The Sense of Self and Sensorimotor Functions

by

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Author’s Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

This thesis investigates whether biological sex and motor function have a role in the visual representation of the self. The principal contribution is a new virtual reality experiment that systematically varied an avatar's sex and motion, after which participants recorded judgments about the relationship between themselves and the avatar. Virtual reality aims to produce the authentic experience of being present or the feeling of being there in an artificial environment. The third person perspective is similar to looking at oneself in a mirror but different than the first-person perspective, which places the user inside the body of the avatar, which are virtual simulated characters that can act as a visual representation of the self.

The experiment assessed the role of biological sex and self-motion by presenting participants with pairs of avatars that visually represent the participant ("self avatar"), or another person ("opposite avatar"). Additionally, the avatars' motion either corresponded to the participant's motion, or was decoupled from the participant's motion. Decoupled motion consisted of swaying slightly from side to side. By manipulating sex and motion, I tested whether these aspects affect how participants perceive themselves. The results support the conclusion that sex and normal motion both affect the visual representation of the self.

These results relate to two theories of bodily awareness: the representationalist theory and sensorimotor theory. These theories explain how individuals come to have awareness of their bodies from the inside. While the representational theory focuses on sensorimotor representations, the sensorimotor theory focuses on sensorimotor functions and voluntary action. The results relate to the representational theory because sex and motion are both relevant to the body schema and body image. Although there is no consensus among researchers of their definitions, body schema is generally regarded as an unconscious, bottom-up, dynamic representation, relying on proprioceptive information from the muscles, joints, and skin. On the other hand, the body image is a more conscious, top down, cognitive representation, incorporating semantic knowledge of the body, and mostly used to make perceptual judgements. The results relate to the sensorimotor approach since motion and sensorimotor functions were manipulated. This finding is limited, however, by the fact that participants were not affected by motion in some trials.

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Preface

What constitutes the sense of self? How does the self relate to the physical world around us? Within philosophy, psychology, and cognitive science the sense of self is frequently discussed, although it is rarely explicitly defined. Throughout this thesis, I will use the human "sense of self" to mean one's conscious sense (experience or awareness) of personal identity in thought, emotion, body, and action. In these disciplines, this construct has been called by different names, such as "soul" or "spirit", or newer psychological terms such as "person", "mind", or "self."

I take an interdisciplinary approach to studying the sense of self, drawing on ideas from multiple areas of cognitive science, specifically philosophy and psychology (Gallagher, 2000). Researchers in these areas have proposed at least twenty-one distinct notions of the self (Strawson, 2004), some of which are complex and multi-faceted. In this thesis, I will not address the question of whether there is a single best definition of "self," nor will I make substantive assumptions about the self being "unified" (compare Martin, 2006). Instead, I will simply assume that a sense of self involves, at least, conscious awareness of one's own experiences; this is sometimes called "the minimal self" (Zahavi, 1999; see also Northoff, 2014; Blanke and Metzinger, 2009). I will also assume that for members of a highly social species, such as humans, socially important properties such as personality traits, habits, and biological sex can make contributions to one's sense of self.

This thesis investigates whether biological sex and motor function have a role in the visual representation of the self. Sensorimotor functions are part of humans' voluntary

movement and involve the process of receiving sensory input and producing a motor output. For organisms that reproduce sexually, biological sex is a fundamentally important attribute. Relevant evidence for evaluating my principal questions comes from a review of existing theories and findings, as well as the results of a new virtual reality behavioral experiment. The experiment assessed the role of biological sex and self-motion in the visual representation of the self by presenting participants with pairs of avatars that visually represent the participant ("self avatar"), or another person ("opposite avatar"). Additionally, the avatars' motion either corresponded to the participant's motion, or was decoupled from the participant's motion. Decoupled motion consisted of swaying slightly from side to side. By manipulating sex and motion, I tested whether these aspects affect how participants perceive themselves. The results support the conclusion that sex and normal motion both affect the visual representation of the self.

“I’m not myself today, you see,” Alice said to the caterpillar. “I don’t see,” said the caterpillar.

-(Carroll 1928, p.86)

1. Introduction

What constitutes the sense of self? Two main influential theories are the representational theory of bodily awareness (O'Shaughnessy, 1980; Carruthers, 2008; Vignemont, 2010) and sensorimotor theory of bodily awareness (Merleau-Ponty, 1962). These theories explain how individuals come to have awareness of their bodies from the inside. While the representational theory focuses on sensorimotor representations, the sensorimotor theory focuses on sensorimotor functions and voluntary action. My proposed contribution to the topic is a new virtual reality behavioural experiment which assesses the role of motion and sex to the visual representation of the self.

This thesis has three main sections: a literature review, a new virtual reality behavioural experiment, and a conclusion. In section 2, I provide a literature review on the self and sense of self, including philosophical and empirical contributions. In section 3, I report a new virtual-reality behavioral experiment. In section 4, I argue that the experimental results suggest that self motion and sex are important to one's visual self-representation. I also relate the results of the experiment to the representational and sensorimotor theories and indicate some limitations and future research for the experiment.

2. Literature Review

In this section, I review relevant theories of the self from Plato, Aristotle, Descartes, John Locke, David Hume, and Derek Parfit.

Plato (428-348 B.C.)

In Plato's *Republic*, Socrates, the spokesperson for Plato's views, argues the soul has three interacting parts: reason, spirit, and appetite (Shields, 2011). For Socrates, the mortal parts of the soul are spirit, which is responsible for emotions, and appetite, which is responsible for desires such as hunger and thirst. On the other hand, the soul's reason is the rational and immortal part, which controls the desires. The rational part survives bodily death and is separable from the body. This means the body and soul are separate parts of a person. Additionally, since Plato divided consciousness into three separate aspects, the self has three different locations: the head, heart, and gut. For Plato, then, the soul is the source for the sense of self.

Plato views the body as separate from the conscious soul. For Plato, the soul is a helpless prisoner, chained hand and foot in the body and views reality only through its prison bars (Shields, 2011). This illustrates Plato's dualism: that the soul and body are separate entities. Since the conscious soul is separate from the body and the conscious soul is supreme over the body, the body does not play a part in self-motion.

Moreover, for Plato, since the body is given a lower status to the soul, there is a hierarchy of reason over the senses:

> Don't you think that the person who is likely to succeed in this attempt [to reach the goal of reality] most perfectly is the one who approaches each object, as far as possible, with the unaided intellect, without taking account of any sense of sight in his thinking, or dragging any other sense into his reckoning—the man who pursues the truth by applying his pure and unadulterated thought to the pure and unadulterated object, cutting himself off as much as possible from his eyes and ears and virtually all the rest of his body, as an impediment which by its presence prevents the soul from attaining to truth and clear thinking? Is not this the person, Simmias, who will reach the goal of reality, if anybody can? What you say is absolutely true, Socrates, said Simmias. (Reale 1987, p.50)

On Plato's account, it seems that the conscious soul is cut off from the senses, motor control, and the rest of the body, because they are not needed for the understanding of the good. It seems under Plato's account, then, that motion or the movement of the body has a lower status than the rational mind's intention for motion.

Aristotle (384 -322 B.C.E)

Unlike Plato, Aristotle was concerned with the soul's relationship to the body and human nature. Aristotle opposed Plato's dualism and advocated instead for materialism. On Aristotle's view, all living things have souls, the vital principle of life, which animate the body and account for it being alive. For Aristotle, then, souls are not a body but require a body. In effect, although these two entities are distinguished conceptually, the body and soul are interdependent and inseparable.

In contrast to Plato, Aristotle argued for three different levels of the soul: nutritive, sensitive, and intellectual (Aristotle et al. 1995). At the bottom level, the nutritive soul is found in plants and is responsible for growth, nourishment, and reproduction. The next higher level is the sensitive soul, which is in non-human animals and has the same powers as the nutritive soul plus locomotion and perception, which are sensorimotor functions. The top level is the intellectual soul, which is found only in humans. It has the same powers of the vegetative and sensitive souls plus *nous*, which is responsible for thought. For Aristotle, then, the intellectual soul is responsible for motion. Thus, Aristotle gives sensorimotor function a more important role in the human self than Plato did. Further, unlike Plato, Aristotle discussed and ranked all five senses: sight is superior to touch, hearing, and smell to taste (Smith, 2007). This suggests that Aristotle appreciated that sensorimotor function was important for humans' sense of self.

In *De Partibus Animalium*, Aristotle argues that the self is in the heart. Call this the *cardiocentric model*. For Aristotle, "nature, when no other more important purpose stands in her way, places the more honourable part in the more honourable position; and the heart lies about the centre of the body, but rather in its upper than its lower half and also more in front than behind" (Aristotle 1882, p.67). Aristotle held this view because he noticed the heart was the first developed organ in stillborn embryos, which, on his interpretation, implied that it was the most important organ. Accordingly, Aristotle, claimed that the heart is the location of the self.

René Descartes (1596-1650)

French rationalist philosopher Descartes agrees with Plato that the soul is separable from the body, that the self is not the body, and could exist even if the body did not. The relation between one's self and the world encompasses the relation between one's self and one's body. In his *Sixth Meditation*, Descartes argues that one's self is not located in one's body as a pilot within a ship, but instead is "very closely joined" and "intermingled" with it, so that the two "form a unit" (Descartes 1988, p.116). On Descartes's view, the mind and body interact in ways that make the two of them function as if they were one. For Descartes, the self and body are two separate entities.

Under Descartes account, although the mind or soul cannot be localized into a specific part of the body, the causal connection between the two substances functions through the brain, and specifically in the pineal gland. For Descartes, the pineal gland is a possible place for a channel between the brain and soul since it is in the centre of the brain, which makes it ideal for controlling sensorimotor functions. For Descartes there is a two-way causal interaction between the soul and brain:

> the fluids in the brain ventricles mediate the messages between the body, brain, and the soul. Vibrations of the pineal were believed to be transformed into vibrations of the fluids in the third ventricle, which were then conducted to the muscles as commands to move the extremities. Nerves were believed to be hollow tubes…that mediate distance causal effects to the muscles through changes of hydraulic pressure in the nerves. Stimulation of the sensory nerves…was believed to be conducted to the brain, to be

> transformed into vibration of the fluids in the ventricles and thereby communicated to the pineal, which forwarded them to the soul. (Revonsuo, 2010, p.8)

Under Descartes' account, then, sensorimotor functions do not seem to have a role in constituting the self or soul. Instead, the two- way connection between the brain and soul seems to enable sensorimotor functions.

Personal Identity

Personal identity is concerned with what makes the self the same self despite psychological and physical changes that a person undergoes over a lifetime. For John Locke (1632-1704), even if one does believe in souls, they are not relevant to the problem of personal identity. Moreover, if one identifies one's self with one's soul, then the same soul could be connected at different times to different bodies. Instead of identifying the self with an immaterial soul, Locke argues personal identity is a matter of consciousness, and, specifically, memory:

> For, since consciousness always accompanies thinking, and it is that which makes every one to be what he calls self, and thereby distinguishes himself from all other thinking things, in this alone consists personal identity, i.e. the sameness of a rational being: and as far as this consciousness can be extended backwards to any past action or thought, so far reaches the identity of that person; it is the same self now it was then; and it is by the same self with this present one that now reflects on it, that that action was done. The existence of a soul, therefore, is simply otiose in the context of personal identity: . .

> . I who write this am the same myself now whilst I write (whether I consist of all the same substance, material or immaterial, or no) that I was yesterday. (Locke, p.222)

What makes the self the same over time, then, is the persistence of memory.

David Hume (1711-1776) agreed with Locke that memory is important but only because it creates the illusion of selfhood. Hume argues that all that we can know derives from impressions or ideas of those experiences. For Hume:

> For my part, when I enter most intimately into what I call myself, I always stumble on some particular perception or other, of heat or cold, light or shade, love or hatred, pain or pleasure. I never can catch myself at any time with a perception, and never can observe anything but the perception. When my perceptions are remov'd for any time, as by sound sleep; so long am I insensible of myself, and may be truly said not to exist. (Hume, p.252)

For Hume, then, selves are just collections of mental states, such as memories, intentions, desires, and hopes.

Derek Parfit (1942-2017) follows Hume but defends his position by considering science fiction thought experiments. In Parfit's first thought experiment, an individual's brain is transplanted into a different body. Despite the change in body, this new individual, composed of the original individual's brain and the new body, seems to retain the original individual's personal identity. In Parfit's second thought experiment, half of an individual's brain is destroyed, but this individual's memories and character persist in the intact hemisphere. This intact hemisphere is transplanted into a new body with memories and character unchanged.

Again, Parfit argues that this new individual, with the intact hemisphere and new body, still seems to retain the original individual's personal identity (Parfit, 1986).

In Parfit's third thought experiment, both hemispheres are intact and can support the individual's mental states. Each hemisphere is transplanted separately into a new body, yielding two new individuals. For Parfit, there are three possible interpretations of this thought experiment, but none are satisfactory (Parfit, 1986). The first interpretation is that the original individual is neither of the new individuals and does not survive. The second interpretation is that the original individual survives as one of the new individuals. But if the two hemispheres are psychologically identical, then there is no principled reason to argue this. The third interpretation is that the original individual survives as both. But, Parfit argues, the two new individuals would live their own lives and become different individuals. The view that the original individual survives as both seems incorrect if these new individuals are so different. Like Hume, Parfit argues that personal identity is incoherent and that there is nothing more than our mental states that make us who we are (Parfit, 1986).

However, although there is concern about the existence of the self and personal identity, cognitive scientists and philosophers also investigate the related question of what constitutes the sense of self, one's conscious sense of personal identity in thought, body, action, and emotion. I turn to some of this research next.

The Sense of Agency and Sense of Ownership

From a phenomenological perspective, human experience has a conscious subject of experience with a sense of one's own experience from the first-person perspective—

the content of one's current field of experience (Strawson, 2004). This self intuitively pervades conscious experience and appears to be directly available to a person through introspection. Moreover, 'I' seem to be in direct contact with the self and at the same time, 'I' am the self. This contrasts with the publicly observable self, which, to others, appears as a particular human being with a complex biological and social history and name.

The minimal self is a basic, immediate, or primitive something that we are willing to call a self (Gallagher, 2000), and thus enables us to capture the most primitive sense of self. Moreover, this immediate something is self-consciousness as an immediate subject of experience and linked to the first-person perspective. The minimal self is also a non-conceptual and pre-reflective point of origin for action, experience, thought, and knowledge about what is identifiable with the pronoun 'I.' This latter aspect means we cannot make a mistake about the person to whom we are referring—an observation known as the immunity principle (Gallagher, 2000).

An important feature of the minimal self is that it is not always experienced as temporally continuous. As one researcher put it, "the minimal self describes a basic sense of self at any given moment in time, but does not yet provide a link between moments in time and thus continuity across time" (Northoff 2014, p.455). For instance, humans' flow of consciousness seems to consist of a series of unrelated selves, like a string of pearls. It is a self without history— a bare locus of consciousness, void of personality and temporal continuity (Strawson, 2004). To say that what underlies the sense of self is a minimal self that does not contribute to personal identity may seem counterintuitive since one's self seems unified and continuously present. But, it does not seem to be the case that being continuously present is a

necessary condition for all features that constitute the self. Further, either having one continuous self or a series of unrelated selves seems to get the same effect— the feeling of a sense of self.

Recent research on the sensorimotor basis of the minimal self distinguishes two key aspects: the sense of agency and sense of ownership (Gallagher, 2000). The sense of ownership is the awareness that I am the one who is undergoing an experience (Cebolla et al. 2016). The sense of ownership depends on an accurate integration of continuously changing body-related multisensory information (Gallagher, 2000). Multisensory integration of bodily signals refers to the brain's capacity to combine information from different sensory modalities to provide stable and coherent perception of the body and its surrounding. Sensory inputs are weighed and integrated based on their reliability, and a source of sensory input which varies the least is the most reliable source of information (Holmes and Spence, 2005). Typically, vision is the most reliable source of information due to its high spatial resolution.

The sense of agency is the awareness that I am the one who is the initiator or source of the action (Cebolla et al. 2016). The sense of agency enables individuals to distinguish self-generated actions from actions produced by another agent. The most basic sense of agency originates from sensorimotor processes, since it depends on a causal link between an action and the sensory consequences of that action (Synofzik et al, 2008).

The sense of ownership and the sense of agency are first-order, phenomenological (nonconceptual) aspects of experience, pre-reflectively implicit in action. In normal experience of voluntary or willed action, sense of agency and sense of ownership coincide and are

indistinguishable. In the case of involuntary movement, however, it is possible to distinguish these two senses (Gallagher, 2000). The growing consensus on this division between sense of agency and sense of ownership is that the sense of agency for action is based on that which precedes action and translates intention into action, while sense of ownership for motor action can be explained in terms of ecological self-awareness built into movement and perception (Gallagher, 2000).

There are two approaches to explain the existence of the sense of agency and ownership, and both include two "different forms of bodily self-representation: feeling (perceptual representation of body) and judgment (propositional representation of the body)" (Balconi 2010, p.176). The bottom-up approach requires higher-order conceptually informed attributions of ownership and agency to be dependent on first-order experiences. The attribution of ownership is the reflective ascription of a certain action to myself. The attribution of agency is the reflective ascription that I am the cause or author of a certain action. This approach starts at the level of experience and two separable modalities of experience: a sense of ownership and a sense of agency (Gallagher, 2000).

In contrast, the top-down approach requires that the sense occurs only if there is the attribution. For instance, an individual's sense of agency depends on whether they attribute a specific action to themselves. This approach requires a higher-order distinction where ownership and agency should be primarily thought of as attributions based on a reflective acknowledgment (Stephens and Graham, 1994).

Embodiment

Embodiment is important for the conscious experience of the self. It requires body ownership (the experience of owning my body), self-location (the experience of where 'I' am in space), and first-person perspective (the experience from where 'I' perceive the world) (Blanke and Metzinger, 2009). It involves the ability to pay attention to ourselves, to feel our sensations and movements, in the present moment, without the mediating influence of judgmental thoughts. Embodiment is part of embodied self-awareness—the centering of our subjective experience in our physical bodies—that senses that our body belongs to us and to no one else. Embodied self-awareness is different than conceptual self-awareness or thinking about oneself (Table 1).

Embodiment has a role in how humans perceive themselves from a first-person visual perspective and third-person visual perspective (Jenkinson et al, 2013). In contrast to viewing the body directly from a first-person visual perspective, perceiving the body in a mirror creates visual feedback of ourselves from a third-person perspective (Vogeley & Fink, 2003). In humans, embodiment and the sense of agency enables self-recognition. For instance, to recognise oneself in a mirror requires one to recognise the equivalence between the movement of the image and the movement of one's body (Povinelli, 2001). One must recognise that what is true of one's body is also true of one's mirror image. This would be done by comparing movement of one's body to that of the mirror image (Povinelli, p. 84–85). The subject must also recognise that the body that moves is his own, that it is the body he is bounded in, and the movements

that he controls are reflected in the mirror (Carruthers, 2007). Both the sense of ownership and embodiment, then, have a role in self-recognition.

Table 1: Two Kinds of Self-Awareness

Conceptual Self-Awareness	Embodied Self-Awareness
Based in linguistic and symbolic forms of expressions	Based in sensing, feeling, and acting
Rational, logical, explanatory	Spontaneous, creative, open to change
Abstract, transcends the present moment	Concrete, lived in the present moment

Source: Varela, Thompson, and Rosch (1991)

Researchers study embodiment by studying how the brain represents the body and how this representation is altered under certain neurological conditions (Lenggenhager et al. 2006; Metzinger, 2009). When embodied self-awareness is disrupted, the body is brought to the foreground of consciousness and one realizes the complexity and the richness of the experience of one's body. This is disembodiment or the feeling of being detached from oneself and one's actions, as if in a third-person perspective or without any perspective at all. For example, vestibular disorder patients, individuals with a discrepancy between vestibular and other body-related signals, experience deficiencies in how the brain represents the body since their sensory input has been compromised. This disunity of self and body creates the feeling and thought of disembodiment. In one study, Grigsby and Johnston (1989) collected depersonalization experiences in vestibular disorder patients. Within this data, one patient described depersonalization as "a sense of unreality" and claimed "I feel like I'm outside of myself. I feel like I'm not in myself" (p. 531). Another patient reported "I am not actually being there or

having anything to do with my body" (p. 532). Three aspects mark depersonalization: a feeling of disturbed bodily subjectivity; a diminishment of affective feeling; and a corresponding and overarching sense of unreality, which carries with it a sense of estrangement or alienation (Sierra, 2009). The result is a deterioration of the experience of the body and surroundings.

Theories of Bodily Awareness

There are two main approaches to first-personal bodily awareness: the representationalist approach and the sensorimotor approach. A major difference between these approaches is that whereas the representationalist approach is mainly anchored in analytic philosophy and posits mental representation(s) of the body for the core of bodily awareness, the sensorimotor approach is mainly anchored in the phenomenological tradition and highlights the importance of interacting with the world.

Sources of Bodily Awareness

Humans perceive their bodies not only from the outside, such as looking at one's arm, but also from the inside, such as proprioceptive awareness of one's arm being raised. This distinction is often reduced to the dichotomy between external senses and body senses, which include touch, proprioception, and the vestibular, nociceptive and interoceptive systems (Blanke, 2012). Cutaneous mechanoreceptors mediate touch by carrying information both about the external world and about the body. Proprioception provides information about the position and movement of the body. The vestibular system provides information about the balance of the body. Nociceptors respond to intense mechanical stimuli, to mechanothermal

stimuli or to thermal and chemical stimuli. Interoception provides information about the physiological condition of the body to maintain optimal homeostasis.

At the cortical level, tactile, proprioceptive, and nociceptive signals are processed in the primary and secondary somatosensory cortex. Wilder Penfield and Edwin Boldrey found that the sensorimotor cortex is topographically organized—areas of the body map onto cortex areas, resulting in an anatomical reconstruction of the human body in the brain (Penfield and Boldrey, 1937). The primary somatosensory area does not represent the anatomical contiguity of body parts. For instance, the hand area is next to the face area. Additionally, some body parts are over-represented, whereas others are under-represented. For instance, a relatively large cortical area responds to hand-related signals and a relatively small cortical area responds to torso-related signals. The size of the brain's representation is proportional to the sensitivity in the primary somatosensory cortex and dexterity in the primary motor cortex of the represented area. For instance, the somatosensory representation of the thumb is as large as the leg since the skin on the thumb is densely populated by cutaneous receptors, creating a high degree of sensitivity and large cortical representation (Penfield and Boldrey, 1937).

The problem with this view, however, is that these representations are mostly only through touch or sensations on the skin. Although these representations allow humans to feel their bodies and move through space, they are insufficient to describe the maps of bodily representation. Instead, the stronger embodiment mechanisms are in the posterior parietal cortex, which integrates the body senses. For instance, body representation and embodiment do not only include the body space but also the area immediately around the body, such as close visual stimuli and close sounds which are massively integrated (Blanke and Metzinger,

2009). Moreover, bodily representation involves integration of self-related signals across visual, auditory, somatosensory, vestibular and interoceptive domains underlie the feeling of being a self in normal conscious experience.

Representationalist Theory of Bodily Awareness

Proponents of the representationalist approach claim that to account for bodily awareness one needs to appeal to representations of the body, which are internal structures that have the function to track the state of the body and encode it, that can misrepresent it, and that can be decoupled from it. There are at least two main models of bodily representation. One is a dual model of body representation distinguishing the body image and the body schema (Gallagher and Cole 1995; Dijkerman and De Haan 2007), or short-term and long-term body representations (Carruthers 2008). The second is triadic model of body representation that makes a distinction between a visuo-spatial body map and body semantics within the body image, in addition to the body schema (Schwoebel and Coslett 2005).

The current most commonly used classification between different body representations is that of body schema and body image. Although there is no consensus among researchers of their definitions, body schema is generally regarded as an unconscious, bottom-up, dynamic representation, relying on proprioceptive information from the muscles, joints, and skin. It is thought to be used to govern posture and motor actions. On the other hand, the body image is a more conscious, top down, cognitive representation, incorporating semantic knowledge of the body, and mostly used to make perceptual judgements (Paillard, 1999). Moreover, body image "refers to a conscious, essentially visual, representation of the body in its canonical

position and, with the sort of structural and semantic detail that is familiar from seeing oneself in the mirror" (Longo et al. 2008, p.1181-1182). For instance, biological sex can refer to the body image. The sex organs, however, are also represented in the body schema.

Moreover, neuropsychological studies have provided evidence for the dissociation between at least two body representations: one which is used during motor action, or body schema, and one underlying perceptual judgement, or body image. This dissociation is largely based on neurological patients with numbsense who are unable to perceive proprioceptive and tactile stimuli but are nevertheless able to point to these targets (Paillard, 1999), and patients with autotopagnosia who are impaired in localizing perceptually different body parts, but remain able to guide their actions (Buxbaum & Coslett, 2001).

Under the dual model of body representation, there are two main taxonomies: the temporal dyadic and functional dyadic. The temporal dyadic taxonomy (O'Shaughnessy, 1980; Carruthers, 2008) is based on the dynamics of body representations. One can contrast the representation of long-term bodily properties, such as limb size and the representation of short-term bodily properties, such as limb posture. Long-term body representations are relatively stable. They may include some innate components that carry information about the structure of the human body, such as having two arms. On the other hand, short-term body representations are constantly updated based on afferent and efferent information.

The functional dyadic taxonomy (Paillard, 1999; Dijkerman and de Haan, 2007; Vignemont, 2010) is based on the functional role played by each body representations. The underlying assumption is that the way one uses information about the body determines the

way the information is encoded. Under this approach, the body schema is used for action planning and action control. It consists in sensorimotor representations of bodily properties that are relevant for action. On the other hand, the body image groups all the other representations about the body that are not used for action, whether they are perceptual, conceptual, or emotional (Gallagher, 1995). For instance, changes in one's physical bodily structure occurs during development and because of diet, exercise, or trauma. Body representation thus requires some degree of plasticity so that changes in actual bodily form can be mirrored by corresponding changes in both the brain's maps of somatosensory inputs and in the conscious body image.

These models of body representations, however, encounter a conceptual problem when tested experimentally. The distinctions between body representations are often made on a single dimension, such as temporal dynamicity (O'Shaughnessy 1995) or functional role (Paillard 1999). Depending on the criterion, different distinctions are possible, leading to widespread confusion (de Vignemont 2007). Even more importantly, there are more dimensions on which body representations can be dissociated than the ones highlighted above. For example, the body schema probably includes short-term information (e.g., body posture) as well as long-term information (e.g., the size of the limbs).

Another problem is the nature of the evidence that current models of body representations rely upon. Since there is disagreement on the number and definitions of body representations, there is also disagreement on the classification of bodily disorders. Moreover, these taxonomies result in opposite interpretations of the same bodily disorders. For instance, personal neglect, the lack of exploration of half of the body, has been interpreted as resulting

from a deficit of body schema (Coslett, 1998) and from a deficit of body image (Gallagher, 1995). Furthermore, although most taxonomies rely on neuropsychological dissociations, it does not seem likely that they can account for all bodily disorders.

Sensorimotor Theory of Bodily Awareness

Under the sensorimotor approach, instead of mental and cognitive representations of the body and outside world, the main feature of bodily awareness is actively interacting with the world. For Maurice Merleau-Ponty (1908-1961), there are three main claims to the sensorimotor approach: the body is not an object that can be represented, the presence of the body is the presence of the body in the world, and the body we experience is the body in action (Merleau-Ponty, 1962).

Merleau-Ponty is concerned with characterizing agency and bodily awareness from the perspective of the experiencing subject, which is primarily a living body. For Merleau-Ponty, there is a discontinuity between experienced spatiality of the physical world or the objective body, and the experienced spatiality of the body humans experience from the inside or the lived body. The objective body is the body made of muscles, bones, and nerves, whereas the lived body is the body that humans experience in pre-reflective awareness. Merleau-Ponty argues that the lived body is not an object that can be perceived from various perspectives or localized in objective space. Instead, the lived body is the site of the first-person perspective, the manifestation of the minimal self.

In effect, one's experience is enabled and structured through a body that is always there, and hence the body is not just part of the physical world, but also the vehicle that

enables being a self in this world (Merleau-Ponty, 1962). One's self is not merely embodied, but bodily: "But I am not in front of my body, I am in my body, or rather I am my body" (Merleau-Ponty 1962, p. 150). Merleau-Ponty, however, does not argue that the self is a complex physical object. Instead, the self is a bodily or physical subject. Merleau-Ponty, then, rejects the traditional relation of mind and body and the ontologies of dualism, materialism, and idealism.

Under the sensorimotor approach, then, humans are "sensorimotor beings [and] the environment that emerges…is a sensorimotor world of perception, action, and emotional significance" (Maisse 2010, p.19). The lived world presents itself as a field of certain possibilities, opportunities, or obstacles. The lived body lets humans interact with the world via perception and action since it is a space of actions endowed with ways of existing towards objects. The self's role, then, is to navigate the world and this is partly due to sensorimotor functions that allow one to engage and experience one's surroundings.

Sensorimotor Theory and Body Schema and Image

Merleau-Ponty introduces body image to explain the dynamic of motility (Merleau-Ponty, 1962). Moreover, Merleau-Ponty argues that through body image humans get a total awareness of their position in the inter-sensory world. Our body-image or body-space is to be understood as a background to our practical capacity to organize our bodily movements. On the other hand, Merleau-Ponty argues that the body schema is our primary way of being in the world is not reflexive or intellectual but bodily. The body provides sensorimotor functions, and how they relate and link us to the world. Since we operate in the world using sensorimotor functions, we are always connected to the environment as a being-in-the-world. The body's

sensorimotor functions, then, have an imperative role in being a being-in-the-world since they allow humans to perceive the world through sensory functions and act upon the world using motor functions.

Current phenomenology also articulates the difference between body schema and body image on two points: "1. The body schema consists of (mostly) non-conscious processes that regulate posture and movement. The body image, on the other hand, is a (conscious) representation of the own body. It consists of perceptual, cognitive and/or emotional representations. 2. The body schema refers to the possibility to move, the body image to the capacity to reflect" (Preester, p.259). Moreover, schemas are representations or an unconscious functional sensorimotor map of the body that provides the essential information needed to move one's own body. These sensorimotor processes unconsciously organize perception and action, so an individual can move around the world and focus their energy and attention elsewhere.

Under the sensorimotor approach, then, the body's sensorimotor functions that link the body with the environment yield and constitute the minimal self and the first-person perspective. This means that the minimal self is embodied and embedded—integrated in both body and environment. Moreover, minimal selfhood emerges from this experience of a unified, situated living body as a "sensorimotor unity anchored to its world" (Legrand, 2006). In effect, the self is a locative system, organised with parts and functions and the sense of self is conditioned by one's embodiment, physicality, and the organization of the locative system. For our purposes, then, the sensorimotor functions of the minimal self, which is attached to embodied conscious beings, partially constitutes the sense of self at the level of experience.

Summary

Section 2 has highlighted the relevant literature on the self and sense of self. Since there are numerous definitions of the self, researchers use the minimal self to empirically study its aspects—agency and ownership—to learn about embodiment and the sense of self. There are also two approaches to bodily awareness: the representational approach and sensorimotor approach and both theories relate to the body schema and body image.

In the next section, I will first describe some of the current bodily self-consciousness experiments, such as body part and whole-body. I will then detail the methods, hypothesis, procedure, and results of our new virtual reality behavioral experiment that researches the role of two aspects, sex and self-motion, on the visual representation of the self.

3. Researching the Sense of Self

To empirically investigate the sense of self, researchers use bodily self-consciousness, which is a complex mental construct linked to the strong sense that we recognize that our body belongs to us, our conscious self is housed within our physical body in a first-person perspective, and our body inhabits a specific physical location in external space (Aglioti and Candidi, 2011). Moreover, bodily self-consciousness is the feeling of being a subject in a body or awareness of the body and its link to neural body representations. The most fruitful trend in contemporary research is investigating the components of bodily self-consciousness, embodiment and the sense of agency, and their relative impairments (Blanke and Metzinger, 2009). Experiments on embodiment and the sense of agency shed light on the components and mechanisms that structure the sense of self since disembodiment and the loss of the sense of agency can lead to the disruption of the sense of self (Blanke and Metzinger 2009; see also Lopez et al 2008).

Bodily self-consciousness experiments separate three self-referential components of ordinary conscious experience or embodiment: body ownership (the experience of owning my body), self-location (the experience of where 'I' am in space), and first-person perspective (the experience from where 'I' perceive the world) (Blanke and Metzinger, 2009). Researchers have developed approaches to investigate these separate components of bodily self-consciousness by inducing bodily illusions through the presentation of conflicting sensory information regarding one's own body. These studies research healthy participants and individuals with

altered states of bodily self-consciousness by using experimental paradigms, such as virtual reality, to manipulate and control its components.

Experimental Manipulations on the Sense of Agency

Many studies have introduced a sensorimotor mismatch between action and outcome to study the sense of agency. This operationalization draws upon the forward model of motor control and the notion of efference copies as predictors of movement outcome. If a sensory event does not match the movement, or if the predicted and actual outcome do not correspond, the event is attributed to another person or source rather than to oneself (Synofzik et al 2008). For instance, in some studies, participants perform simple movements, such as finger movements (David et al, 2008), or more complex movements, such as line drawing (Nielsen, 1963), moving a joystick (Franck et al 2001), or button presses (Blakemore et al, 1998), while participants' sensory feedback is manipulated. In one experiment, a subject drew a line with a pencil, while the provided visual feedback was either the subject's own hand or the experimenter's hand, which drew a spatially deviated line (Nielsen, 1963). The subjects were unaware that they were adjusting their movements to the false feedback, but only to a certain degree of deviation, when they recognized that it was not themselves who drew the line (Nielsen, 1963). Studying bodily agency in experiments, then, is important for bodily self-consciousness research since it confirms what components and mechanisms are required for an individual to have a normal sense of self.

Experimental Manipulations of Body Ownership

Presenting conflicting multisensory information about the location and appearance of one's body or body parts can temporally modify the sense of body ownership. One major study in multisensory body representation research is the Rubber Hand Illusion (RHI), which puts into conflict that when humans see and feel the touch in a certain position it should come from the same position in space (Ehrsson et al. 2005). In this illusion, this is not the case. The maps are activated on the vision of the rubber hand, but participants feel the strokes on the actual hand. Since these integration maps cannot work properly, the brain dissociates these two senses.

The RHI critically depends on synchronous stroking of the hands. To induce the illusion, one researcher strokes the middle finger of the participant's real hand while simultaneously strokes the same finger on the rubber hand. In combining the visual information with the touch sensations, the brain mistakenly concludes that the rubber hand must be part of the person's body. Synchronous touches onto a visible rubber hand and onto the hidden participants' hand produce the compelling feeling of ownership of the fake hand.

The illusion is induced due to the dominant role of vision over the proprioceptive signals, and results in the self-attribution of the rubber hand and referral of touch to the rubber hand. The illusion, however, breaks down when there is ~200ms synchrony between brushes occurs (Ehrsson et al. 2005). This experiment suggests that self-recognition depends in part on one's sense of what is one's body, a component of the sense of embodiment. This experiment also shows the pivotal role played by multisensory mechanisms in body representation since multisensory stimulation induces a sense of ownership over a fake limb.

Different studies on RHI also suggest that multisensory integration is the crucial mechanism for the experience of our body as our own. For instance, multiple versions of the RHI have examined how different physical and spatial features of the rubber hand influence the illusion. While the similarity of physical features of an embodied artificial limb and the real limb does aid self-attribution, subjects are able to embody limbs with different physical features. For instance, it has been shown that color does not determine embodiment of an artificial limb (Longo et al. 2009). Regarding size, it has been shown that a rubber hand larger than one's real hand (Pavani and Zampini, 2007) and longer arms (Kilteni et al., 2012) can be embodied by subjects. Other researchers found that the illusion could be induced in the mirror, and with no difference in the strength of the illusion when viewing the rubber hand directly or in the mirror (Jenkinson et al, 2013). It is likely that, given our life-long exposure to mirrors, mirror-based visual information about the body can be readily transformed to egocentric coordinates and combined with other bodily signals in personal and peripersonal space (Jenkinson et al, 2013).

The self, however, is experienced as a single, coherent whole-body representation rather than as multiple representations of separate body parts. Although the RHI paradigm has accumulated important knowledge about the brain mechanisms underlying the sense of body ownership, induction of the full body illusions has shown to be important to investigate global bodily self-consciousness. Studies on the RHI thus investigate only body part ownership or the attribution and localization of a body part with respect to the global bodily self, that is, a part-to-whole relationship. Accordingly, these studies did not investigate global bodily self-consciousness, namely localization and attribution of the whole-body to which the selected body part is attributed (Lopez et al. 2008). The aspects of global ownership, self-location, and

first-person perspective are central to the representation of the self as an unitary and coherent whole and not only a sum of body parts.

Body Ownership and Clinical Conditions

The partial or global sense of body ownership may be disturbed in various neurological conditions (Critchley, 1950). Disturbances affecting the partial sense of body ownership can be observed in patients suffering from somatoparaphrenia. These patients manifest the delusion of disowning their left-sided body parts, most often their hand and arm due to the brain damage of the right parieto-temporal and insular regions (Vallar and Ronchi, 2009). Disturbances affecting the global sense of body ownership can be observed in autoscopic phenomena—illusory own body perceptions that affect the whole body, such as autoscopic hallucination and out-of-body experiences (Blanke and Mohr, 2005). In autoscopic hallucination, patients see their own body in extrapersonal space, as in a mirror, but they perceive themselves to be located within their physical body. The sense of self-location and first-person perspective, then, remain intact.

Patients suffering from out-of-body experiences of neurological origin experience themselves as located outside their own bodily boundaries, and report looking at their real body from an elevated perspective in extrapersonal space or abnormal first-person perspective (Irwin, 1985; Blanke et al. 2004). In out-of-body experiences, there is extracorporeal self-location or disembodiment since the individual is localized outside their body; there is extracorporeal first-person perspective since they perceive their body from a disembodied

perspective; and there is self-identification with the elevated body. This is the key distortion to an out-of-body experience, since the self is not experienced within the usual body.

Investigations into the neural correlates of out-of-body experiences provide insights on the multisensory nature of self-consciousness and the loss of a sense of self. For instance, in out-of-body experiences, self-location and first-person perspectives are abnormal in neurological patients and can be manipulated experimentally in healthy subjects by imposing multi-sensory conflicts. These components rely on the multisensory integration of spatiotemporally congruent exteroceptive (mainly visual), somatosensory (tactile and proprioceptive), interoceptive and vestibular signals. Clinical studies showed that out-of-body experiences are linked to dysfunctions of the temporo-parietal junction (Blanke et al. 2004; Blanke and Mohr, 2005). Furthermore, electrical stimulation of the TPJ induces similar experiences to out-of-body experiences (Penfield, 1955; De Ridder et al. 2007). Based on these findings, an association between TPJ dysfunction and out-of-body experiences has been proposed (Blanke and Mohr, 2005; De Ridder et al. 2007). Studying bodily ownership in certain clinical conditions, then, is important for bodily self-consciousness research since it confirms what components and mechanisms are required for an individual to have a normal sense of self.

Experimental Manipulations of Body Ownership: Whole-Body and Virtual Reality

Advances in virtual reality systems, together with the reduction in cost of associated equipment, have led scientists to consider virtual reality as a useful tool for conducting experimental studies in fields such as neuroscience and experimental psychology. In virtual

reality, it is possible to replace the participant's body with a virtual body seen from a first-person perspective and third person perspective, enabling a wide variety of experiments concerned with how the brain represents the body (Blanke, 2012) that could not be realized without virtual reality. The third person perspective is similar to looking at oneself in a mirror but different from the first-person perspective, which places the user inside the body of the avatar, which are virtual simulated characters that can act as a visual representation of the self. This mirror view of the body is subject to several unusual properties (Gregory, 1997), one being that the mirror image is left-right reversed, such that the left side of the body is located on the left side of the mirror space. In addition, the image of the body is observed in a location that is distant to the physical location of the body.

Virtual reality aims to produce the authentic experience of being present in an artificial environment termed "presence", which is the feeling of being there (Grimshaw, 2014). The basic function of presence is to allow individuals to differentiate between the internal (the self) and the external (the world). Moreover, presence produces a "sense of agency and control: subjects are "present" if they feel themselves able to enact their intentions in an external world" (Grimshaw 2014, p.206). Self-presence, then, is a psychological state in which virtual selves are experienced as the self in either sensory or non-sensory ways. Moreover, it is the feeling that not only is one's avatar a mechanism to interact with the virtual environment, but also an extension of the self.

In one virtual reality whole-body illusion, the bodily self is projected to a virtual avatar (Blanke and Metzinger, 2009). This is like the RHI, but instead of having a visual stimulus on the hand at a different location, researchers displaced the touch of the back on the touch on the

back of the avatar. The participant feels the touch on their back and sees the touch on the avatar's back. The result of this experiment found that synchronous stroking produces a strong illusion—the participant displaces their perceptions from their body to a different position in space, the avatar. If there is a delay between the two, this illusion will not work.

This suggests that participants can identify with their avatar and that one's center of awareness can be shifted into the direction of the avatar. Moreover, after this whole-body experiment participants were asked to estimate where they themselves were in the room and all participants made a systematic error forward, toward their virtual selves (Blanke and Metzinger, 2009). This suggests that there is dominance of the visual embodiment mechanism over the touch mechanism. This illusion is more than self-projection. It is not just a projection from the participant into the space or into the avatar, but a bi-directional change—there is also an impact of what they see on their body representation**.** Studying bodily ownership in virtual reality, then, is important for bodily self-consciousness research since it confirms what components and mechanisms are required for an individual to have a normal sense of self.

These studies show that body representation can flexibly incorporate body parts and whole bodies that are very different from an individual's own body, even when this incorporation conflicts dramatically with stored knowledge about the body. These findings suggest that some form of "body model" serves as a perceptual filter, allowing certain types of stimuli to become incorporated while filtering out others. Although individuals know what their own bodies are like, the limits of bodily awareness appear to be set by a categorical representation of what human bodies are like in general. However, studies have found there are limitations, such as a rubber hand smaller in size than an individual's real hand is not

embodied (Pavani and Zampini, 2007). That the smaller size of the rubber hand did not induce embodiment means that there are limitations to body plasticity.

The SOSVR Experiment

The aim of the experiment was to research whether self-motion and anatomical characteristics, such as biological sex, have a role in the visual representation of the self. To do this, I used virtual reality and two virtual avatars, which participants viewed from the third person perspective. The experiment assessed the role of biological sex and self-motion by presenting participants with pairs of avatars that visually represent their self, or another person. The avatar of the same sex was named the *self avatar*, while the avatar of the opposite sex was named the *opposite avatar*. These avatars also visually represent their self with coupled motion, and another person with decoupled motion, meaning the idle motion of an avatar that is swaying slightly from side to side. The opposite avatar was used to assess the role of the visual attributes of sex and motion. By manipulating sex and motion, I tested whether these aspects may have some role in how individuals perceive their self.

Hypothesis

I hypothesized that there would be a stronger consensus towards participants selecting the self avatar with normal motion when paired with the opposite avatar with decoupled motion than selecting the self avatar with decoupled motion when paired with an opposite avatar with normal motion. I made this hypothesis since self avatars and normal motion represent the normal functioning of the body image and body schema of the individual. If this is correct, then, participants should choose certain avatar pairing over others.

The visual representation of the self is important for one's sense of self, since without it individuals will lose some degree of their sense of self. For instance, when individuals visualize themselves as a different sex, they likely will not associate or identify themselves to this avatar. Similarly, when individuals are not able to self-recognize their movements to the movements of an avatar, they will likely not self-recognize themselves to this avatar. Avatars with decoupled motion or of the opposite sex, then, may not be visually represented as the participant's self.

Procedure

The SOSVR experiment was approved by the University of Waterloo's Research Ethics Committee, which complies with the Declaration of Helsinki. In the first stage of the experiment, nine Korean participants, aged 24-54 years old, were welcomed and instructed on the overall process of the study. Participants were then instructed to create a computer-generated avatar of the same sex that most represents their self using Adobe Fuse Creative Cloud. This program has numerous available body parts for participants to choose from. I also had mirrors available for participants to adequately choose the corresponding body part in the program.

The participant made their own virtual avatar of the same sex (self avatar), while a researcher created a virtual avatar of the opposite sex, matching the exact body, arms, legs, and face shape chosen for the self avatar (opposite avatar). The clothing used on the opposite avatar was also chosen to match the self avatar (Figure 1). This was done since resemblance of the avatar body to a human body improves embodiment into the avatar (Maselli and Slater, 2013), and the feeling of presence in the virtual world (Eastin, 2006).

Additionally, although participants created their self avatar, this does not necessarily mean that they identified more with this customized avatar than the opposite avatars researchers created. Although virtual reality users have been shown to feel more connected and identify with an avatar that they created (Lim and Reeves, 2009), it has also been shown users identify with human-looking avatars even when they present different visual characteristics than their real selves. For instance, ownership can be induced over a body of a different race, age, or gender (Petkova and Ehrsson, 2008; Maister et al. 2014).

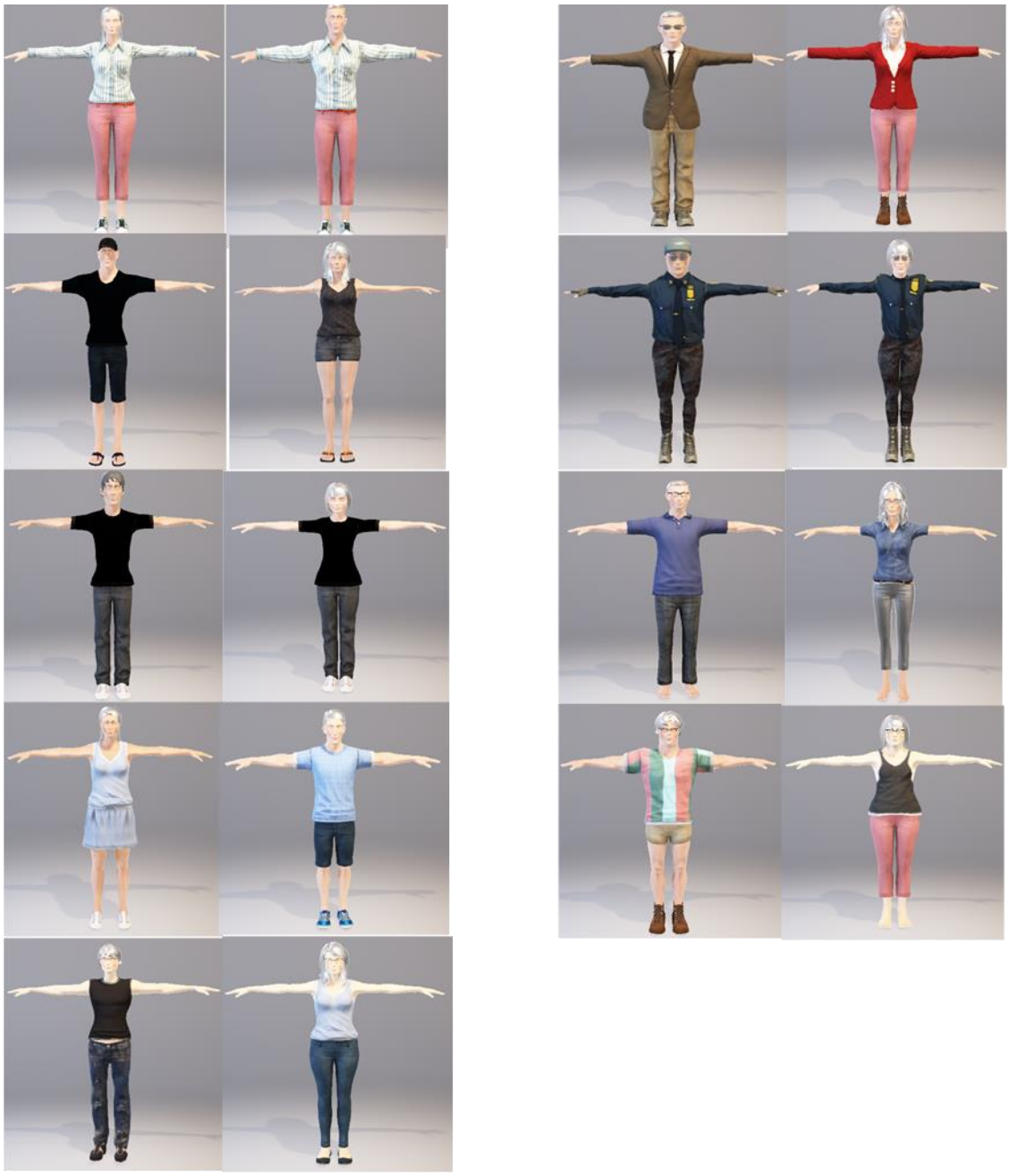

Figure 1: Nine Self Avatars Created by Participants (Left Side) and Nine Opposite Avatars Created by Researchers (Right Side)

During the experiment, the participant was fitted with the VIVE virtual reality head mounted display (VRHMD). The VIVE VRHMD had the LEAP motion capture device mounted to the front to capture movement of the participants' hands. The Microsoft Kinnect motion capture device was used to capture movement of the participants' whole-body motion, while the LEAP motion was used to track the hands.

The experiment had eight trial conditions, which mixed avatar type and motion to the left and right avatar (Table 2). Each condition was tested ten times for a total of eighty trials. On each trial, the participant was exposed to a realistic visual scene with 3D depth information that depicted the self avatar alongside either a self avatar or an opposite avatar, or two opposite avatars. Self motion was manipulated by assigning one of the avatars to have normal motion, like the participant's movement using motion tracking, or alternatively, by adding different motion to participant movement to present realistic but decoupled motion. This means that the motion of the avatar was normal to the participant's motion or decoupled—the idle motion of an avatar that is swaying slightly from side to side.

Table 2: Experimental Conditions

Condition	Left Avatar	Right Avatar	Left Motion	Right Motion
1	"self"	"self"	normal	Decoupled
2	"self"	"self"	Decoupled	normal
3	"other"	"other"	normal	Decoupled
4	"other"	"other"	Decoupled	normal
5	"self"	"other"	normal	Decoupled
6	"self"	"other"	Decoupled	normal
7	"other"	"self"	normal	decoupled
8	"other"	"self"	Decoupled	normal

Participants were encouraged to move around for up to ten seconds and attend to both avatars. At the end of each trial the participant was prompted by the VRHMD to answer the question "Which of the two avatars represents your self most, left or right?". Participants indicated their response by raising their arm and touching the index finger to the thumb of the same side of the avatar representing their self. During and after the experiment, participants were asked to report how they felt on a scale of one to twenty, with twenty being the highest sickness intensity. None of the participants reported a sickness score higher than five from using the virtual reality equipment.

Results

For each of the eight cells in the experimental design, participant response was averaged across all trials, creating a calculated scaled measure of sense of self. This calculated measure was then analyzed using Bayesian paired t-tests, to accommodate outliers.

As Bayesian estimation for two groups can handle outliers by describing the data as heavy tailed distributions instead of normal distributions (Kass and Raftery, 1995), we performed a Bayesian paired t-test on the data between the self vs opposite avatar conditions (normal motion vs decoupled motion applied to the self avatar) using JASP v0.8.0.1. Here Bayes Factors (BF) provide a numerical value that quantifies how well a hypothesis (H1; self avatar with normal motion more likely than self avatar with decoupled motion) predicts the data relative to a competing null hypothesis (H0; no difference in likelihoods across conditions), where a BF10 between 0 and 1, indicates support for the H0, and a BF10 greater than 1 indicates support for the H1.

Our results show support for the alternative hypothesis (H1) that despite an outlier participant being included, the average likelihood of selecting the self avatar with normal motion when paired with the opposite avatar with decoupled motion was higher than selecting the self avatar with decoupled motion when paired with an opposite avatar with normal motion (BF10 = 1.547; default Cauchy prior width = 0.707). A traditional t-test does not find a difference between these last two conditions. However, it is close with an outlier in the second last position. Using a Bayesian t-test that can handle outliers we find that there is more support for there being a difference between these last two conditions than there is not.

Discussion

The results of the experiment are shown in Figure 2. When comparing the self avatar with normal motion versus the self avatar with decoupled motion, participants were at chance (i.e., 50%) when identifying which of the two avatars most represented themselves. This suggests that changes in self-motion introduced in the experiment did not affect the sense of self when using the self avatar only.

When participants viewed two opposite avatars, where one had normal motion and the other with decoupled motion, participants were above chance at identifying with the avatar with normal motion over the avatar with decoupled motion. This suggests that the sense of self is affected by change in self-motion, but only when the visual representation of the body is different from the true self.

When comparing the self avatar with the opposite avatar, participants are much more likely to select their self avatar over the opposite avatar, when normal motion is applied to the

self avatar. This suggests that participants identify more with the avatar when correct sex and motion are paired together.

When normal motion is applied to the opposite avatar when paired with the self avatar with decoupled motion, participants go back to chance. This shows that sex and self-motion both have a role in this condition. If participants only used normal motion, then they would go with the opposite avatar. If they only go with sex, then they would pick their self avatar. But because they are at chance, the results show, by also using the results from the other conditions, that sex and normal motion both affect the visual representation of the self.

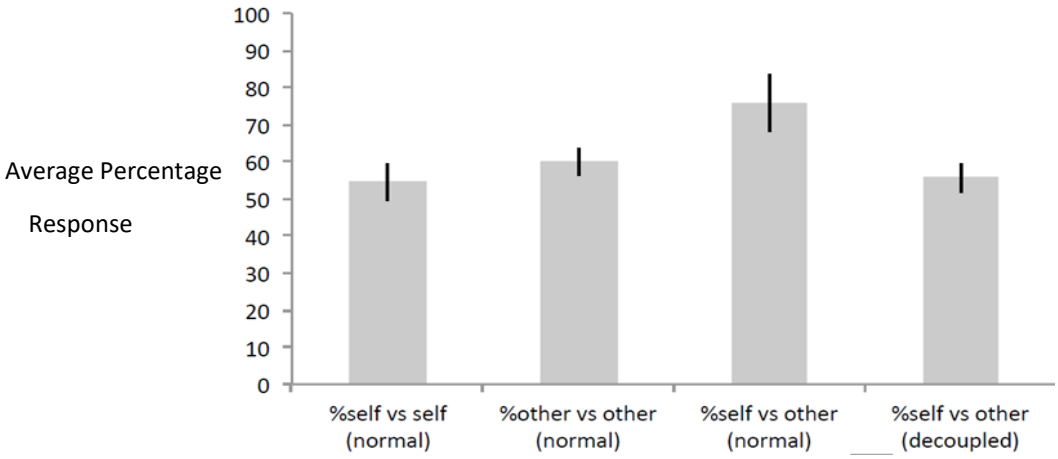

Figure 2: Average Percentage Response According to Each Category Listed on the X Axis

4. Conclusion

What constitutes the sense of self? The purpose of this experiment was to research whether self-motion and biological sex are important attributes to the visual representation of the self. The results of the experiment suggest that both are important attributes to the visual representation of the self. When applied to my experiment, the sense of ownership and agency predict that when individuals perceive an opposite avatar or decoupled motion, this different visual representation of the self may have some negative effect on one's conscious sense of personal identity in thought, motion, body, and emotion. When individuals do not have a coherent perception of themselves through time, individuals' sense of self may be disrupted.

The sense of agency is the sense of being the one who is causing an action or generating a thought, including the sense of being in control over own movements and thoughts (Blanke and Metzinger, 2009). It enables individuals to distinguish the actions that has been self-generated from those that have been produced by another agent. In my experiment, if the participants noticed the decoupled motion of the avatar, this would possibly lead to these participants having a loss of the sense of agency and attributing the avatar to an external agent and not the self. However, this prediction was inconsistent in some trials, such as when comparing the self avatar with normal motion and the self avatar with decoupled motion. This trial suggests that changes in self-motion did not affect the sense of self when using the self avatar only.

The sense of ownership is the experience that the body and bodily sensations belong to the individual and depends on an accurate integration of continuously changing body-related

multisensory information (Gallagher, 2000). Presenting conflicting multisensory information about the location or appearance of one's body or body parts can temporally modify the sense of ownership. In my experiment, the sense of ownership seems to predict that when participants view an opposite avatar, that these participants will attribute this avatar to an external agent and not the self. This prediction seems to be consistent in the experiment since most of the trails confirmed it. The trial that could not confirm this prediction, which was not an inconsistency with the predication, was when two opposite avatars were being compared.

However, previous studies show that body representation can flexibly incorporate body parts and whole bodies that are very different from an individual's own body, even when this incorporation conflicts dramatically with stored knowledge about the body. These findings suggest that some form of "body model" serves as a perceptual filter, allowing certain types of stimuli to become incorporated while filtering out others. Although individuals know what their own bodies are like, the limits of bodily awareness appear to be set by a categorical representation of what human bodies are like in general. This predicts that the opposite avatar will be attributed as the self. However, this prediction is inconsistent with some results, such as when the opposite avatar with normal motion is paired with the self avatar with decoupled motion, participants are at chance. If both sexes are attributed to the self, then the opposite avatar with normal motion should have been chosen.

In the next two sections, I will discuss how the results of this experiment relate to both bodily awareness theories.

Representation Theory of Bodily Awareness

Under the representational approach, due to different interpretations of body image and body schema, sex and motion may or may not be based on different underlying body representations. If sex and motion were based on different body representations, then, they would be differentially sensitive to the trials. Moreover, if both sex and motion were based on a single body representation, then the results should be highly correlated. But, as the results show, there is not always a correlation between sex and motion suggesting that these two aspects have different body representations. In fact, sex is part of the body image and schema. Although the experiment may not provide definitive evidence, it is consistent with the idea of dissociable underlying body representations for action and sex. Moreover, the results of the current study are consistent with the idea of a dissociation between at least two body representations, one used for action and one for perceptual judgements. Despite these results, the question concerning the nature of the two body representations remains.

Sensorimotor Theory of Bodily Awareness

Under the sensorimotor theory, perception is the activity of exploring the environment. Perceptual experience has two phenomenal features. First, sensory information changes as soon as one performs movement. This property, called “bodiliness” (O’Regan et al. 2005), explains the intimate quality of perceptual experience since sensory information is sensitive to body motions. The second feature is “grabbiness” (O’Regan et al. 2005), which consists of fast attention when there are sudden changes in the stimulation. A change in the visual field triggers a movement of the eye so that the fovea becomes lined up to the location of the

change. Thus, a visual variation is immediately recognized and analyzed. Grabbiness, then, makes all parts of the visual field very vivid and present—intimately related to us.

Under this theory, the brain perceives an entity as one's body part or whole-body if physical properties are sufficient to allow certain actions associated to that limb or full body. This claim is supported by some bodily self-consciousness studies, which illustrate that physical features are important to having a sense of self, and the transfer of embodiment and ownership to a body part or whole-body. In what follows, some of these studies will be related to the sensorimotor theory with its focus on sensorimotor functions.

The RHI is possible with rubber hands of different color (Longo et al. 2009), texture (Haans et al. 2008), and gender since these features do not directly affect the limb's proper functions. On the other hand, a wooden stick (Tsakiris and Haggard, 2005) or wooden slab (Guterstam et al. 2013) make functions impossible and as a result are likely not attributed as one's arm. Moreover, multiple rubber hands can be embodied at one time (Ehrsson, 2009) since it does not deteriorate hand functionality. Moreover, embodiment of limbs is also less sensitive to longer artificial arms (Kilteni et al., 2012) and larger rubber hands (Pavani and Zampini, 2007) since functionality is maintained. On the other hand, smaller rubber hands (Pavani and Zampini, 2007) do not keep functionality since the hands are to small to adequately perform tasks. Additionally, a cuboid with no limbs will not be attributed easily as one's body (Lenggenhager et al. 2007). On the other hand, the brain can embody avatars that afford these actions in the given environment, even when the avatars are non-human, or different in size and gender (Petkova and Ehrsson, 2008; Maister et al. 2014).

The sensorimotor theory also makes some predictions regarding the results of my virtual-reality experiment. Instead of passive stroking on the hand like in the RHI or the back as in the virtual reality whole-body illusion, the experiment required the participants to engage in active sensorimotor interactions, such as moving around in the environment. The sensorimotor theory predicts that when the avatars had decoupled motion, that the avatar's limbs will not be perceived as properly functioning to the limb's proper actions. Moreover, this theory predicts that the inability to properly reach a human arm out in the virtual environment at the same speed that one's own bodily sensations are encoding, would likely lead to the brain not attributing the avatar as one's body since the arm would appear to limit the limb's proper functions, such as reaching. As a result, if the avatar's motions are decoupled, there would likely not be the perception of the self towards the avatar. However, the experiment's results were sometimes inconsistent with this prediction since self-motion did not always affect the results, such as when comparing the self avatar with normal motion and the self avatar with decoupled motion. Here, participants were at chance when identifying which of the two avatars most represented themselves. This result suggests that when the avatars are of the same sex, that decoupled motion did not affect their decision of their self.

The sensorimotor approach also predicts that the opposite avatar will not affect the attribution of the opposite avatar to the self since sex does not affect the participants' actions in the environment. However, this prediction is inconsistent with some results, such as when the opposite avatar with normal motion is paired with the self avatar with decoupled motion, participants are at chance. If both sexes are not attributed to the self, then the opposite avatar with normal motion should have been chosen.

Limitations and Future Research

The sensorimotor theory's predictions are consistent with its focus on sensorimotor functions. Whereas the sensorimotor theory does not have sex as an important factor to bodily awareness, my experiment's results suggest that sex is an important factor to the visual representation of the self. However, my experiment's results may also reflect certain limitations of my experiment, such as participant biases, the small sample size of nine participants, and not having an option in the trials for when the participant did not think either avatar represents their self. For future experiments, then, addressing these limitations would be beneficial to explaining what role and how strong of a role sensorimotor functions have on the visual representation of the self.

Even with these limitations, future research could use my experiment as a starting point for cross-cultural research. If individuals locate the self differently depending on their culture (Adam et al. 2015), then, certain cultures might, for instance, view certain aspects of this experiment, such as being an opposite avatar differently. This may lead to bias towards one avatar over the other. Future research, then, may want to compare the experiment's results to other cultures.

Another area for future research is to directly study whether participants feel or perceive themselves as embodied in the avatar. Although some argue that the first-person perspective is the most suitable condition to induce a high sense of embodiment (Maselli and Slater, 2013), others do not observe significant differences between the two viewpoint modes (Debarba et al., 2015). Moreover, that the avatar was positioned in congruence and mirroring

the participant's actual body posture that is seen and felt (Blanke and Metzinger, 2009) allows for the possibility of embodiment to the avatar. Otherwise, when using a third-person perspective, if the avatar is not in this position the brain does not integrate the avatar as self. If the brain does not integrate, then the participant will not feel embodied in the avatar and that the avatar is their self. This means there is a possibility that participants felt embodied in the avatar that most represents their self. But to directly study embodiment with, for instance questionnaires after the experiment, would be beneficial.

A problem, however, with studying embodiment is that a large part of the self is grounded in low level embodiment such as gut feelings, inner organ perception, the sense of weight, heart rate, and the vestibular sense. Moreover, these experimental paradigms only study the judgment of ownership or reflective and belief-like processes, and not the sense of ownership. The sense of ownership is characterized by lower-level, pre-reflective, sensorimotor processes.

One such recent experiment is the cardio-visual version of the rubber hand illusion (Suzuki et al. 2013), which studied the effects of a heart rate on the sense of self. Participants wore a head mounted display through which they saw a virtual-reality version of their own hand projected in front of them, while their real hand remained hidden out of view. The virtual hand was made to pulse to red and back either in-time or out-of-time with their heartbeat. The researchers found that the virtual hand was more likely to be experienced as part of a person's body when the 'cardio-visual' feedback was aligned with the actual heartbeat, than when it was misaligned. This shows that the brain integrates its perception of the body from the outside with its perception from the inside in determining what is experienced as its body. For future

experiments, then, measures of the eye movements, heart rate, motor potentials, and brain activity may better access the feeling of ownership. For instance, within our experiment, the avatar could be created to pulse with the participant's heart rate during some of the trials.

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