separated people to touch each other by means of haptic or tactile feedback technology (for a recent overview, see, e.g., Haans & IJsselsteijn, 2006).

8.1. Mediated Social Touch

Touching is an important part of our social interaction repertoire. Human touch, perhaps more than any other means of communication, bears the capacity for very intimate interpersonal interaction. Even a short touch by another person can elicit strong emotional experiences: from experiencing comfort when being touched by one's spouse, to the experience of anxiety when touched by a stranger. Despite the significance of touch, current communication devices rely predominantly on vision and hearing. In recent years, however, several designers and researchers have developed prototypes that allow for mediated social touch; enabling people to touch each other over a distance by means of haptic and tactile feedback technology. Examples of such prototypes are the inTouch (Brave & Dahley, 1997), "hug over a distance" (Mueller et al., 2005), Taptap (Bonanni et al., 2006), and the FootIO (Rovers & van Essen, 2006; for a recent overview, see Haans & IJsselsteijn, 2006). Designers of such systems conjecture that the addition of a haptic or tactile communication channel will enrich mediated interactions, and generally refer to the symbolic and intrinsic (e.g., recovery from stress) functions of social touch, as well as to the supposed intimate nature of addressing the skin. However, there are several notable differences between a real touch and the tactile and haptic stimulation provided by the prototypes described earlier.

First, interpersonal touching requires people to be in very close proximity of each other, and thus involves a possible violation of a person's personal space (i.e., the culturally defined area around the body in which the presence of others is considerate inappropriate; e.g., Hall, 1966; Hayduk, 1983). The strong relation between touch and physical closeness makes the notion of "touch over a distance" somewhat of a paradox, especially when compared to the mediation of visual or auditory interaction, which by their nature are less dependent on physical proximity. Second, simulating the sensation or "feel" of a human touch is difficult and expensive, despite advancements in tactile and haptic display technologies (for an overview, see, e.g., Burdea, 1996; Hayward & MacLean, 2007). As a result, current prototypes rely on simple electromechanical actuators, such as vibration motors, which are a poor substitute for real physical contact (i.e., in terms of the qualitative experience or "feel").

Several interesting questions present themselves. What would be the effect of combining mediated touch with visual feedback? To our knowledge, published work on prototypes that allow for mediated social touch have not yet considered to combine vision and touch (see also Gallace & Spence, 2010; Haans & IJsselsteijn, 2006).[23] Combining mediated touch with video technology would allow people to see, and at the same time feel, their interaction partner performing the touches on an input medium. Research on the rubber-hand illusion predicts that combining tactile and visual stimulation will allow people to incorporate the input medium into the body image as a phenomenological extension of the self. However, as demonstrated in the previous chapters, self-attribution is dependent on the extent to which the visual stimulation is temporally and morphologically correct (see also Tsakiris & Haggard, 2005). We can thus expect that, to facilitate self-attribution, the input medium should be adequately matched to the human body, both in terms of appearance and in the mapping of seen and felt touch. Based on the relation between self-attribution and telepresence, we can thus expect that people will develop a more vivid experience of "being there" (i.e., of being in the same room as their interaction partner), when they see the touch act being performed on a morphologically congruent input medium as compared to an morphologically incongruent input medium. Relevant in this respect are recent attempts to induce a full-body analogue of the rubber-hand illusion, in which self-attribution is not limited to a fake hand but involves a whole body.

8.2. A Full-Body Analogue of the Rubber-Hand Illusion

Lenggenhager, Tadi, Metzinger, and Blanke (2007) aimed at inducing a full-body analogue of the rubber-hand illusion by means of virtual reality technology (for a similar experiment, see Ehrsson, 2007). In their experiment, participants wore a head-mounted display through which a virtual character was displayed standing with its back toward the participant. This virtual character was created by a real-time recording of a fake human figure (i.e., a mannequin). The experimenter stroked the backs of the participant and the mannequin in a synchronous manner. The participant could then feel the strokes on his or her body, while seeing the virtual person being stroked at the same time. With this experimental setup, Lenggenhager and colleagues were able to induce a full-body analogue of the rubber-hand illusion, as demonstrated with both self-reports and a behavioral measure. No self-attribution occurred when the backs of the participant and the mannequin were stroked asynchronously, or when a non-human-like object was used rather than a

[23] Interestingly, in the domain of internet-based adult toys (for which Ted Nelson coined the term teledildonics in the 1970s), there are several commercial systems available that take advantage of combining tactile stimulation with visual feedback.

mannequin (as would be expected from research on the rubber-hand illusion; e.g., Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005; Chapters 3, 4, & 6). This study demonstrates that it is possible to elicit a full-body analogue of the rubber-hand illusion in which a fake body, as a whole, is attributed to the self. This, in turn, illustrates the potential of combining mediated social touch with visual feedback, as it demonstrates that people can come to incorporate a morphologically congruent input medium (i.e., the mannequin in the study by Lenggenhager et al., 2007) into the body image.

8.3. Experiment

8.3.1. Research Aims and Hypotheses

In this experiment, we investigated the effect of combining touch with morphologically correct visual feedback on people's experiences with media technologies that allow for mediated social touch (i.e., that allow for interpersonal touching over a distance by means of a tactile display). Four hypotheses were formulated with respect to the differences between seeing the touch acts being performed on a morphologically congruent (which resembles the human body, and allows for a one-to-one mapping between seen and felt touch) and an incongruent input medium.

Our first hypothesis states that combining mediated touch with morphologically congruent visual feedback will increase the experience of telepresence (i.e., a sense of being at the same location as one's interaction partner). We thus expect that people will report a higher sense of telepresence, and correspondingly a higher sense of transparency (i.e., forgetting about the interface), when they see the touch acts being performed on an morphologically congruent as compared to an incongruent input medium.

Our second hypothesis states that seeing the touch act being initiated on a morphologically congruent input medium will increase the perceived naturalness of the felt touches. That is, we expect that the electromechanical vibrations commonly used in mediated social touch will be experienced as more touch-like when people see the touch act being performed on a morphologically congruent as compared to an incongruent input medium.

Our third hypothesis states that men will be more uncomfortable with a mediated touch by another man when they can see the touch act being performed on a morphologically congruent as compared to an incongruent input medium. We test this hypothesis by means of both self-reports and the extent to which people experience physiological arousal in response to being touched (measured by means of Electrodermal Activity; EDA). This hypothesis is based on social psychological research in North America and North Western Europe which demonstrates that men generally dislike and avoid touching other men (for an overview, see, e.g., Floyd, 2000).[24]

We anticipate such effects of morphologically congruent visual feedback on people's experiences with mediated social touch, because a morphologically congruent input medium will be more easily attributed to the self, than a morphologically incongruent input medium. Our fourth hypothesis, thus, states that people will experience a more vivid full-body analogue of the rubber-hand illusion with a morphologically congruent as compared to an incongruent input medium. We will test this hypothesis by means of self-reports and the measurement of people's physiological arousal. Being touched by another person might involve the violation of one's personal space. Research has demonstrated that such personal space violations are accompanied by increased physiological arousal (as assessed by means of EDA; McBride, King, & James, 1965). The measurement of EDA then provides an interesting means of corroborating the self-reported vividness of a possible full-body analogue of the rubber-hand illusion. If a person shows higher signs of physiological arousal when his or her interaction partner, rather than keeping a respectable distance, moves very close toward the input medium before initiating the touch, then this provides strong evidence that the input medium is incorporated into the body image (as his or her personal space must have extended to include the input medium).[25] Since self-attribution is expected to depend on the morphological congruence between the input medium and the human body, the effect of the distance between the interaction partner and the input medium is expected to be larger with a morphologically congruent as compared to an incongruent input medium.

8.3.2. Method

Participants. Our sample was drawn from the participant database of the JF Schouten School at Eindhoven University of Technology, Eindhoven, the Netherlands. Twenty-two

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[24] In this chapter, we will not test whether male participants indeed find same-sex mediated touch to be less pleasant than opposite-sex mediated touch. However, tentative evidence for such an effect of dyad composition in mediated situations is provided by Haans, de Nood, and IJsselsteijn (2007).

[25] A similar argument involving the extension of personal space as the result of using technology, such as driving a car, is made by Blakeslee and Blakeslee (2007).

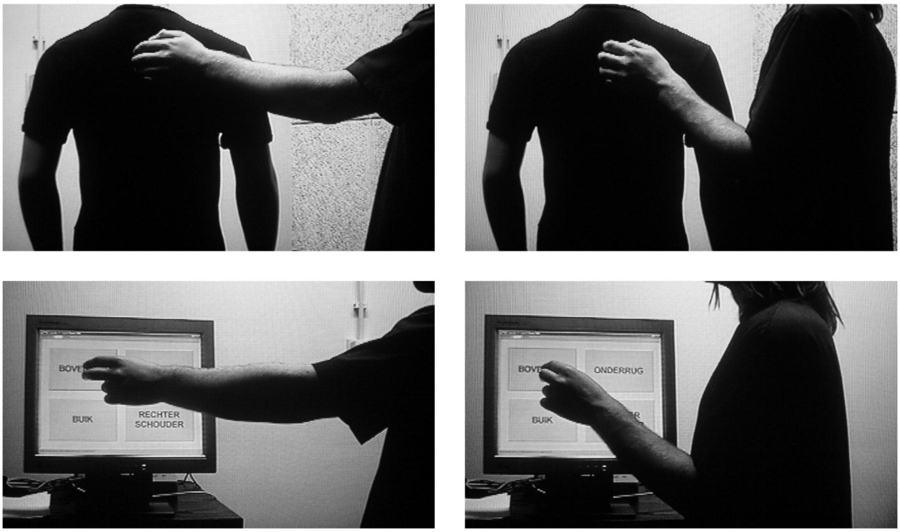

Figure 8.1: Visual stimuli for the four conditions. The images are video stills converted to grayscale. Rows depict the morphologically congruent (top) and incongruent visual feedback (bottom). Columns depict the far distance (left) and close distance touches (right).

persons, all male, and free of medication use and known medical conditions, were invited to participate in the experiment. Two persons were excluded from the data set because of problems with controlling the mediated touches. Of the remaining 20 participants, the mean age was 35.0 (*SD* = 18.5; range 18 to 65 years); All participants were of Dutch nationality. All participants received a compensation of € 10.00.

Experimental Design. The experiment consisted of three sessions: two experimental and one control. In each session, the participants were remotely touched by another person (a confederate of the experimenter). At the same time, the participants could see the confederate performing the touches on an input medium through a television screen, which displayed a real-time recording of the confederate's actions.

In the experimental sessions, a two (Morphologically Congruent vs. Incongruent input medium) by two (Large vs. Small Distance to input medium) repeated-measures experiment was conducted. In the experimental "Mannequin" session, participants could see the confederate performing the touches on a human-like input medium (i.e., a mannequin; see Figure 8.1). This input medium was congruent with the morphology of the human body not only in appearance, but also in the mapping between seen and felt touch. In the experimental "Touch Screen" session, the human-like input medium was replaced by a set of buttons, each corresponding to a body location (displayed on a touch screen; see Figure 8.1). This input medium was incongruent with the human body both in appearance and in the mapping of felt and seen touch. The order of the Mannequin and Touch Screen sessions was counterbalanced across participants.

In both experimental sessions (i.e., the Mannequin and Touch Screen session), participants received eight mediated touches (four body locations by two distances from the interface). In the Large Distance condition, the confederate would touch the mannequin or touch screen while keeping the largest possible distance between himself and the input medium (see Figure 8.1). In the Small Distance conditions, the confederate would step up towards the input medium before initiating the touch, thereby clearly violating social norms with respect to personal space (should such space extend to the input medium). The mediated social touches were presented in such an order that the same body location was not touched consecutively, and that no more than two large or small distance touches were given after each other. The order of the touches was counterbalanced across participants. For each participant, however, the same order was used in the Mannequin and Touch Screen session. During these experimental conditions, we assessed each participant's physiological arousal in response to being touched by means of skin conductance responses (abbreviated as SCRs).

Due to the measurement of SCR, the visuotactile stimulation in the experimental sessions might be too poor in information for the central nervous to extract a sufficiently strong correlation between seen and felt touch (cf. Chapter 6). Participants were touched only eight times, in only four specific ways, and with the time between two touches being relatively long (sometimes as much as 20 seconds). Therefore an additional control session, further referred to as the "Illusion Induction" session, was included in the experiment to assess the degree to which a full-body analogue of the rubber-hand illusion could be elicited with our particular experimental setup. In the Illusion Induction session, participants received a series of mediated touches, while watching the touches being performed on the morphologically congruent input medium (i.e., the mannequin). This time, no SCRs were being recorded. Again, the confederate touched the human-like input medium, and thus the participant's body, on the various body locations. In contrast to the experimental conditions, mediated touches were performed in a random fashion with the touches following shortly after each other (thus with a high amount of information contained in the stimulation). Each participant was stimulated in such a manner for five minutes. If the information-poorness of the visuotactile stimulation in the experimental Mannequin condition constrains participants in developing a vivid full-body analogue of the rubber-hand, then a more vivid such illusion is expected to occur in the Illusion Induction control condition.

Stimuli and Apparatus. Tactile stimulation was provided through a neoprene vest equipped with electromechanical actuators (i.e., vibration motors). This vest was similar to that used by Haans and colleagues (Haans, de Nood, & IJsselsteijn, 2007; Haans & IJsselsteijn, 2009a). Series of eight actuators were located at the stomach, 16 at the upper-back, and 12 at the lower back region. Two actuators were placed on the right shoulder. The input medium used in the Morphologically Congruent conditions consisted of a male mannequin equipped with reed contacts (i.e., an electrical switch operated by applying a magnetic field). The position of the reed contacts on the mannequin were matched to the position of the actuators in the vest, with each reed contact directly connected to one actuator. Small magnets were attached to the confederate's fingers. By bringing a magnet near a reed contact, the contact would close and the corresponding vibration motor was actuated. Mediated touches to the stomach and lower and upper back were given by stroking the magnet over the reed contacts on the mannequin. Mediated touches to the participant's shoulder were given by briefly touching the reed contacts on the shoulder of the mannequin, thereby resembling a tap rather than a stroke. Whereas, touches to the stomach were done with the right hand, touches to the shoulder, the lower back and upper back were done with the left hand. Since the reed contacts on the mannequin were matched to the position of the actuators in the vest, the mannequin input medium allowed for a one-to-one mapping between seen and felt touch for both body location and direction of touch.

For the Morphologically Incongruent conditions, the input medium consisted of a touch screen on which four buttons were displayed. Each button corresponded to one of the four body locations (see Figure 8.1). Each button was labeled with the name of the body part it represented. In contrast to the mannequin interface, the touch screen did not provide a one-to-one mapping between seen and felt touch. Each time the confederate briefly pressed a button on the touch-screen, the software actuated the corresponding vibration motors to either produce a stroke (i.e., for the stomach, lower, and upper back) or a tap (i.e., for the shoulder). The hardware and software used for controlling the actuators in the Morphologically Incongruent conditions were similar to that used by Rovers and Van Essen

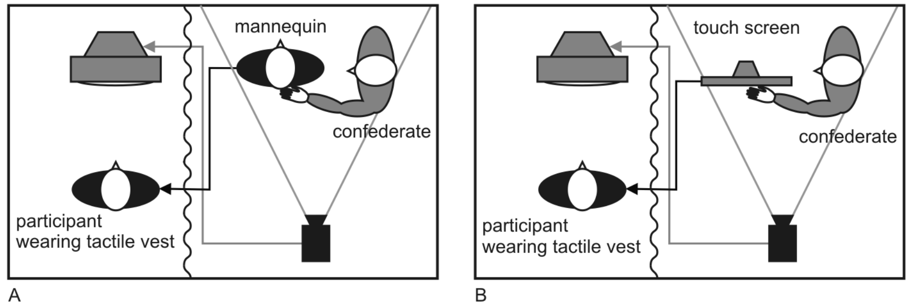

Figure 8.2: Experimental setup for the Mannequin condition (Panel A) and the Touch Screen condition (Panel B). The gray arrow depicts the visual channel, and the black arrow depicts the tactile channel.

(2006; see also Haans et al., 2007; Haans & IJsselsteijn; 2009a). The buttons were always pressed with the left hand. The confederate was trained extensively to match the duration of the mediated touches in the Mannequin session with those in the Touch Screen session.

The room in which the experiment was conducted was divided in two sections by means of a black curtain (see Figure 8.2). One section housed the mannequin and touch-screen input media, as well as a digital camera that recorded the confederate's actions. In the other section of the room, a 21 inch television screen was placed at face height. During the sessions, the participant stood facing the television screen at a distance of approximately 1.50 meters. The television was connected to the camera standing in the other section of the room, allowing the participant to watch, in real-time, the confederate's actions on the input medium (see Figure 8.1).[26] To avoid that participants could see their own reflection in the television screen during the sessions, lights could be switched off in this section of the laboratory room.

Procedure. Participants were invited to the laboratory to evaluate a multimodal communication device together with another person. This other person was a male confederate of the experimenter. The confederate was casually dressed in a manner appropriate for a young man of his age (21 years). At their arrival, participants were asked

[26] It would be technologically challenging to assess precisely the extent of temporal asynchrony between seen and felt touches caused by the mediating technology. However, such a delay is expected to be well below the 200 ms delay that reduces self-attribution in the rubber-hand illusion (see Chapter 6).

to wash their hands with soap and water. After the participant washed his hands, the experimenter assisted him with putting on the tactile vest. Next, the participant was asked to put disposable earplugs in his ears in order to block background noise. Meanwhile the experimenter prepared the electrodes for the measurement of EDA by filling the cavities with electrolyte gel. The electrodes were attached to the fingers of the participant's non-dominant hand by means of hook-and-loop fastener straps. They remained attached to the participant's fingers throughout the two experimental sessions. Subsequently, the participant was asked to stand in front of the television screen, and the experimenter connected the tactile vest to the cables coming from the interface (either the Mannequin or the Touch Screen; see Figure 8.2). Next, the experimenter switched off the lights in the section of the room in which the participant was standing. Then, with the camera still off, the participant was administrated a single mediated touch to the upper back to familiarize him with how the touches would feel. Subsequently, the participant was instructed that the first session would start after a five-minute waiting period, which was required for the electrolyte to sufficiently interact with the skin, and also allowed the experimenter to assess the baseline EDA for each participant.

At the start of each of the experimental sessions (one with the mannequin and one with the touch screen as the input medium), the participant was instructed to pay attention to the touches he saw and felt. Next, the experimenter would turn on the camera, thereby providing the participant with a view of the input medium and the confederate through the television screen. The experimenter monitored the participant's EDA on a computer screen for signs of SCRs not related to the mediated touches (i.e., non-specific SCRs). For this purpose, a high pass filter of 0.05 Hz was applied to the absolute EDA signal. By applying such a filter, the EDA signal centers around 0 micro Siemens (μS) when no SCR is in progress. When the relative EDA was zero, the experimenter would signal the confederate to initiate a mediated touch. After the last mediated touch, the experimenter turned off the camera, and switched the lights back on. Since the number of non-specific SCRs differs per individual, the duration of each experimental session was different for different individuals. At the end of the session, the participant completed a questionnaire, while the experimenter switched the input media. The second session proceeded in a similar manner as the first.

After the Mannequin and Touch Screen sessions, the experimenter removed the electrodes and asked the participant to return to his place in front of the television screen. With the camera running and the lights in the participant's side of the room switched off, the confederate would touch the mannequin, and thus the participant, for five minutes. In contrast to the previous sessions, the various locations of the participant's body were touched in a random fashion (both tapping and stroking) with the touches following shortly after each other. After this session, the participant again completed a questionnaire.

Measures. In this study, we employed a combination of self-reports and the measurement of a participant's physiological arousal by means of EDA recordings. For the latter, we recorded skin conductance responses (SCRs) during the two experimental sessions (i.e., the mannequin and the touch screen session). For the former, a questionnaire containing multiple measures was completed by the participants after each session. Since the effect of the distance between the confederate and the input medium was manipulated within rather than between the two experimental sessions, the effect of Distance was assessed by means of SCRs only.

Electrodermal Activity (EDA) was measured as skin conductance changes by means of the BIOPAC MP100 system (BIOPAC Systems Inc., Santa Barbara, California, USA) and the BIOPAC GSR100B amplifier, which applies a constant voltage of 0.5 volt over two Ag-AgCl electrodes (TSD103A) prepared with electrolyte gel (Signa Gel; a multipurpose electrolyte by Parker). The electrodes were attached to the volar surfaces of the distal phalanges of the index and middle fingers of the participant's non-dominant hand by means of hook-and-loop fastener straps. A waiting period of at least five minutes ensured that the electrolyte interacted sufficiently with the participant's skin. The sensitivity (i.e., the gain) was set to the highest value that the individual's skin conductance level allowed. The GSR100B amplifier was set to DC with the low-pass filter at 1 Hz.

Absolute skin conductance was recorded in micro Siemens (μS) with 500 samples per second. Any skin conductance response (SCR) starting within five seconds after the initiation of a mediated touch was considered to be a response to that stimulus. If no response occurred within these five seconds, a value of 0 μS was given as a person's SCR to that stimulus. In case there were two (stacked) responses starting within the five second time frame, the average SCR was calculated. A range correction was applied to the SCR data before analysis, as suggested by Lykken and Venables (1971; see also Boucsein, 1992). For this range correction, each SCR was divided by the highest SCR observed for that particular individual. For each person, the average of the range-corrected SCRs in each experimental condition was used in the analyses. Due to various reasons, we did not obtain reliable measures of EDA for two out of 20 participants.

Table 8.1: Items of the Unpleasantness of Being Touched, the Naturalness of the Mediated Touches, and Telepresence self-report measures.

	Unpleasantness of Being Touched
1	To what extent did you have, or did you not have, an oppressive feeling when being touched by the other person?
2	How pleasant or unpleasant was it to be touched by the other person?
3	How comfortable, or uncomfortable, did you feel when being touched by the other person?
4	How annoying, or not annoying, was it to be touched by the other person?
	Naturalness of the Mediated Touches
1	How natural, or unnatural, were the touches?
2	To what extent were the touches of a mechanical, or a human-like, nature?
3	How synthetic, or non-synthetic, were the touches?
4	To what extent did you perceive of the touches as realistic or unrealistic?
	Telepresence
1	Sometimes, it felt as if the other person was standing closely beside me.
2	Sometimes, I forgot that I was looking at a television screen.
3	Sometimes, it felt as if the other person was touching me directly on the skin.
4	Sometimes, it felt as if the other person was standing on my side of the room (within the curtained area).

Unpleasantness of Being Touched. After the Mannequin and the Touch Screen session, we assessed the extent to which the participant found it unpleasant to be touched by the other person. Unpleasantness was assessed by means of four self-report items, such as "How pleasant or unpleasant was it to be touched by the other person?" (for a complete description of the items, see Table 8.1). Participants could respond on a five-point scale with labels ranging from, for example, "pleasant" (coded with a 0), through "neutral" (coded with a 2), to "unpleasant" (coded with a 4). The mean score across these four items was used in the analyses. The reliability (Cronbach's alpha) of this aggregated Unpleasantness measure was α = .74 in the Mannequin, and α = .83 in the Touch Screen condition. There were no missing responses.

Naturalness of the Mediated Touches. After the Mannequin and the Touch Screen session, we assessed the extent to which the participants perceived the mediated touches as natural. Perceived naturalness was assessed by means of four self-report items, such as "To

Table 8.2: Items of the Self-Attribution measure, and percentage of affirmative responses in the Mannequin (M), Touch Screen (TS), and Illusion Induction (II) session.

		% Affirmative		
	Items	M	TS	II
1	Sometimes, it appeared as if I felt the touch on the location where I saw the *input medium* being touched, rather than on my own body.	60%	25%	65%
2	Sometimes, it felt as if the *input medium* was a part of my own body.	20%	10%	20%
3	Sometimes, I had the impression that I was looking at myself.	40%	15%	45%

The term input medium *was replaced by the appropriate term for each session (i.e. "mannequin" or "touch Screen"). Affirmative responses are either "slightly agree" or "agree"*

what extent were the touches of a mechanical, or a human-like, nature?" (see Table 8.1). Participants could respond on a five-point scale with labels ranging from, for example, "mechanical" (coded with a 0), through "neutral" (coded with a 2), to "human-like" (coded with a 4). The mean score across these four items was used in the analyses. The reliability (Cronbach's alpha) of this aggregated Naturalness measure was $\alpha = .93$ in the Mannequin, and $\alpha =.84$ in the Touch Screen condition. There were no missing responses.

Telepresence. After the Mannequin and the Touch Screen session, we assessed the degree to which the participants perceived a sense of telepresence. This was measured, retrospectively, by means of four self-report items. The self-reports were written in the form of statements regarding the experience of "being there" and the perceived transparency of the haptic communication device (see Table 8.1). These statements were based on existing presence questionnaires (e.g., ICT-SOPI; Lessiter, Freeman, Keogh, & Davidoff, 2001). Participants could respond on a five-point scale with labels ranging from "disagree" (coded with a 0), through "neutral" (coded with a 2), to "agree" (coded with a 4). The mean score across these five items was used in the analyses. The reliability (Cronbach's alpha) of this aggregated Telepresence measure was $\alpha = .64$ in the Mannequin, and $\alpha = .73$ in the Touch Screen condition. There were no missing responses.

Self-Attribution. After each of the three sessions (i.e., the Touch Screen, the Mannequin, and the Illusion Induction session), we assessed the degree to which people experienced a full-body analogue of the rubber-hand illusion by means of three self-reports (see Table 8.2). The self-reports were written in the form of statements, and were based on questionnaires commonly used to assess the vividness of the rubber-hand illusion (e.g., Botvinick & Cohen, 1998; see also Chapter 6) and on self-reports used by Lenggenhager and colleagues (2007) and Ehrsson (2007). Participants could respond on a five-point scale with

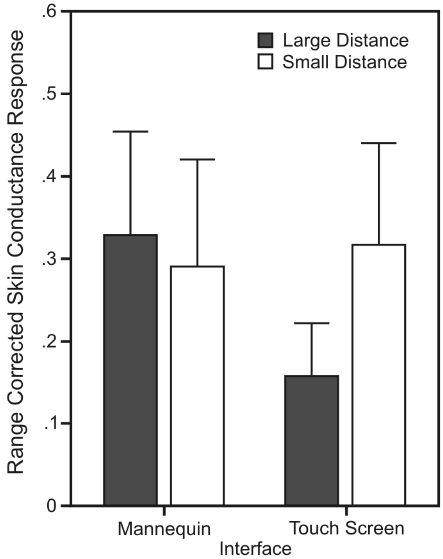

Figure 8.3: Skin conductance responses (SCRs) and corresponding 95% confidence intervals for the four experimental conditions.

labels ranging from "disagree" (coded with a 0), through "neutral" (coded with a 2), to "agree" (coded with a 4). There were no missing responses. Since the reliability (Cronbach's alpha) of the Self-Attribution items was poor ($\alpha \geq .53$), we did not calculate aggregate scores, but used each item as an individual indicator.

8.3.3. Results

Electrodermal Activity (EDA). The average range-corrected SCRs for the four experimental conditions are depicted in Figure 8.3. With these SCRs as the dependent variable, we performed a two (Morphologically Congruent vs. Morphologically Incongruent input medium) by two (Large vs. Small Distance to the input medium) repeated measures analysis ANOVA. Assumptions of normality and sphericity were met. We found a significant effect of Morphological Congruence on the size of people's SCRs, with $F(1, 15) = 5.1$, $p = .04$, and partial $\eta^2 = 25.4\%$. As expected, participants reacted more strongly to the mediated touches when they saw the Mannequin being touched rather than the Touch Screen. We also found a significantly effect of the Distance between the confederate and the input medium, with $F(1, 15) = 8.1$, $p = .01$, and partial $\eta^2 = 64.1\%$.

Again as expected, the smaller the distance to the interface, the more strongly the participant responded to the mediated touches. In addition, we found a significant Morphological Congruence by Distance interaction, with $F(1, 15) = 5.1$, $p = .04$, and partial $\eta^2 = 2.5\%$. Contrary to our expectations, however, the effect of Distance was larger for the Morphologically Incongruent input medium (i.e., the touch screen) as compared to the Morphologically Congruent medium (i.e., the mannequin). Additional simple effects analyses revealed a significant effect of Morphological Congruence for the Large Distance touches, with $F(1, 15) = 9.2$, and $p < .01$, but not for the Small Distance touches, with $F(1, 15) = 0.2$, and $p = .71$.

Unpleasantness of Being Touched. We performed a paired-sample *t*-test to investigate how the morphological congruence of the input medium affected people's self-reported Unpleasantness of Being Touched by another male person. We did not find a significant difference between the Morphologically Congruent input medium (i.e., the mannequin) and the Morphologically Incongruent medium (i.e., the touch screen), with $t(19) = .35$ and $p = .73$ (see Figure 8.4A). Additionally, we explored the correlations between self-reported Unpleasantness and SCRs. We found a marginal significant correlation between self-

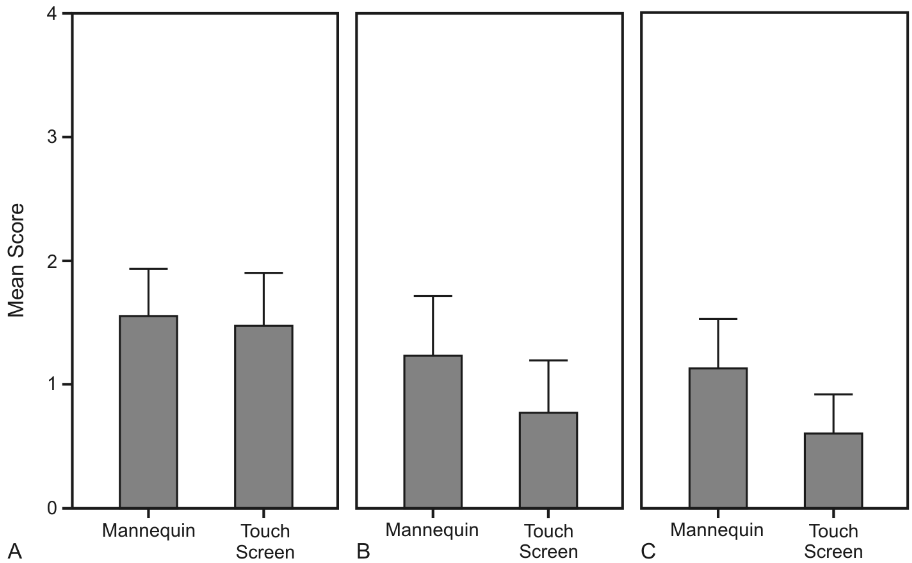

Figure 8.4: Average self-reported Unpleasantness of being touched (Panel A), Perceived Naturalness of the mediated touches (Panel B), and Telepresence (Panel C). Error bars depict 95% confidence intervals.

reported Unpleasantness and SCRs in the Mannequin session, with $r = .44$ and $p = .09$. Further exploration revealed that self-reported Unpleasantness correlated significantly with SCR's in response to touches made from a large distance, with $r = .56$ and $p = .03$, but not with SCR's in response to touches made from a short distance, with $r = .13$ and $p = .64$. In contrast, there were no significant correlations between self-reported Unpleasantness and the various SCRs in the Touch Screen session, with $r \leq .20$ with $p \geq .45$.

Naturalness of the Mediated Touches. Since self-reported Naturalness was found not to be normally distributed, the non-parametric Wilcoxon signed-rank test was performed to investigate the effect of morphological congruence of the input medium on the perceived naturalness of the mediated touches. As expected, our participants reported a higher perceived naturalness when touches were performed on the Morphologically Congruent (i.e., the Mannequin session) as compared to the Morphologically Incongruent input medium (i.e., the touch screen), with $Z(N = 20) = 2$, and $p = .046$ (see Figure 8.4B).

Telepresence. We performed a paired-sample t-test to investigate how the morphological congruence of the input medium affected people's self-reported Telepresence. As expected, people reported to experience a higher degree of Telepresence when touches were performed on the Morphologically Congruent input medium (i.e., the Mannequin session) as compared to the Morphologically Incongruent medium (i.e., the Touch Screen session), with $t(19) = 2.6$ and $p = .02$ (see Figure 8.4C).

Self-Attribution. Did participants report to have experienced a full-body analogue of the rubber-hand illusion? To investigate this question, the three impression items were recoded into a dichotomous response format by collapsing “slightly agree" and "agree" into a single category “assert”, and “disagree”, “slightly disagree”, and “neutral” into “refute” (see Table 8.2). In the Mannequin and Illusion Induction sessions, 20% of the participants affirmed to have encountered the impression that the input medium was a part of the body (see Table 8.2). Only 10% of the participants reported to have encountered this impression in the Touch Screen session. More participants, however, claimed to have had the impression that they were looking at themselves through the television screen: 45% of the participants in the Illusion Induction session, 40% in the Mannequin session, but only 15% in the Touch Screen session. The most frequently encountered impression, however, entailed the experience that the touches were felt on the location where they were seen: 65% of the participants in the Illusion Induction session, 60% in the Mannequin session, but only 25%

in the Touch Screen session. These data demonstrate that at least some of our participants reported to have encountered impressions related to a full-body analogue of the rubber-hand illusion. Further analysis by means of the non-parametric Friedman test, revealed a significant difference between the three conditions for the impression that the touches were felt on the input medium (i.e., Item 1 in Table 8.2), with $\chi^2(2, N = 20) = 8.8$, and $p = .01$. Similarly, a significant difference between the three conditions was found for the impression of looking at oneself through the television screen (i.e., Item 3 in Table 8.2), with $\chi^2(2, N = 20) = 6.2$, and $p = .045$. In contrast, no significant difference between the three conditions was found for the impression that the input medium became a part of the body (i.e., Item 2 in Table 8.2), with $\chi^2(2, N = 20) = 1.1$, and $p = .57$. Further contrast analysis by means of a series of Wilcoxon signed-rank tests revealed that, as expected, more participants affirmed to have encountered impressions 1 and 3 in the Mannequin session as compared to the Touch Screen session, with $Z(N = 20) \geq 2.2$, and $p \leq .03$. In contrast, the Illusion Induction session did not differ significantly from the Mannequin session in eliciting these impressions, with $Z(N = 20) \leq 0.4$, and $p \geq .66$. In other words, whereas a morphologically congruent input medium facilitated participants in developing impressions related to a full-body analogue of the rubber-hand illusion, increasing the amount of information contained within the visuotactile stimulation did not.

8.4. Discussion

With a sample of only 20 participants, we were able to support most of our hypotheses regarding the effects of combining mediated social touch with morphologically congruent visual feedback. As expected, our participants reported a higher sense of transparency and telepresence with the morphologically congruent (i.e., the mannequin) as compared the incongruent input medium (i.e., the touch screen). This finding illustrates the importance of morphologically congruent multisensory stimulation in the experience of transparency and telepresence (e.g., IJsselsteijn, 2005). In addition, participants perceived the same electromechanical stimulation (by means of vibration motors) as more natural when they saw the mannequin being touched rather than the touch screen. This finding demonstrates that combining touch and vision can alleviate, at least partially, the technological limitations of current day tactile displays in accommodating natural interpersonal touch (i.e., in terms of "feel").

Social psychological research in North America and North Western Europe demonstrates that men generally avoid touching other men, and that same-sex touching is perceived of as less pleasant than opposite sex touching (for an overview, see, e.g., Floyd, 2000). We thus expected that our male participants would be more uncomfortable with a mediated touch when they could see the male confederate performing the touch acts on a morphologically congruent input medium. Although the self-reports did not reveal the expected difference, SCRs were larger in response to a mediated touch that was combined with morphologically congruent as compared to incongruent visual feedback.

We hypothesized that these effects would result from the incorporation of the input medium into the body image. In support of this hypothesis, our participants reported to have experienced a more vivid full-body analogue of the rubber-hand illusion in the Mannequin as compared to the Touch Screen session (consistent with Lenggenhager et al., 2007). Closer examination of our participants' self-reports revealed that at least some of our participants claimed to have encountered impressions related to a full-body analogue of the rubber-hand illusion in the sessions with the morphologically congruent input medium (see Table 8.2). However, these self-reports were not supported by the SCRs. If a person had attributed the input medium to the self, then we hypothesized that his personal space would have extended to include the input medium. Since personal space violations are known to result in increased physiological arousal (see McBride et al., 1965), we expected that small distances touches (with the confederate standing very close to the input medium) would result in higher SCRs than large distance touches (with the confederate at a "respectable" distance from the input medium). As expected, small distance touches evoked larger SCRs than large distance touches. However, this effect of distance was found to be largest in the Touch Screen session in which self-attribution was unlikely to occur (see Figure 8.3). One explanation for this unexpected finding is that the mere observation of the confederate moving toward the input medium increased a person's physiological arousal, thereby confounding with SCRs to the small distance touches. The SCRs to small distance touches, thus, might not reflect reliably arousal in response to being touched, but the SCRs to large distance touches probably did. This is supported by two findings. First, we found SCRs to be related with self-reported unpleasantness, but only for the large distance touches in the Mannequin session. Secondly, the observed main effect of morphological congruency was due to differences in SCRs to large distance touches only (see Figure 8.3). Similarly, a larger part of the confederate's body was visible on the television screen with the small distance touches as compared to the large distance touches. This too might have biased the results.

Although research on the rubber-hand illusion predicts otherwise (see Chapter 6), increasing the frequency and information richness of the stimulation did not result in a more vivid full-body analogue of the rubber-hand illusion (see Table 8.2). One explanation for this unexpected finding is that our experimental setup and design might have constrained the development of a vivid illusion to such an extent that increasing the amount of information in the stimulation had no facilitating effect. First of all, we used relatively simple mediating technology. Using a head-mounted display rather than a television screen, for example, would have provided a more immersive view on the remote site, thereby potentially increasing the extent to which self-attribution could occur. Similarly, replacing the vibrating electromechanical actuators with touches from a real human hand might have had a similar effect, as a discrepancy in the nature of expected and felt touch might constrain self-attribution (see Chapter 4). Secondly, since the mannequin was positioned with its back toward the participant, the actual touches to the stomach could not be seen by the participants. This, in turn, might have negatively affected the development of a vivid full-body analogue of the rubber-hand illusion. The unexpected finding that increased information richness did not result in a more vivid illusion might also indicate that the observed effects of morphologically congruent visual feedback are not dependent on self-attribution. It would, indeed, be rather surprising when eight touches which are spread over a relative long period of time can result in a similarly vivid illusion as five minutes of nonstop stimulation. If the observed effects of combining mediated touch with morphologically congruent visual feedback are not dependent on self-attribution, then what can explain the observed effects? Although more research is required to answer this question, there are at least two possible alternative explanations.

One alternative explanation for the observed effects is provided by research on the visual enhancement of touch. This research demonstrates that looking at the stimulated body part, even without seeing the stimulation itself, enhances a person's tactile acuity (e.g., Kennett, Taylor-Clarke, & Haggard, 2001). A similar facilitating effect is observed when the visual stimuli are presented on another person's body, but not when they are presented on objects that do not resemble a human body (e.g., Haggard, 2006; Thomas et al., 2006; see also Chapter 6). Recent research by Moseley, Parsons and Spence (2008) demonstrates that the perception of pain is modulated by vision as well. In their study, people with chronic hand pain were asked to look at their affected hand through either a magnifying or a minifying glass. Whereas magnifying the affected hand increased pain, minifying the affected hand resulted in a significant decrease in pain. These studies indicate that combining mediated social touch with morphologically congruent visual feedback might in itself be a sufficient explanation for the effects observed in the present experiment.

A second alternative explanation for the observed effects is that participants did not perceive the mannequin as a part of their body, but as an object that represented them at the remote site as seen through the television screen (similar to an avatar being a representation of a person in a mediated environment). A similar argument has recently been made by Ehrsson and Petkova (2008). They argue that the full-body analogue of the rubber-hand illusion (as reported by Ehrsson, 2007; Lenggenhager et al., 2007) is heavily dependent on the use of media technologies. Furthermore, they argue that the impressions reported by the participants in these studies might not result from self-attribution, but from people's knowledge from using media technology (i.e., media schemata). In our experiment, 40 to 45 percent of the participants reported to have encountered the impression that they were looking at themselves when seeing the mannequin being touched on the television screen (i.e., Item 3 in Table 8.2). Such reports make sense both when people perceived the mannequin as a part of the body, and when they perceived the mannequin as a representation of themselves. The reported effects of combining mediated touch with morphological congruent visual feedback might thus result from psychological, rather than perceptual, means of self-identification.

There were three notable limitations to the present study. First, there were many differences between the morphologically congruent (i.e., the mannequin) and the incongruent input medium (i.e., the touch screen), including differences in shape and color, the mapping of seen and felt touch, and the presence of text. Subsequent research is needed to determine more precisely which of these differences can explain the reported effects. Secondly, our experimental setup involved an actual interaction between two persons. Although this setup allowed for a more ecologically valid experimental situation, we could not ensure that the visuotactile stimuli were perfectly similar across sessions and participants. Our findings should therefore be confirmed with pre-recorded stimuli. By using pre-recorded stimuli the touch act can also be isolated from the interaction partner's movement toward the input medium, thereby eliminating the possible artifact of movement in the measurement of EDA. A third limitation of the present experiment is that we have provided little evidence with respect to the role of self-attribution in media-related experiences, such as the phenomena of the telepresence. Interesting future research might, for example, determine whether the individual differences in people's susceptibility for bodily illusions are also reflected in their experience of telepresence.

Despite these limitations, we have demonstrated that combining touch with morphologically congruent visual feedback can alter people’s experiences with media technologies that allow for mediated social touch, including the experience of telepresence or "being there". What is perhaps most striking is that we demonstrated these effects with relative simple tactile and visual displays. Our experiment illustrates that combining touch with feedback from vision might enable genuine embodied interaction with technology, perhaps eventually blurring the boundary between our "unmediated" self and the "mediating" technology (Haans & IJsselsteijn, 2006).

— Chapter 9 —

Epilogue

The research presented in this thesis focused on the perception of technological tools and artifacts as a phenomenal extension of the self. This process in which the central nervous system categorizes an object as a part of the body, and in which thus a discrimination is made between what is contained within and outside the boundaries of the body, is called self-attribution. By using the paradigm of the rubber-hand illusion (Botvinick & Cohen, 1998), we investigated what characteristics of the individual, and what features in the situation, constrain or facilitate the attribution of foreign objects to the self. In addition, we explored the role of self-attribution in people's experiences with media technology, such as the phenomenon of telepresence (i.e., the experience of "being there" in a mediated environment). In this final chapter, we discuss the main contributions and limitations of this thesis. In addition, we discuss interesting future research directions, while taking a broader perspective on the field of research on media technologies and corporeal awareness.

The first contribution of this thesis is the formulation of a theoretical framework around the conception of the user of technology as an embodied agent (i.e., the embodied user; Chapter 2). Integrating ideas from, for example, Metzinger (2006), Edelman (2006), and Gallagher (2005b), this theoretical framework describes the often confused body schema and body image as two distinct aspects of human embodiment. The body schema is defined as a dynamic distributed network of procedures aimed at guiding behavior. In contrast, the body image is defined as a part of the process of consciousness and, thus, as consisting of those higher-order discriminations (or qualia) that pertain to the body. We found this theoretical framework useful to our research practices in several ways. First, the framework proved valuable in structuring and organizing much of the empirical literature referred to in this thesis. Secondly, the framework distinguishes between the various ways in which technological tools and artifacts can be incorporated into the body, including *functional* and *phenomenological* incorporations (cf. Gallagher & Cole, 1995). Finally, the theoretical framework assisted us in explaining some of the empirical findings presented in this thesis.

The second contribution of this thesis consists of the empirical evidence regarding the features of the experimental setup that constrain or facilitate the development of a vivid rubber-hand illusion. Research suggests that self-attribution is largely dependent on sensorimotor integration, and thus on the capability of the central nervous system to extract correlations between the various sensory modalities (e.g., Armel & Ramachandran, 2003). In support of this view, research has demonstrated that the rubber-hand illusion will diminish or break down when a delay of 500ms or more is introduced between the stimulation of the fake hand and that of the participant's concealed hand (e.g., Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). In this thesis, we demonstrated that even asynchronies as small as 200 ms will constrain, or impede, the development of a vivid illusion (Experiment 2 in Chapter 6; for a recent similar finding, see Shimada et al., 2009). Additionally, our experiment revealed a clear relation between the extent of temporal asynchrony and the level of impediment that these asynchronies bring about (see Figure 6.3). Additionally, Armel and Ramachandran (2003) hypothesized that stimulating the participant's concealed hand and the fake hand in a more random and erratic (and thus information-rich) manner will allow the central nervous system to extract a stronger correlation between seen and felt touch. As a result, people are expected to develop a more vivid rubber-hand illusion. Armel and Ramachandran (2003) reported anecdotal evidence to support this hypothesis. In this thesis, we corroborated this evidence by demonstrating that a stimulation pattern consisting of short strokes (i.e., information-rich) as compared to taps (i.e., information-poor stimulation) significantly increased the development of a vivid illusion (Experiment 2 in Chapter 6). Taken together, the reported effects of temporal asynchrony and information-richness on the vividness of the illusion provide strong corroborating evidence for the importance of visuotactile integration in the rubber-hand illusion.

Previous research has demonstrated that the development of a vivid rubber-hand illusion is dependent on the extent to which the foreign object resembles a human hand (e.g., Armel & Ramachandran, 2003; Tsakiris & Haggard, 2005). In the experiment in Chapter 4, we corroborate this research by demonstrating that hand-shaped objects can be more easily attributed to the self than non-hand-shaped objects. In addition, we demonstrated that people will develop a less vivid rubber-hand illusion when a flat image of a human hand (i.e., a real-time recording of a fake hand projected on the table) rather than a three-dimensional fake hand is used as the foreign object (Chapter 3). In addition, we investigated the effect of the anatomical awkwardness of the position of the fake hand (i.e., the extent to which it is anatomically impossible for a person to place his or her own concealed hand in the position of the fake hand; see Chapter 7). Our experiment demonstrated that people will experience the rubber-hand illusion at a lower level of vividness when the fake hand is placed in an anatomically implausible orientation, as compared to a similarly incongruent (with respect to the orientation of the participant's concealed hand) but morphologically plausible orientation (Figure 7.3). Taken together our experiments on the situational factors that constrain or facilitate the rubber-hand illusion point toward a role of top-down mechanisms that impose restrictions on the appearance of the foreign object, thereby supporting the view that the rubber-hand illusion is affected, top-down, by a cognitive representation of the human body (Tsakiris and Haggard, 2005; see also de Vignemont et al., 2006). Our experiments suggest that such a top-down cognitive body representation needs to include a specification of the three dimensional shape as well as the action possibilities of the hand. The recent demonstration that the rubber-hand illusion can be induced in upper-limb amputees (Ehrsson et al., 2008) suggests that these action possibilities are afforded by the body schema rather than the morphology of the body.

A third contribution of this thesis entails the empirical demonstration of large individual differences in susceptibility for the rubber-hand illusion. In other words, we have demonstrated that the level of vividness at which a person experiences the rubber-hand illusion is dependent, not only on the situational features of the empirical setup (such as the appearance of the foreign object), but on the characteristics of the individual as well. Consistent with existing research on experimentally induced bodily illusion (e.g., Burrack & Brugger, 2005; Mussap & Salton, 2006), we demonstrated that a person's susceptibility for the rubber-hand illusion is reflected in the stability/tenacity of his or her body image (as assessed by means of the Body Image Aberration scale; Chapman et al., 1978; see Chapter 7). In addition, we demonstrated a relation between a person's susceptibility for the rubber-hand illusion and his or her response times on a speeded left and right hand identification task (i.e., the MOHT-test; similar to, e.g., Cooper & Shepard; 1975; Parsons, 1987; see Chapter 7). Consistent with the common interpretation of these response times, we can argue that the ability to engage in mental simulations of hand movements is a characteristic of the individual that facilitates the development of a vivid rubber-hand illusion. Further research is required to uncover the nature of the relation between individual susceptibility and the ability to engage in mental own hand transformations. However, we expect that some people automatically (i.e., involuntarily) engage in the mental positioning of the concealed hand in the location of the fake hand, thereby facilitating self-attribution. Such an explanation seems reasonable given the role of the body schema in the observation of other people and their body parts (see Chapter 2).

A fourth contribution of this thesis relates to the measurement of the vividness with which people experience the rubber-hand illusion. First, we have developed and tested a model of the vividness of the rubber-hand illusion based on self-reports. In three experiments (Chapters 6 & 7), we were successful in modeling people's self-reported experiences related to the rubber-hand illusion based on (a) estimates about a person's susceptibility for the illusion, (b) estimates about the processing demand that is required for a particular experience, and (c) estimates about the suppression/constraints imposed by the situation. In our model tests, we have demonstrated that the vividness impressions related to the illusion (e.g., the fake hand felt as my own) are invariably ordered with respect to the frequency of being encountered. This invariant order is assumed to reflect the processing requirements behind the different experiences. As such, these experiences and processes are expected to be comparable for different persons: each person has to meet the processing requirements needed to develop the illusion at a certain level of vividness. The invariant order, thus, implies that the rubber-hand illusion is marked by a more or less universal phenomenology. This, in turn, is important as it allows for an objective quantification of the individual and situational determinants of the vividness of the rubber-hand illusion. Note that this invariant order in the impressions related to the rubber-hand illusion cannot be explained by a response bias resulting from the order of the items on the questionnaire, as we randomized this order for each participant in the experiment in Chapter 7. The proposed model proved accurate in its assessment of individual susceptibility and the constraints imposed by the experimental setup, with reliabilities $\geq .83$. The construct validity of the proposed vividness model is supported by several findings. First, we corroborated a significant relation between body image instability and susceptibility for the rubber-hand illusion (cf. Burrack & Brugger, 2005; Mussap & Salton, 2006; Chapter 7). Secondly, estimated individual differences in susceptibility correlated with two behavioral measures: proprioceptive drift (Experiment 1 in Chapter 6) and the responses times on a speeded left and right hands identification task (i.e., the MOHT-test; Chapter 7). Finally, the estimated vividness of the rubber-hand illusion was found to be dependent on several features of the experimental setup commonly recognized as constraining the development of a vivid illusion, including temporal asynchrony between seen and felt stimulation (e.g., Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005; Experiment 2 in Chapter 6), and the orientation of the fake hand (e.g., Tsakiris & Haggard, 2005; Chapter 7). Moreover, we were able to reliably differentiate small manipulations of the situation with respect to the level of impediments they brought about (e.g., temporal asynchrony and information richness in Experiment 2 in Chapter 6). This, then, speaks for the applicability of the proposed vividness model for experimental research.

Secondly, we have demonstrated that proprioceptive drift (as defined by Tsakiris & Haggard, 2005) has poor validity as a measure of the vividness of the rubber-hand illusion. Our experiments in Chapter 5 demonstrated that proprioceptive drift, or the perceptual recombination of proprioception, can be observed in situations in which no rubber-hand illusion is expected to occur (e.g., when our participants were looking at a fake hand in absence of any stimulation; see also Holmes et al., 2006). In addition, our experiments illustrated that the use of proprioceptive drift as a measure for the vividness of the rubber-hand illusion might yield different conclusions than an assessment by means of self-reports. This finding was corroborated by a small, but significant, correlation between a person's self-reported susceptibility and the extent of his or her proprioceptive drift (Experiment 1 in Chapter 6). Although proprioceptive drift is not a valid measure of the vividness of the illusion, this correlation indicates that the perceptual recombination of proprioception appears to be a mechanism behind self-attribution in the rubber-hand illusion; cf. Holmes et al., 2006).

The difference between proprioceptive drift and the vividness of the rubber-hand illusion can, in our opinion, be made more comprehensible, if one considers that human beings are embodied on various levels (as discussed in Chapter 2). The rubber-hand illusion is effective on the level of the body image as it entails a change in the perception of the boundaries of the body. In contrast, people usually appear to be unaware of the perceptual recombination of proprioception that occurs in the rubber-hand illusion. Although we cannot support such a claim with empirical evidence of our own, most of the participants in a study by Gross and Melzack (1978; see Chapter 4) were utterly surprised when they discovered the discrepancy between actual and felt location of their hand. In other words, proprioceptive drift is often observable only to the experimenter, and does not appear to constitute a personal experience of the participant. This is reflected, also, in the comparatively high processing demands for impressions that involve a felt movement of one's concealed hand (i.e., Item 2 in Table 6.1) or a visual movement of the fake hand (i.e., Item 1 in Table 6.1; see also Holmes & Spence, 2007). Proprioceptive drift thus appears to reflect changes in the body schema, rather than the body image. Although the perceptual recombination of proprioception is required for the development of a vivid illusion, body schema procedures (including the perceptual recombination of proprioception, visual capture, and the perceptual binding of seen and felt touch) are not equivalent with the vividness of the rubber-hand illusion.

Finally, a fifth contribution of this thesis consists of our investigation into the relation between self-attribution and the phenomenon of telepresence (i.e., the experience of being physically located at a remote site; e.g., Held & Durlach, 1991). In our experiment, participants received a series of mediated touches provided by a vest equipped with vibrating electromechanical actuators. At the same time, the participants watched a real-time recording (displayed on a television screen) of their interaction partner initiating the touches on an input medium (Chapter 8). We expected that a morphologically congruent input medium (i.e., a sensor-equipped mannequin) would be more easily attributed to the self (resulting in a full-body analogue of the rubber-hand illusion; see, e.g., Lenggenhager et al., 2007). Correspondingly, we anticipated that our participant's would experience a higher degree of telepresence when they could see the touches being performed on the morphologically congruent (the mannequin) as compared to an incongruent input medium (a touch screen). This was indeed found to be the case as demonstrated by our participants' physiological arousal (i.e., electrodermal activity), and their self-reported experiences related to telepresence and the perceived naturalness of the mediated touches. However, these effects of combining touch with morphologically congruent visual feedback might not have resulted from self-attribution. Although our Experiment 2 in Chapter 6 predicts that increasing the amount of information contained within the stimulation will facilitate the development of a more vivid rubber-hand illusion, no such effect was found on the full-body analogue of the illusion. Although more experiments are required to explain this unexpected finding, we proposed two alternative explanation for the observed effects in Chapter 8: visual enhancement of touch (e.g., Thomas et al., 2006), and psychological rather than perceptual mechanisms of self-identification.

One psychological mechanism of self-identification that is worth investigating in this respect is synchronic identification. Synchronic identification entails the categorization of two objects, located at different locations, as being one and the same (Bischof, 1985). It allows people to connect real objects with their mental or virtual counterparts (Bischof-Köhler, 1991). It thus allows a person to identify with, for example, his or her avatar in a mediated environment. Compared to self-attribution, synchronic identification does not rely, or at least not as heavily, on multisensory integration. It thus provides an explanation for the unexpected finding that increasing the amount of information in the stimulation did not facilitate the development of a more vivid full-body analogue of the rubber-hand illusion in Chapter 8. Interesting future research might investigate how self-attribution and other mechanisms of self-identification interact, and how they can be empirically distinguished.

One limitation of this thesis is that we have limited ourselves to the experimental paradigm of the rubber-hand illusion. In this illusion, people are sitting passively behind a table, and movement of the arm or hand is not allowed. In fact, if people nevertheless move their arm or hand, then the illusion will diminish or break down. Yet, motor action and corresponding efferent and afferent information are equally important for self-attribution as is shown in several studies (for an overview, see, e.g., Jeannerod, 2003; Knoblich, 2002). Of course, this has implications for the extent to which the reported findings may be generalized to situations involving movement, such as in the use of interactive media technologies (e.g., the teleoperation systems described in Chapter 1). Interesting future research then would be to extent the experimental paradigm of the rubber-hand illusion by allowing for the possibility of moving the fake hand (e.g., by means of technologies that enable the tracking of body limbs in time and space). A second limitation of this thesis is that we have largely ignored other possible mechanisms, besides self-attribution, that might facilitate self-identification with mechanical or virtual bodies and body parts (as became particularly apparent in Chapter 8).

With respect to the rubber-hand illusion, one interesting research direction is the development of a functional model of the rubber-hand illusion which specifies the various body schema procedures that are involved in the induction of the illusion. To our knowledge, there has been only one attempt to formulate such a functional model (see Makin, Holmes, & Ehrsson, 2008). These models should be based on the empirical evidence regarding the individual and situational factors that facilitate or constrain the development of a vivid illusion, as well as on the available neuroimaging data (e.g., Ehrsson et al., 2004). In addition, they might be based on the phenomenology of the rubber-hand illusion, and thus on the anticipated processing demands behind the various impressions related to the vividness of the illusions (as found in Chapters 6 & 7). Ultimately, such a functional model should be able to predict people's self-reported experiences with respect to differentially vivid rubber-hand illusions. In turn, these predictions, and the models on which they are based, will aid in improving the self-report items used in the measurement of the vividness of the rubber-hand illusion.

More research is also required to understand the large individual differences in susceptibility for the rubber-hand illusion. One interesting research direction in this respect would be to investigate the relation between a person's susceptibility for the illusion and his or her empathic abilities. Such a relation is to be expected given the role of the body schema in the observation of other people (e.g., Funk et al., 2005; Reed & Farah, 1995; see Chapters 2 & 7). Research on neural mirror-like mechanisms, for example, demonstrates that the actions of other individuals are automatically mapped onto one's own motor system as if one is performing the action oneself (for a recent review, see Rizzolatti & Craighero, 2004; see also Chapter 2). Similar mirror-like neural mechanisms are found for the observation of emotions (e.g., disgust; Wicker et al., 2003) and touch (Keysers et al., 2004). These studies provide empirical evidence for Lipps' (1903) notion of *einfühlung* as an empathy-related process in which the distinction between "I" and "you" disappears (see also Freedberg & Gallese, 2007; Gallese, 2001).[27]

Biocca (1997) introduced the term self-presence to refer to the effects of media technology on corporeal awareness and self-identity (for a refinement of the term self-presence, see Lee, 2004). Self-presence research requires a multidisciplinary approach in which the scientific disciplines of engineering, human-computer interaction, and the various sub-disciplines of psychology work together. For the future, we anticipate several interesting developments within this field of research including, but not limited, to the following (see also IJsselsteijn & Haans, 2008a; 2008b). Further research on the mechanisms behind self-attribution and other aspects of our corporeal awareness is expected to provide the necessary guidelines for the design of media technologies that might benefit from self-attribution, such as teleoperation systems or prosthetic devices. Advanced media technologies, in turn, are expected to contribute to the research on self-identification and corporeal awareness. First, mediated environments combine the ability to systematically

[27] Based on Lipps' definition of einfühlung, Gordon (1934) published a "device for demonstrating empathy" which consisted of a series of photos of a Mexican character that had either its left or right arm raised. The photos were taken from different angles, and people were asked to determine whether the left or right arm was raised in each picture. According to the author, many people reported having the urge to take on the same posture as the human figure, and others even made small, but observable, movements with the arm before making their responses. Apparently, people automatically take the perspective of the human character; thereby mentally placing themselves into the other person's shoes. A similar process might be involved in the rubber-hand illusion as is illustrated by the correlation between a person's susceptibility for the illusion and his or her responses times in a speeded left and right hand identification task (see Chapter 7).

tweak relevant variables with high ecological validity, and the precise replication of conditions (Loomis et al., 1999; see also Chapter 3). Secondly, research on corporeal awareness depends traditionally on the investigation of anomalies of body perception, such as those found in clinical populations. Such populations are, however, often limited in size, and the anomaly under study is often accompanied by other impairments. The ability to manipulate body perceptions by means of well controlled media environments offers an interesting approach to substantiate the research on clinical populations with research on healthy participants that have an experimentally induced alteration of the body (Sanchez-Vivez & Slater, 2005). Moreover, a deeper understanding of anomalous body consciousness and self-perception, such as those occurring in body dysmorphia 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.

Interesting in this respect is recent research by Bailenson and colleagues on how changing the virtual representation of a person's body in an interactive media environment (i.e., a person's avatar) will affect his or her behavior. Their research on this so-called Proteus effect has, for example, demonstrated that people will behave more confidently in negotiations when represented by a tall as compared to a small avatar (Yee & Bailenson, 2007). In another study, they provided their participants with the avatar of an older person (Yee & Bailenson, 2006). Participants would move in front of a virtual mirror in which they could see the face of their avatar. Afterwards, participants with an older avatar showed less signs of negative stereotyping toward older people, than participants with a younger avatar. In a third study, Fox and Bailenson (2009) asked their participants to engage in physical exercises. Using motion tracking, participants saw a representation of themselves performing the same movements in a virtual environment. Participants whose avatar visually lost weight (i.e., became slimmer) were found to engage more vicariously in the exercises as compared to participants who did not have a body represented in the virtual environment, or whose representation did not lose weight. In a second experiment, they demonstrated that this effect on exercising behavior was dependent on the resemblance between the participant and his or her avatar: A weaker effect was found when participants were looking at a virtual representation of another person. Moreover, further investigation revealed that this particular Proteus effect might even last up to 24 hours after the experiment: Participants who could see a representation of themselves performing the exercises reported to have engaged in more exercising behaviors, than participants who saw another person's avatar performing the exercises.

Another interesting development entails the investigation of the effects of even more dramatic alterations of the body. Since the 1980's, Jaron Lanier, who coined the term virtual reality, has explored the possibility of providing people with unusual bodies in virtual reality (see also Blakeslee & Blakeslee, 2007):

"What if your eyes were on your fingers? ... What if you took all the measurements and the movements of your physical body and somehow put them through a mathematical function that allowed you to learn to control six arms at once with practice? These sorts of things that play games with the feedback loop ... will be the real cutting edge of exploration of virtual reality as opposed to any particular symbolic content" (Lanier & Biocca, 1992; p. 162).

Although the limits of what Lanier calls homuncular flexibility are still unknown, its promise is the experience of multiple alternative morphologies (or multiple atypical embodiments; see Murray, 1999). Some of these alternative morphologies may even be an improvement over our familiar bodies, so that "we may, someday, even *prefer* to be telepresent" (IJsselsteijn, 2004; p. 243). Perhaps in the future, it may be possible to answer Nagel's (1974) question of what it is like to be a bat by ways of firsthand experience.

References

Anastasi, A. (1954). *Psychological testing.* New York: MacMillan.

Armel, K. C., & Ramachandran, V. S. (2003). Projecting sensations to external objects: Evidence from skin conductance response. *Proceedings of the Royal Society of London B, 270,* 1499-1506.

Arzy, S., Mohr, C., Michel, C. M., & Blanke, O. (2007). Duration and not strength in temporo-parietal cortex positively correlates with schizotypy. *NeuroImage, 35,* 326-333.

Austen, E. L., Soto-Faraco, S., Enns, J. T., & Kingstone, A. (2004). Mislocalizations of touch to a fake hand. *Cognitive, Affective, & Behavioral Neuroscience, 2,* 170–181.

Banissy, M. J., & Ward, J. (2007). Mirror-touch synesthesia is linked with empathy. *Nature Neuroscience, 10,* 815-816.

Berlucchi, G., & Aglioti, S. (1997). The body in the brain: Neural bases of corporeal awareness. *Trends in Neurosciences, 20,* 560-564.

Berti, A., & Frassinetti, F. (2000), When far becomes near: Re-mapping of space by tool use. *Journal of Cognitive Neuroscience, 12,* 415-420.

Biocca, F. (1997). The cyborg's dilemma: Progressive embodiment in virtual environments. *Journal of Computer-Mediated Communications, 3*(2).

Bischof, N. (1985). *Das Rätsel Ödipus* [Oedipus's riddle]. München, Germany: Piper Verlag.

Bischof-Köhler, D. (1991). The development of empathy in infants. In M. E. Lamb & H. Keller (Eds.), *Infant development: Perspectives from German speaking countries* (pp. 245-273). Hillsdale, NY: Lawrence Erlbaum.

Blanke, O. Mohr, C. Michel, C. M., Pascual-Leone, A., Brugger, P., Seeck, M., Landis, T., & Thut, G. (2005). Linking out-of-body experience and self processing to mental own-body imagery at the temporoparietal junction. *The Journal of Neuroscience, 19,* 550–557.

Blanke, O., Ortigue, S., Landis, T., & Seeck, M. (2002). Stimulating illusory own-body perceptions. *Nature, 419,* 269-270.

Blakeslee, S., & Blakeslee, M. (2007). *The body has a mind of its own: How body maps in your brain help you do (almost) everything better.* New York: Random House.

Bonanni, L., Vaucelle, C., Lieberman, J., & Zuckerman, O. (2006). TapTap: A haptic wearable for asynchronous distributed touch therapy. In G. M. Olson & R. Jeffries (Eds.), *Extended abstracts of the 2006 SIGCHI conference on human factors in computing systems* (pp. 580-585). New York: ACM Press.

Bond, T. G., & Fox, C. M. (2007). *Applying the Rasch model: Fundamental measurement in the human sciences* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum.

Bonda, E., Petrides, M., Frey, S., & Evans, A. (1995). Neural correlates of mental transformations of the body-in-space. *Proceedings of the National Academy of Sciences of the Unites States of America, 92,* 11180–11184.

Botvinick, M. (2004). Probing the neural basis of body ownership. *Science, 305,* 782-783.

Botvinick, M., & Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. *Nature, 391,* 756.

Boucsein, W. (1992). *Electrodermal activity.* New York: Plenum Press.

Brave, S., & Dahley, A. (1997). InTouch: A medium for haptic interpersonal communication. In S. Pemberton (Ed.), *Extended abstracts of the 1997 SIGCHI conference on human factors in computing systems* (pp. 363-364). New York: ACM Press.

Brooks, R.A. (1991). Intelligence without representation. *Artificial Intelligence, 47,* 139-159.

Brugger, P., & Funk, M. (2007). Out on a limb: Neglect and confabulation in the study of aplasic phantoms. In S. Della Sala (ed.), *Tall tales about the mind and brain: Separating fact from fiction* (pp. 348-368). New York: Oxford University Press.

Brugger, P., Kollias, S. S., Müri, R. M., Crelier, G., Hepp-Reymond, M-C., & Regard, M. (2000). Beyond re-membering: Phantom sensations of congenitally absent limbs. *Proceedings of the National Academy of Sciences of the Unites States of America, 97,* 6167-6172.

Burdea, G. C. (1996). *Force and touch feedback for virtual reality.* New York: John Wiley.

Burrack, A., & Brugger, P. (2005). Individual differences in susceptibility to experimentally induced phantom sensations. *Body Image, 2,* 307-313.

Chapman, L. J., Chapman, J. P., & Raulin, M. L. (1978). Body-image aberration in schizophrenia. *Journal of Abnormal Psychology, 87,* 399-407.

Charles, E. P. (2005). The correction for attenuation due to measurement error: Clarifying concepts and creating confidence sets. *Psychological Methods, 10,* 206-226.

Clark, A. (2007). Re-inventing ourselves: The plasticity of embodiment, sensing, and mind. *Journal of Medicine and Philosophy, 32,* 263-282.

Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension.* Oxford, NY: Oxford University Press.

Cole, J., Sacks, O., & Waterman, I. (2000). On the immunity principle: A view from a robot. *Trends in Cognitive Sciences, 4,* 167.

Cooper, L. A., & Shepard, R. N. (1975). Mental transformations in the identification of left and right hands. *Journal of Experimental Psychology: Human Perception and Performance, 104,* 48-56.

Critchley, M. (1979). *The divine banquet of the brain and other essays.* New York: Raven press.

de Vignemont, (2007). How many representations of the body? *Behavioral Brain Sciences, 30,* 204-205.

de Vignemont, F., Tsakiris, M., & Haggard, P. (2006). Body mereology. In G. Knoblich, I. M. Thornton, M. Grosjean & M. Shiffrar (Eds.), *Human body perception from the inside out* (pp. 147-170). New York: Oxford University Press.

Dennett, D. C. (1991). *Consciousness explained.* Boston: Little, Brown.

Desmond, D., & MacLachlan, M. (2002). Psychological issues in prosthetic and orthotic practice: A twenty-five year review of psychology in Prosthetics & Orthotics International. *Prosthetics & Orthotics International, 26,* 182-188.

Dourish, P. (2001). *Where the action is: The foundations of embodied interaction.* Cambridge, UK: MIT Press.

Eddington, A. S. (1928). *The nature of the physical world.* New York: Macmillan.

Edelman, G. M. (2003). Naturalizing consciousness: A theoretical framework. *Proceedings of the National Academy of Sciences of the United States of America, 100,* 5520-5524.

Edelman, G. M. (2006). *Second nature: Brain science and human knowledge.* New Haven, CT: Yale University Press.

Ehrsson, H. H. (2007). The experimental induction of out-of-body experiences. *Science, 317,* 1048.

Ehrsson, H. H., & Petkova, V. I. (2008). E-letter response to: H. H. Ehrsson (2007). The experimental induction of out-of-body experiences, *Science, 317,* 1048.

Ehrsson, H. H., Rosén, B, Stockselius, A., Ragnö, C., Köhler, P., & Lundborg, G. (2008). Upper limb amputees can be induced to experience a rubber hand as their own. *Brain, 131,* 3443-3452.

Ehrsson, H. H., Holmes, N. P., & Passingham, R. E. (2005). Touching a rubber hand: Feeling of body ownership is associated with activity in multisensory brain areas. *The Journal of Neuroscience, 25,* 10564-10573.

Ehrsson, H. H., Spence, C., & Passingham, R. E. (2004). That's my hand! Activity in premotor cortex reflects feeling of ownership of a limb. *Science, 305,* 875-877.

Ehrsson, H. H., Wiech, K., Weiskopf, N., Dolan, R. J., & Passingham, R. E. (2007). Threatening a rubber hand that you feel is yours elicits a cortical anxiety response. *Proceedings of the National Academy of Sciences of the United States of America, 104,* 9828-9833.

Fallis, G. T. (1888). *Walking toy.* U.S. Patent No. 376588.

Farnè, A., Pavani, F., Meneghello, F., & Làdavas, E. (2000). Left tactile extinction following visual stimulation of a rubber hand. *Brain, 123,* 2350-2360.

Floyd, K. (2000). Affectionate same-sex touch: The influence of homophobia on observers' perceptions. *Journal of Social Psychology, 140,* 774-788.

Fox, J., & Bailenson, J. N. (2009). Virtual self-modeling: The effects of vicarious reinforcement and identification on exercise behaviors. *Media Psychology, 12,* 1-25.

Freedberg, D., & Gallese, V. (2007). Motion, emotion, and empathy in aesthetic experience. *Trends in Cognitive Science, 11,* 197-203.

Funk, M., Shiffrar, M., & Brugger, P. (2005). Hand movement observation by individuals born without hands: Phantom limb experience constrains visual limb perception. *Experimental Brain Research 164,* 341-346.

Gallace, A., & Spence, C. (2010). The science of interpersonal touch: An overview. *Neuroscience & Biobehavioral Reviews, 34,* 246-259.

Gallagher, S. (1986). Body image and body schema: A conceptual clarification. *Journal of Mind and Behavior, 7,* 541-554.

Gallagher, S. (2005a). Dynamic models of body schematic processes. In H. de Preester & V. Knockaert (Eds.), *Body image and body schema* (pp. 233-250). Amsterdam: John Benjamins.

Gallagher, S. (2005b). *How the body shapes the mind.* New York: Oxford University Press.

Gallagher, S., & Cole, J. (1995). Body schema and body image in a deafferented subject. *Journal of Mind and Behavior, 16,* 369-390.

Gallese, V. (2001). The "shared manifold" hypothesis: From mirror neurons to empathy. *Journal of Consciousness Studies, 8*(5-7), 33-50.

Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain, 119,* 593–609.

Gallup, G. G., Jr. (1970). Chimpanzees: Self-recognition. *Science, 167,* 86–87.

Gazzola, V., Aziz-Zadeh, L., & Keysers, C. (2006). Empathy and the somatotopic auditory mirror system in humans. *Current Biology, 16,* 1824-1829.

Gordon, K. (1934). A device for demonstrating empathy. *Journal of Experimental Psychology,* 17, 892-893.

Gorsuch, R. L. (1997). Exploratory factor analysis: Its role in item analysis. *Journal of Personality Assessment, 68,* 532-560.

Groen, J., & Werkhoven, P. J. (1998). Visuomotor adaptation to virtual hand position in interactive virtual environments. *Presence: Teleoperators and Virtual Environments, 7,* 429-446.

Gross, Y., & Melzack, R. (1978). Body image: Dissociation of real and perceived limbs by pressure-cuff ischemia. *Experimental Neurology, 61,* 680-688.

Gross, Y., Webb, R., & Melzack, R. (1974). Central and peripheral contributions to localization of body parts: Evidence for a central body schema. *Experimental Neurology, 44,* 346-362.

Haans, A., & IJsselsteijn, W. A. (2006). Mediated social touch: A review of current research and future directions. *Virtual Reality, 9,* 149-159.

Haans, A., & IJsselsteijn, W. A. (2007). Self-attribution and telepresence. In L. Moreno & Starlab Barcelona S. L. (Eds.), *Proceedings of the 10th annual international workshop on presence* (pp. 51-58). Barcelona, Spain: Starlab Barcelona S. L.

Haans, A., & IJsselsteijn, W. A. (2009a). A virtual Midas touch: Helping behavior after a mediated social touch. *IEEE Transactions on Haptics, 2,* 136-140.

Haans, A., IJsselsteijn, W. A. (2009b). "I'm always touched by your presence, dear": Combining mediated social touch with morphologically vorrect visual feedback. In *Proceedings of the 12th annual international workshop on presence* [CD-Rom], November 11-13, Los Angeles, CA.

Haans, A., de Nood, C., & IJsselsteijn, W. A. (2007). Investigating response similarities between real and mediated social touch: A first test. In B. Begole, S. Payne, E. Churchill, R. St. Amant, D. Golmore & M. B. Rosson (Eds.), *Extended abstracts of the 2007 SIGCHI conference on human factors in computing systems* (pp. 2405-1410). New York: ACM press.

Haans, A., IJsselsteijn, W. A., & de Kort, Y. A. W. (2008). The effect of similarities in skin texture and hand shape on perceived ownership of a fake limb. *Body Image, 5,* 389-394.

Haans, A., IJsselsteijn, W. A., Graus, M. P., & Salminen, J. A. (2008). The virtual Midas touch: Helping behavior after a mediated social touch. In *Extended abstracts of the 2008 SIGCHI conference on human factors in computing systems* (pp. 3507-3512). New York: ACM press.

Haans, A., Kaiser, F. G., IJsselsteijn, W. A., & Bouwhuis, D. G. (2009). V*ividness of the rubber-hand illusion: A function of individual susceptibility, processing demand, & situational impediments.* Submitted for publication.

Haggard, P. (2006). Just seeing you makes me feel better: Interpersonal enhancement of touch. *Social Neuroscience, 1,* 104-110.

Hall, E. T. (1966). *The hidden dimension.* Garden City, NY: Doubleday.

Hardy, S. (2001). *Chapman schalen voor psychose-vatbaarheid: Psychometrische kwaliteiten van de Amerikaanse en Nederlandse Chapman schalen* [Chapman scales for psychotic symptoms: Psychometric quality of the American and Dutch Chapman scales]. Unpublished manuscript, University of Maastricht, Maastricht, The Netherlands.

Hayduk, L. (1983). Personal space: Where we now stand. *Psychological Bulletin, 94,* 293-335.

Hayward, V., & MacLean, K. E. (2007). Do It Yourself Haptics, Part I. *IEEE Robotics and Automation Magazine, 14*(4), 88-104.

Head, H., & Holmes, G. M. (1911). Sensory disturbances from cerebral lesions. *Brain, 34,* 102-254.

Held, R., & Durlach, N. (1991). Telepresence, time delay and adaptation. In S. R. Ellis (Ed.), *Pictorial communication in virtual and real environments* (2nd ed. pp. 233-246). London: Taylor & Francis.

Holmes, N. P., & Spence, C. (2004). The body schema and multisensory representation(s) of peripersonal space. *Cognitive Processing, 5,* 94-105.

Holmes, N. P., & Spence, C. (2006). Beyond the body schema: Visual, prosthetic, and technological contributions to bodily perception and awareness. In G. Knoblich, I. M. Thornton, M. Grosjean & M. Shiffrar (Eds.), *Human body perception from the inside out* (pp. 15-64). Oxford: Oxford University Press.

Holmes, N. P., & Spence, C. (2007). Dissociating body image and body schema with rubber hands. *Behavioral and Brain Sciences, 30,* 211-212.

Holmes, N. P., Snijders, H. J., & Spence, C. (2006). Reaching with alien limbs: Visual exposure to prosthetic hands in a mirror biases proprioception without accompanying illusions of ownership. *Perception & Psychophysics,* 68, 685-701.

IJsselsteijn, W. A. (2004). *Presence in depth.* Eindhoven, the Netherlands: Eindhoven University of Technology.

IJsselsteijn, W. A. (2005). Towards a neuropsychological basis of presence. *Annual Review of CyberTherapy and Telemedicine, 3,* 25-30.

IJsselsteijn, W. A., de Kort, Y. A. W., & Haans, A. (2006). Is this my hand I see before me? The rubber hand illusion in reality, virtual reality, and mixed reality. *Presence: Teleoperators and Virtual Environments, 15,* 455-464.

IJsselsteijn, W. A., & Haans, A. (2008a). Malleable body images: Mediated environments as a tool for investigating brain plasticity, body consciousness and self-perception. In I. van Keulen (Ed.), *Brain visions: How the brain sciences could change the way we eat, communicate, learn and judge* (pp. 240-246). The Hague, The Netherlands: Stichting Toekomstbeeld der Techniek (STT).

IJsselsteijn, W. A., & Haans, A. (2008b). Touch, tools, and telepresence: The role of embodiment in mediated environments. In B. E. Rogowitz & T. N. Pappas (Vol. Eds.), *Proceedings of SPIE: Vol. 6806, Human vision and electronic imaging XIII* (Publication No. 68060J). Bellingham, WA: SPIE.

Iriki, A., Tanaka, M., & Iwamura, Y. (1996). Coding of modified body schema during tool use by macaque postcentral neurones. *Neuroreport, 7,* 2325–2330.

Jabbi, M., Swart, M., & Keysers, C. (2007). Empathy for positive and negative emotions in the gustatory cortex. *NeuroImage, 34,* 1744–1753.

James, W. (1890). *The principles of psychology.* New York: Henry Holt.

Jeannerod, M. (2003). The mechanisms of self-recognition in humans. *Behavioral Brain Research, 142,* 1-15.

Juhel, J., & Neiger, H. (1993). The illusory movement sensation paradigm: Some personality correlates. *Personality and Individual Differences, 14,* 293-296.

Kaiser, F. G., & Wilson, M. (2000). Assessing people's general ecological behavior: A cross-cultural measure. *Journal of Applied Social Psychology, 30,* 952-978.

Kennett, S., Taylor-Clarke, M., & Haggard, P. (2001). Noninformative vision improves the spatial resolution of touch in humans. *Current Biology, 11,* 1188-1191.

Keysers, C., Wicker, B., Gazzola, V., Anton, J. L., Fogassi, L., & Gallese, V. (2004). A touching sight: SII/PV activation during the observation and experience of touch. *Neuron, 42,* 335-346.

Kitada, R., Naito, E., Matsumura, M. (2002). Perceptual changes in illusory wrist flexion angles resulting from motor imagery of the same wrist movements. *Neuroscience, 109,* 701-707.

Knoblich, G. (2002). Self-recognition: Body and action. *Trends in Cognitive Sciences, 6,* 447-449.

Kugel, J. (1969). *Lichaamsplan, lichaamsbesef, lichaamsidee: De psychologische betekenis van de lichamelijke ontwikkeling* [Body plan, body consciousness, and body idea: The psychological significance of physical development]. Groningen, The Netherlands: Wolters-Noordhoff.

Lackner, J. R. (1988). Some proprioceptive influences on the perceptual representation of body shape and orientation. *Brain, 111,* 281-297.

Lanier, J., & Biocca, F. (1992). An insider's view of the future of virtual reality. *Journal of Communication, 42*(4), 150-172.

Lee, K. M. (2004). Presence, explicated. *Communication Theory, 14,* 27-50.

Lenggenhager, B., Tadi, T., Metzinger, T., & Blanke, O. (2007). Video ergo sum: Manipulating bodily self-consciousness. *Science, 317,* 1096-1099.

Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J. (2001). A cross-media presence questionnaire: The ITC-Sense of Presence Inventory. *Presence: Teleoperators and virtual environments, 10,* 282-297.

Linacre, J. M. (1994). *Many-facet Rasch measurement* (2nd ed.). Chicago: MESA.

Linacre, J. M. (1998). Detecting multidimensionality: Which residual data-type works best? *Journal of Outcome Measurement, 2,* 266-283.

Linacre, J. M. (2003). Data variance: Explained, modeled and empirical. *Rasch Measurement Transactions, 17,* 942-943.

Linacre, J. M. (2006). *Facets Rasch measurement computer program.* Chicago: Winsteps.com.

Lipps, T. (1903). Einfühlung, innere Nachahmung, und Organempfindungen [Empathy, inner imitation and sense-feelings]. *Archiv für die gesammte Psychologie, 1,* 185-204.

Lloyd, D. M. (2007). Spatial limits on referred touch to an alien limb may reflect boundaries of visuo-tactile peripersonal space surrounding the hand. *Brain and Cognition, 64,* 104-109.

Longo, M. R., Schüür, F., Kammers, M. P. M., Tsakiris, M., & Haggard, P. (2008). What is embodiment? A psychometric approach. *Cognition, 107,* 978-998.

Longo, M. R., Schüür, F., Kammers, M. P. M., Tsakiris, M., & Haggard, P. (2009). Self awareness and the body image. *Acta Psychologica, 132,* 166-172.

Loomis, J. M. (1993). Understanding synthetic experience must begin with the analysis of ordinary perceptual experience. In *Proceedings of the IEEE symposium on research frontiers in virtual reality* (pp. 54-57). Los Alamos, CA: IEEE Press.

Loomis, J. M., Blascovich, J. J., & Beall, A. C. (1999). Immersive virtual environment technology as a basic research tool in psychology. *Behavior Research Methods, Instruments, & Computers, 31,* 557-564.

Lykken, D. T., & Venables, P. H. (1971). Direct measurement of skin conductance: A proposal for standardization. *Psychophysiology, 8,* 656-672.

MacLachlan, M., Desmond, D., & Horgan, O. (2003). Psychological correlates of illusory body experiences. Journal of Rehabilitation *Research and Development, 40,* 59-66.

Makin, T. R., Holmes, N. P., & Ehrsson, H. H. (2008). On the other hand: dummy hands and peripersonal space. *Behavioral Brain Research, 191,* 1-10.

Maravita, A., & Iriki, A. (2004). Tools for the body (schema). *Trends in Cognitive Science, 8,* 79-86.

Maravita, A., Spence, C., & Driver, J. (2003). Multisensory integration and the body schema: Close to hand and within reach. *Current Biology, 13,* 531-539.

McBride, G., King, H. G., & James, J. W. (1965). Social proximity effects on galvanic skin response in adult humans. *Journal of Psychology, 61,* 153-157.

Melzack, R., & Bromage, P. R. (1973). Experimental phantom limbs. *Experimental Neurology, 39,* 261-269.

Metzinger, T. (2003). *Being no one: The self-model theory of subjectivity.* Cambridge, MA: MIT press.

Metzinger, T. (2006). Reply to Gallagher: Different conceptions of embodiment. *Psyche 12*(4).

Minsky, M. (1988). *The society of mind.* New York: Simon and Schuster.

Mohr, C., Blanke, O., & Brugger, P. (2006). Perceptual aberrations impair mental own body transformations. *Behavioural Neuroscience, 120,* 528-534.

Moseley, G., Parsons, T., & Spence, C. (2008). Visual distortion of a limb modulates the pain and swelling evoked by movement. *Current Biology, 18,* 1047-1048.

Mueller, F., Vetere, F., Gibbs, M. R., Kjeldskov, J., Pedell, S., & Howard, S. (2005). Hug over a distance. In G. C. van der Veer & C. Gale (Eds.), *Extended abstracts of the 2005 SIGCHI conference on human factors in computing systems* (pp. 1673-1676). New York: ACM Press.

Mussap, A. J., & Salton, N. (2006). A 'rubber-hand' illusion reveals a relationship between perceptual body image and unhealthy body change. *Journal of Health Psychology, 11,* 627–639.

Nagel, T. (1974). What is it like to be a bat? *The Philosophical Review, 83,* 435-450.

Nico, D., Daprati, E., Rigal, F., Parsons, L. M., & Sirigu, A. (2004). Left and right hand recognition in upper limb amputees. *Brain, 127,* 120-132.

O'Regan, J. K., Myin, E., & Noë, A. (2005). Skill, corporality and alerting capacity in an account of sensory consciousness. In S. Laureys (Ed.), *Progress in brain research, Vol. 150: The boundaries of consciousness: Neurobiology and neuropathology* (pp. 55-68). Amsterdam, The Netherlands: Elsevier.

Pachella, R. G. (1974). The interpretation of reaction time in information-processing research. In B. H. Kantowitz (Ed.), *Human information processing: Tutorials in performance and cognition* (pp. 41-82), Hillsdale, NJ: Lawrence Erlbaum.

Parsons, L. M. (1987). Imagined spatial transformations of one's hands and feet. *Cognitive Psychology, 19,* 178-241.

Parsons, L. M. (1994). Temporal and kinematic properties of motor behaviour reflected in mentally simulated action. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 709-730.

Parsons, L. M., Fox, P. T., Downs, J. H., Glass, T., Hirsch, T. B., Martin, C. C., Jerabek, P. A., & Lancaster, J. L. (1995). Use of implicit motor imagery for visual shape discrimination as revealed by PET. *Nature, 375,* 54-58.

Parsons, L. M., Gabrieli, J. D. E., Phelps, E. A., & Gazzaniga, M. S. (1998). Cerebrally lateralized mental representations of hand shape and movement. *Journal of Neuroscience, 18,* 6539-6548.

Pavani, F., Spence, C., & Driver, J. (2000). Visual capture of touch: Out-of-the-body experiences with rubber gloves. *Psychological Science, 11,* 353-359.

Peled, A., Ritsner, M., Hirschmann, S., Geva, A. B., & Modai, I. (2000). Touch feel illusion in schizophrenic patients. *Biological Psychiatry, 48,* 1105-1108.

Plotnik, J. M., de Waal, F. B., & Reiss, D. (2006). Self-recognition in an Asian elephant. *Proceedings of the National Academy of Sciences of the United States of America, 103,* 17053-17057.

Povinelli, D. J., & Cant, J. G. H. (1995). Arboreal clambering and the evolution of self-conception. *Quarterly Review of Biology, 70,* 393-421.

Price, E. H. (2006). A critical review of congenital phantom limb cases and a developmental theory for the basis of body image. *Consciousness and Cognition, 15,* 310–322.

Prior, H., Schwarz, A., & Güntürkün, O. (2008). Mirror-induced behavior in the Magpie (Pica pica): Evidence of self-recognition. *PLoS Biology, 6,* 1642-1650.

Raaijmakers, Q. A. W., van Hoof, A., Hart, H. T., Verbogt, T. F. M. A., & Vollebergh, W. A. M. (2000). Adolescents' midpoint response on Likert-type scale items: Neutral or missing values? *International Journal of Public Opinion Research, 12,* 208-216.

Ramachandran, V. S., & Blakeslee, S. (1999). *Phantoms in the brain: Human nature and the architecture of the mind.* London: Fourth Estate.

Ramachandran, V. S., & Hirstein, W. (1998). The perception of phantom limbs: The D.O. Hebb lecture. *Brain, 121,* 1603-1630.

Reed, C. L., & Farah, M. J. (1995). The psychological reality of the body schema: A test with normal participants. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 334-343.

Reiss, D., & Marino, L. (2001). Mirror self-recognition in the bottlenose dolphin: A case of cognitive convergence. *Proceedings of the National Academy of Sciences of the United States of America, 98,* 5937-5942.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27,* 169-192.

Rochat, P., & Striano, T. (2000). Perceived self in infancy. *Infant Behavior & Development, 23,* 513-530.

Rovers, A. F., & van Essen, H. A. (2006). Guidelines for haptic interpersonal communication applications: An exploration of foot interaction styles. *Virtual Reality, 9,* 177-191.

Sanchez-Vives, M. V., & Slater, M. (2005). From presence to consciousness through virtual reality. *Nature Reviews Neuroscience, 6,* 332-339.

Saxe, R., Jamal, N., & Powell, L. (2006). My body or yours? The effect of visual perspective on cortical body representation. *Cerebral Cortex, 16,* 178–182.

Schumacker, R. E. (1999). Many-facet Rasch analysis with crossed, nested, and mixed designs. *Journal of Outcome Measurement, 3,* 323-338.

Schwoebel, J., Buxbaum, L. J., & Coslett, H. B. (2004). Representations of the human body in the production and imitation of complex movements. *Cognitive Neuropsychology, 21,* 285-298.

Sekiyama, K. (1982). Kinesthetic aspects of mental representations in the identification of left and right hands. *Perception & Psychophysics, 32,* 89-95.

Sheridan, T. B. (1992). Musings on telepresence and virtual presence. *Presence: Teleoperators and Virtual Environments, 1,* 120-125.

Sherrington, C. (1961). *The integrative action of the nervous system* (2nd ed.). New Haven, CT: Yale University Press.

Shiffrar, M., & Freyd, J. (1993). Timing and apparent motion path choice with human body photographs. *Psychological Science, 4,* 379-384.

Shiffrar, M., & Freyd, J. (1990). Apparent motion of the human body. *Psychological Science, 1,* 257-264.

Shimada, S., Fukuda, K., & Hiraki, K. (2009). Rubber hand illusion under delayed visual feedback. *PLoS ONE 4*(7 Serial No. e6185).

Shore, D. I., Spry, E., & Spence, C. (2002). Confusing the mind by crossing the hands. *Cognitive Brain Research, 14,* 153-163.

Schwabe, L., & Blanke, O., (2007). The cognitive neuroscience of agency and ownership. *Consciousness and Cognition, 16,* 661-666.

Thomas, R., Press, C., & Haggard, P. (2006). Shared representations in body perception. *Acta Psychologica, 121,* 317-330.

Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: Visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 80-91.

van Strien, J. W. (1992). Classificatie van links- en rechtshandige proefpersonen [Classification of left- and right-handed participants]. *Nederlands Tijdschrift voor de Psychologie en Haar Grensgebieden, 47,* 88-92.

Varela, F. J., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience.* Cambridge, UK: MIT press.

Wann, J. P., & Ibrahim, S. F (1992). Does limb proprioception drift? *Experimental Brain Research, 91,* 162-166.

Welch, R. B. (1986). Adaptation of space perception. In K. R. Boff, L. Kaufman & J. P. Thomas (Eds.), *Handbook of perception and human performance* (pp. 24.1-24.44). New York: Wiley.

Welch, R. B., & Warren D. H. (1980). Immediate perceptual response to intersensory discrepancy. *Psychological Bulletin, 88,* 638-667.

Wicker, B., Keysers, C., Plailly, J., Royet, J-P., Gallese, V., & Rizzolatti, G. (2003). Both of us disgusted in my insula: The common neural basis of seeing and feeling disgust. *Neuron, 40,* 655-664.

Wright, B. D., & Linacre, J. M. (1994). Reasonable mean-square fit values. *Rasch Measurement Transactions, 8,* 370.

Yamamoto, S., & Kitazawa, S. (2001a). Reversal of subjective temporal order due to arm crossing. *Nature Neuroscience, 4,* 759-765.

Yamamoto, S., & Kitazawa, S. (2001b). Sensation at the tips of invisible tools. *Nature Neuroscience, 4,* 979-980.

Yee, N., & Bailenson, J. N. (2006). Walk a mile in digital shoes: The impact of embodied perspective-taking on the reduction of negative stereotyping in immersive virtual environments. In C. Campanella Bracken & M. Lombard (Eds.), *Proceedings of the 9th annual international workshop on presence* (pp. 147-156). Cleveland, OH: Cleveland State University.

Yee, N. & Bailenson, J. N. (2007). The Proteus effect: Self transformations in virtual reality. *Human Communication Research, 33,* 271-290.

Summary

Human beings are proficient users of tools and technology. At times, our interactions with a technological artifact appear so effortless, that the distinction between the artifact and the body starts to fade. When operating anthropomorphically designed teleoperation systems, for example, some people develop the vivid experience that they are physically there at the remote site (i.e., telepresence). Others might even come to sense the slave robot's arms and hands as their own. The process in which the central nervous system categorizes an object as a part of the body, and in which a discrimination is made between what is contained within and outside the bodily boundaries, is called self-attribution. The aim of this thesis is twofold: (a) To determine the personal factors (e.g., the characteristics of an individual's psychological makeup) and situational factors (e.g., the appearance of objects) that constrain or facilitate self-attribution, and (b) to determine the degree to which these factors affect people's experiences with media technology.

In Chapter 2, we describe the theoretical framework of our research which is centered on a conception of the user of technology as an embodied agent. In this chapter we distinguish two important, but often confused aspects of embodiment: the body schema, and the body image. The body schema is defined as a dynamic distributed network of procedures aimed at guiding behavior. In contrast, we defined the body image as a part of the process of consciousness and, thus, as consisting of those higher-order discriminations (or qualia) that pertain to the body, and one's self-perception thereof.

To investigate the individual and situational factors that constrain or facilitate self-attribution (i.e., incorporation into the body image), we employ the experimental paradigm of the rubber-hand illusion (Botvinick & Cohen, 1998). In this illusion, which is induced by stroking a person's concealed hand together with a visible fake one, some people start to sense the fake hand as an actual part of their body. In Chapter 3, we investigate the rubber-hand illusion under two mediated conditions: (1) a virtual reality condition, where both the fake hand and its stimulation were projected on the table in front of the participant, and (2) a mixed reality condition, where the fake hand was projected, but its stimulation was unmediated. Our experiment reveals that people can develop the rubber-hand illusion under mediated conditions, but the resulting illusion may, depending on the technology used, be less vivid than in the traditional unmediated setup. In Chapter 4, we investigate the extent to which visual discrepancies between the foreign object and a human hand affect

people in developing a vivid rubber-hand illusion. We found that people experience a more vivid illusion when the foreign object resembles the human hand in terms of both shape and texture. Taken together, the experiments in Chapters 3 and 4 support the view that the rubber-hand illusion is not merely governed by a bottom-up process (i.e., based on visuotactile integration), but is affected, top-down, by a cognitive representation of what the human body is like (e.g., Tsakiris and Haggard, 2005).

In the rubber-hand illusion, people commonly misperceive the location of their concealed hand toward the direction of the fake hand (Tsakiris & Haggard, 2005). As such, this so-called proprioceptive drift is often used as an alternative to self-reports in assessing the vividness of the illusion (e.g., Tsakiris & Haggard, 2005). In Chapter 5, we investigate the extent to which the observed shift in felt position of the concealed hand can be attributed to experiencing the illusion. For this purpose, we test how various features of the experimental setup of the rubber-hand illusion, which in themselves are not sufficient to elicit the illusion, affect proprioceptive drift. We corroborate existing research which demonstrates that looking at a fake hand or a tabletop for five minutes, in absence of visuotactile stimulation, is sufficient to induce a change in the felt position of an unseen hand (e.g., Gross et al., 1974). Moreover, our experiments indicate that the use of proprioceptive drift as a measure for the strength of the rubber-hand illusion yields different conclusions than an assessment by means of self-reports. Based on these results, we question the validity of proprioceptive drift as an alternative measure of the vividness of the rubber-hand illusion.

In Chapter 6, we propose and test a model of the vividness of the rubber-hand illusion. In two experiments, we successfully modeled people's self-reported experiences related to the illusion (e.g., "the fake hand felt as my own") based on three estimates: (a) a person's susceptibility for the rubber-hand illusion, (b) the processing demand that is required for a particular experience, and (c) the suppression/constraints imposed by the situation. We demonstrate that the impressions related to the rubber-hand illusion, and by inference the processes behind them, are comparable for different persons. This is a non-trivial finding as such invariance is required for an objective scaling of individual susceptibility and situational impediment on the basis of self-reported experiences. Regarding the validity of our vividness model, we confirm that asynchrony (e.g., Botvinick & Cohen, 1998) and information-poor stimulation (e.g., Armel & Ramachandran, 2003) constrain the development of a vivid rubber-hand illusion. Moreover, we demonstrate that the correlation between a person's susceptibility for the rubber-hand illusion and the extent of his or her proprioceptive drift is fairly moderate, thereby confirming our conclusions from Chapter 5 regarding the limited validity of proprioceptive drift as a measure of the vividness of the rubber-hand illusion.

In Chapter 7, we investigate the extent to which the large individual differences in people's susceptibility for the illusion can be explained by body image instability, and the ability to engage in motor imagery of the hand (i.e., in mental own hand transformations). In addition, we investigate whether the vividness of the illusion is dependent on the anatomical implausibility of the fake hand's orientation. With respect to body image instability, we corroborate a small, but significant, correlation between susceptibility and body image aberration scores: As expected, people with a more unstable body image are also more susceptible to the rubber-hand illusion (cf. Burrack & Brugger, 2005). With respect to the position and orientation of the fake hand on the table, we demonstrate that people experience a less vivid rubber-hand illusion when the fake hand is orientated in an anatomically impossible, as compared to an anatomically possible manner. This finding suggests that the attribution of foreign objects to the self is constrained by the morphological capabilities of the human body. With respect to motor imagery, our results indicate a small, but significant, correlation between susceptibility and response times to a speeded left and right hands identification task. In other words, people who are more attuned to engage in mental own hand transformations are also better equipped to develop vivid rubber-hand illusions.

In Chapter 8, we examine the role of self-attribution in the experience of telepresence. For this purpose, we introduce the technological domain of mediated social touch (i.e., interpersonal touching over a distance). We anticipated that, compared to a morphologically incongruent input medium, a morphologically congruent medium would be more easily attributed to the self. As a result, we expected our participants to develop a stronger sense of telepresence when they could see their interaction partner performing the touches on a sensor-equipped mannequin as opposed to a touch screen. Our participants, as expected, reported higher levels of telepresence, and demonstrated more physiological arousal with the mannequin input medium. At the same time, our experiment revealed that these effects might not have resulted from self-attribution, and thus that other psychological mechanisms of identification might play a role in telepresence experiences.

In Chapter 9, the epilogue, we discuss the main contributions and limitations of this thesis, while taking a broader perspective on the field of research on media technologies and corporeal awareness.

Curriculum Vitae

Antal Haans was born in Tilburg, the Netherlands, on 23 October 1978. He attended the Cobbenhagen College in Tilburg from 1992 to 1997, where he obtained his V.W.O. diploma in 1997. From 1997 to 2004, he studied Technology and Society at Eindhoven University of Technology, Eindhoven, The Netherlands. He obtained a Master's degree in Human Technology Interaction in 2004 (cum laude). His Master's thesis research, conducted in cooperation with Rabobank Facilitair Bedrijf, focused on the measurement of the need for privacy and socializing of office workers. It combined Altman's theory of privacy regulation with Kaiser's theory of goal-directed behavior. After obtaining his Masters degree, he remained at the university as a Ph.D. student at the J.F. Schouten School for User-System Interaction Research. His Ph.D. research focused on embodiment and corporeal awareness in relation to media technologies (this thesis), and mediated social touch (for the European funded PASION project). Since 2008, Antal has been working as a lecturer/researcher within the Human Technology Interaction group at Eindhoven University of Technology.

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