Out of Body, Out of Mind: Interoceptive Awareness and Attention as Modulators for Full Body Illusions

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List of Abbreviations

IA	Interoceptive awareness
IAc	Interoceptive accuracy
BA	Body awareness
MTT	Mental Tracking Task
FA	Focused attention
OM	Open monitoring
1E	First-order embodiment
2E	Second-order embodiment
3E	Third-order embodiment
RHI	Rubber hand illusion
MAIA	Multidimensional Assessment of Interoceptive Awareness
FBI	Full body illusion
DMPFC	Dorsomedial prefrontal cortex
PLP	Phantom Limb Pain

Table of Contents

List of Figures

Abstract

Our sense of body ownership has become a popular topic in recent psychology and neuroscience research. Methods for studying this include the rubber hand illusion and full body illusions, with the latter being the most effective way of studying our sense of body ownership. The goal of the present study was to assess key individual factors that contribute to body ownership, namely interoceptive awareness (IA) and attention. It was expected that participants with high IA would experience a weaker full body illusion, and participants in the attentional intervention group would experience a weaker illusion. Each participant completed a Mental Tracking Task to evaluate interoceptive awareness, and were then divided into two groups for an attentional intervention. One group completed a guided body scan meditation while the other served as a control group. Then all participants experienced a full body illusion, they viewed a first-person perspective of a mannequin body through a head mount display. The illusion was induced through synchronous visuotactile stimulation, with an asynchronous condition serving as a control. The strength of the illusion was measured subjectively using a questionnaire and objectively using a threat test along with skin conductance measurements. Induction of the full body illusion was successful, with significantly higher embodiment scores and skin conductance measures in the synchronous vs. asynchronous condition. There was no significant difference in subjective or objective measures between the two IA groups, or for the two attention intervention groups. These results suggest that interoceptive awareness and attention may not serve as key factors during multisensory integration in full body illusions.

Chapter 1: Introduction

Interoception

Interoception is the perception of internal physical and psychological function of the body (Cameron 2002). This is distinguishable from exteroception, the perception of the external environment and its interactions with the body, and proprioception, the perception of the body in space. Interoception is a topic that has only recently gained popularity as a research field, however, there are several theories of emotion that relate heavily to the perception of the internal world inside your body. Claude Bernard developed the concept of “mileu intérieur” in the nineteenth century which states that the major function of the body is to maintain constancy of its internal conditions and functions (Cameron 2002). This theory was the first to highlight the importance of differentiating the internal world from the external world – the self from the non-self. Several years later, Walter Cannon developed a theory surrounding the same concept when he introduced the idea of homeostasis. This is yet another theory that highlights the importance of the body, however neither of these theories fully appreciated the fact that even at its resting state, the internal environment of the body is always in a dynamic, rather than static state (Cameron 2002). This important distinction is addressed by the James-Lange theory of emotion, developed by William James and Carl Lange. The James-Lange theory of emotion posits that, instead of emotions causing bodily changes (i.e., we cry because we feel sad), bodily changes give rise to emotion (we feel sad because we are crying (Cameron 2002)). This theory addresses the fact that the internal environment of the body is always changing, and it is those changes that cause the overall emotional experience. While this theory has been critiqued ever since its conception (see Cameron 2002 for review), it has been highly influencial in research about emotion. It points out the incredibly important relationship between physiology (specifically visceral input) and behavior in subjective awareness. Visceral input and perception of interoceptive signals from the body are essential for understanding emotional states at any given moment.

In addition to the importance of treating interoception as a dynamic process unfolding from moment-to-moment, another key problem lies at the definitional/conceptual level. In the scientific study of interoception, the concepts of interoception and body awareness have often been used interchangeably (Gibson 2019). Body awareness (BA) has been conceptualized as attentional focus and awareness of the internal sensations of the body (Mehling et al. 2009). Studies involving body awareness struggle to provide a clear definition of body awareness, thus they tend to conflate this process with interoception. However, Gibson (2019) points out the conflicting evidence provided by the IA and BA literature. Body awareness is typically studied within a clinical context, and within this context the body awareness literature suggests that heightened awareness of bodily sensations serves as a marker for anxiety, depression, eating disorders, among others (see Gibson 2019 for references). Thus, they have concluded that a high level of awareness of the processes of the body could ultimately be distressing. However, the interoception literature contradicts this conclusion. For example, previous studies have found that interoception has a positive relationship with emotional regulation (Herbert et al. 2011), decision making (Dunn et al 2010), empathy

(Ernst et al. 2013), and behavioral regulation (Herbert, Pollatos, Schandry 2005). Further research has shown that interoception has implications in a clinical setting for those suffering from eating disorders (e.g Fassino et al. 2004; Lattimore et al. 2017), depression (e.g Limmer et al. 2015; Dunne et al. 2021), somatoform disorders (Flasinki et al. 2020), among others. Healthy forms of interoception are characterized by attentional regulation and acceptance of bodily sensations (Hanley et al. 2017). It is possible that IA and BA are related to one another, where interoception is one of many factors that contribute to BA, and integrates with other sensory information to create the experience of BA. However, this more recent wave of research unveils that body awareness and interoceptive awareness could be (at least partially) independent processes and it would be beneficial to study these processes separately from one another.

A recent study by Sarah Garfinkel and Anil Seth (with colleagues) worked to distinguish three dimensions of interoception: interoceptive accuracy (IAc), interoceptive sensibility (IS), and interoceptive awareness (IA) (Garfinkel et al 2014). They aimed to dissociate the subjective, objective, and metacognitive aspects of interoception by using several different measures of each aspect individually, and to then examine possible relationships between them. They employed two objective measures for interoceptive accuracy: a heartbeat discrimination task and a heartbeat tracking task (Garfinkel et al 2014). The heartbeat discrimination task involved presenting participants with auditory tones and asking them to report whether the tones matched the beat of their heart. The heartbeat tracking task involved asking the participants to silently count their heart rate while it is being recorded, and their accuracy was measured. Although this task has come under some scrutiny recently (Brener and Ring 2016), it is considered one of the standard methods for measuring this aspect of interoception (see Critchley et al. 2004; Füstös et al. 2012; Bornemann et al. 2015). Crucianelli and colleagues (2022) pointed out that the submodalities of IAc (for example, thermosensory perception and nocicpetion) are independent from one another, which means Garfinkel et al.'s study (2014) and many others have focused on the cardiac submodality. They quantified interoceptive awareness through confidence ratings: participants rated how well they thought they performed on the heartbeat detection task. They analyzed the extent to which confidence predicted accuracy in the IAc task, this prediction indicating high or low interoceptive awareness. Interoceptive sensibility was measured with the Porges Body Perception Questionnaire – participants were asked to rate how aware they are of forty-five different bodily sensations. They found a relationship between interoceptive accuracy and interoceptive awareness, but they did not find a relationship between interoceptive awareness and interoceptive sensibility. They were able to conclude that interoceptive awareness, which goes hand in hand with interoceptive accuracy, is the central key to understanding interoception more generally. For the purposes of the current study, IA will be quantified by measuring IAc as they are strongly related with one another.

Interoception and Attention

Interoception is known as the perception of the internal processes within one's body. When thinking about this, it is easy to assume that interoception and attention are inherently linked. A 2015 study conducted by Nitasha Buldeo sought to determine if interoceptive awareness is possible when attention is compromised. They utilized the same heartbeat tracking task as Garfinkel (2014), but in this case it was called the Mental Tracking Task (MTT). They then had participants perform the same task, but they included images of affective faces to distract their attention. They found no difference between the two conditions; participants' scores did not lower in the modified MTT. They suggest that interoceptive awareness and attention can be separated, conscious perception of the internal processes of the body can be achieved even if attention is compromised. However, the results of this study are not the most convincing as they did not quantify the attentional distraction, they simply presented the images on the screen in the hopes of distracting the participant. So, it is still possible that interoceptive awareness and attention are linked to each other, and this link can be explored by investigating a relationship between interoceptive awareness and mindfulness.

Mindfulness

Mindfulness has recently become a popular topic of study in psychological sciences. It holds its roots in Buddhism (Van Dam et al. 2017), and it began to gain traction in the scientific community in 1987 when the Mind and Life Institute was established (Van Dam et al. 2017). It is an umbrella term that is used to characterize several practices and processes with a relation to attention, awareness, memory, and acceptance (Van Dam et al. 2017). A working definition of mindfulness is: "the awareness that emerges through paying attention on purpose, in the present moment, and non-judgmentally to the unfolding experience moment by moment" (Kabat-Zinn 2003). The main issues that emerge when researching mindfulness is the lack of differentiation between mindfulness and meditation (Van Dam et al. 2017). Mindfulness is a more abstract concept: it is the experience of focused attention and awareness. Meditation is one of the main practices that can creates the experience of mindfulness. Findings around mindfulness have shown that mindfulness is associated with improvements in cognitive performance, attentional capabilities, increased compassion, reduced stress, and improvements of symptoms of depression and anxiety (Gibson 2019). These are just a few processes that have been found to be affected by mindfulness practices, the improvements are certainly not limited to those above. However, there are four consistent elements that emerge in mindfulness literature: attention regulation, body awareness, emotional regulation, and a change in the perspective of the self (Gibson 2019). Each of these elements hold an intimate relationship with one another, and improvements of these processes can be achieved through certain meditation practices.

There are several different forms of meditation which are each garnered to produce a different experience of mindfulness. Every form of meditation has an essential component: learning how to intentionally focus on the sensations of the body and redirect that focus when the mind wanders (Gibson 2019). There are two basic categories of meditation practice: focused attention (FA) and open monitoring (OM). FA is the focus and maintenance of attention on a single object, such a breath or heart rate (Gibson 2019). OM involves non-judgmental monitoring of the experience at the present moment (Gibson 2019). This can include awareness of external stimuli, as well as monitoring of internal sensations. Open monitoring is more popularly known as mindfulness meditation, which allows more acceptance towards what is going on moment to moment. It is the mindfulness practice that fits the operational definition the best. However, mindfulness can become more concentrated in one area with focused attention. More contemporary practices of FA include rhythmic breathing, yoga practices, and body scan meditation (Gibson 2019). Rhythmic breathing is active, controlled breathing where attention is fully focused on the rhythm of breathing. It has been shown to facilitate stress regulation, dampen the sympathetic nervous system, and promote parasympathetic dominance (Gibson 2019). Yoga based practices have been associated with changes in observing, acting with awareness, and non-reactivity which show improvements in well-being and perceived stress levels (Gibson 2019). Gibson also asserts that those who engage in body scan meditations derive greater benefit from yoga based practices.

Body Scan Meditation

Body scan meditation is a form of mindfulness where attention is focused inward on the body (Ameli 2014). This form of meditation is not meant for relaxation or to make the practitioner feel good. Instead, it allows the practitioner to take note of the processes of the body with an attitude of acceptance: noticing, allowing, and accepting the sensations within the body (Ameli 2014). The main goal of body scan meditation is to become an unbiased observer of your body and its sensations, which can be pleasant, unpleasant, or neutral.

There is a general template that practitioners follow when performing a body scan meditation (Ameli 2014). First, they must situate themselves in a comfortable position, usually sitting or laying down on a yoga mat. They begin the meditation by focusing inward, gently breathing into the abdomen and completely exhaling. This type of breathing is called mindful breathing, which is meant to quiet the mind. The next step of the meditation is to establish intention. An example of this is having the intention to stay fully present during the duration of the meditation. Then, practitioners take inventory of their bodily sensations. This is essentially taking a general inventory of what is going on within the body, simply noticing these sensations without trying to change them. An example of this is taking note of the parts of the body that are touching the floor, or the parts of the body that are bent and the way they are bent. Then it is time to begin the full body scan. This is done by bringing attention to specific body parts, making sure to notice all the sensations that come from them. These sensations could be pressure, itchiness, warmth, coolness, etc. Usually, the body scan is done in a sequence, and the order of the sequence is decided by the practicioner. Figure 1 shows an example sequence. During the body scan, it is common to continually witness thoughts and feelings, in order to maintain that accepting attitude. It is also important to stay connected with breathing during this process. Body scans can last anywhere from 5 minutes for those who are just beginning, to an hour or even several hours for more advanced practitioners (Ameli 2014).

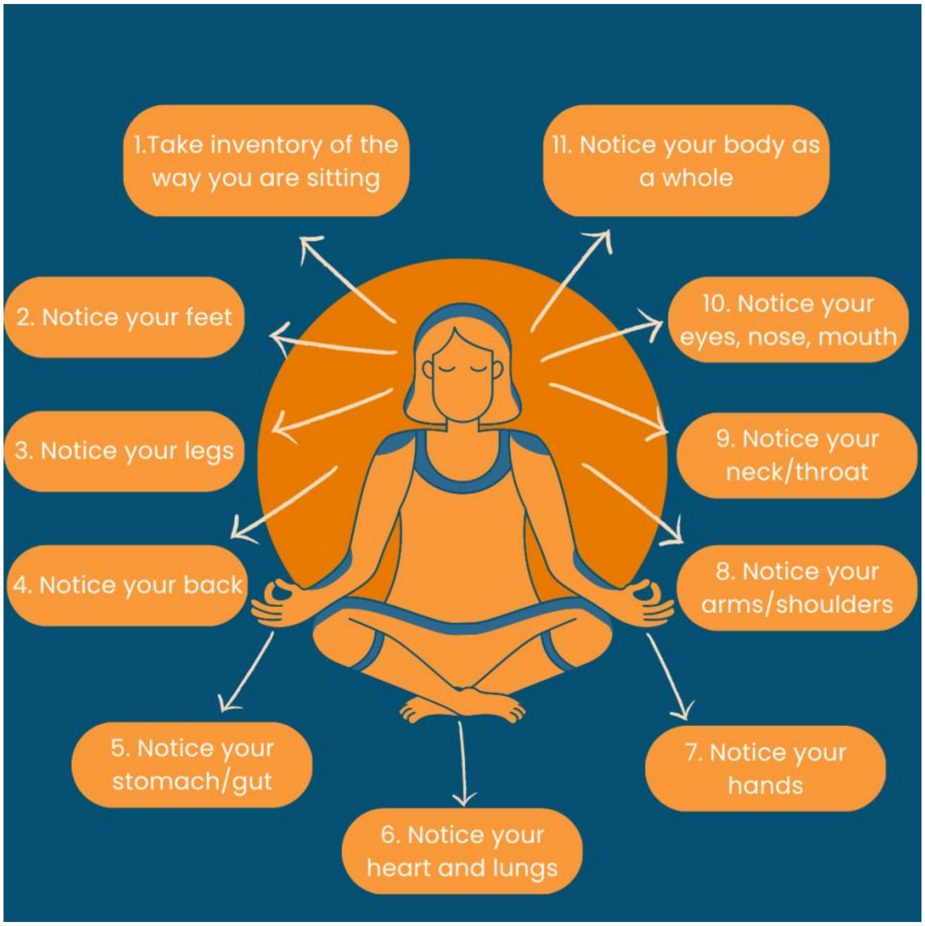

Figure 1: Body Scan Meditation Example.

This is only an example of what a body scan meditation could look like, it is up to the practitioner to decide what order to attend to individual parts of the body. Guided meditations provide support for novice meditators.

Body scan meditation has been proven to have immediate effects on cognition, emotion, and biological functions. A 2012 study by Mirams et al. discovered that with some brief practice, body scan meditations resulted in improved somatosensory perceptual decision making, specifically when identifying near-threshold vibrations at their fingertips. What is interesting about this study is it contrasts with a previous finding where focused interoceptive attention led to increased misperceptions using the same test (Mirams et al. 2012). This suggests that body scan meditation and focused interoceptive attention may have different perceptual effects (Mirams et al. 2012). Another study conducted by Dambrun in 2016 revealed that body scan meditations led to increased happiness and decreased anxiety. Surprisingly, they claimed that this was a result of a decrease in the saliency of perceived body boundaries, which seems to counteract the goal of the body scan meditation. Another study conducted by Ditto et al in 2006 revealed that body scan meditations result in significantly decreased cardiac respiratory sinus arrhythmia and decreased blood pressure, suggesting that there is an immediate biological effect produced from this type of meditation.

Body Ownership and Multisensory Integration

How do we know that we own our own body? What is the relationship between our body and our sense of self? Anil Seth has developed one of the only major theories of consciousness that places the body at the center of it all – this theory is called the “Beast Machine Theory”. He asserts that “our conscious experience of the world around us, and of ourselves within it, happens with, through, and because of our living bodies” (Seth 2021). There is no way to understand our conscious experience without considering the bodies we live in and subjectively experience the world from. In some ways extending the James-Lange theory of emotion where our emotions arise from changes in our bodies, Anil Seth claims that our sense of self arises from the ownership of our body. He builds from the James-Lange theory of emotion by introducing the ideas of interoceptive inference and regulatory action. Interoceptive inference – according to Seth – is primarily about controlling the physiological state of the body (Seth 2021). This control is accomplished through various regulatory actions (e.g., reaching for food, breathing deeply, etc.), and this process can be described as “allostasis”: the process of achieving physiological stability through responses to a changing environment (Seth 2021). Since the brain has no direct access to the physiological states of the body, these states must be inferred. It is this inference that underpins emotional states. In the words of Seth, "these affective experiences [emotions and moods] have their characteristic phenomenology because of the control-oriented and body-related nature of the perceptual predictions [interoceptive inference] they depend on" (Seth 2021). Unlike James-Lange, Seth's theory assumes that emotional states are experienced partly because of external situations beyond the boundary of the body. However, he asserts that at the very core of existence, simply being a living organism lacks these external referents. The true state of conscious selfhood is "a formless, shapeless, control-oriented perceptual prediction about the present and future physiological condition of the body itself" (Seth 2021). Thus, consciousness is rooted, first and foremost, in the body. It is crucial to understand that this is the first step in being a conscious machine, and everything else (emotional states for example) comes afterwards. Another theory, posited by Cassanto in 2009, called the body-specificity hypothesis, claims "to the extent that the content of the mind depends on our interactions with our environment, people with different kinds of bodies - who interact with the environment in systematically different ways - should tend to form correspondingly different neural and cognitive representations" (Shapiro 2014). The body-specificity hypothesis highlights the link between our bodies and our cognition, where our bodies dictate the mental representations we form from our everyday lives. This theory builds upon Seth's beast machine theory by reasoning that if our mental representations arise from our bodies and how we interact with the world, then people with different kinds of bodies must think differently. For example, someone who is seven feet tall experiences the world far differently from someone who is four feet tall, thus their mental representations of the world must be different. These two theories go hand in hand, Cassanto's theory simply highlights the individuality of conscious beings and speculates about how that must affect cognition. But both theories hold the same core value: our bodies are the root of our conscious experience.

Embodiment

Thomas Metzinger, a well-known German philosopher, focuses on the relationship between embodiment and the phenomenology of the self in his chapter titled "First-order Embodiment, Second-Order Embodiment, Third-Order Embodiment" (Metzinger 2014). He specifically delves into the concept of "minimal phenomenal selfhood": which attempts to isolate the minimal set of conditions that are necessary and sufficient for the conscious experience of selfhood (Metzinger 2014). In doing so, he introduces the concepts of first order embodiment (1E), second order embodiment (2E), and third order embodiment (3E). In basic terms, 1E is the adaptive, bottom-up processes that can achieve intelligent behavior naturally through interacting with one's environment (Metzinger 2014). 1E emerges from the cooperation of low level properties, such as interactions with the environment, however in order for more complex behaviors to form, the organism must have a representational model of its own body.

2E is on a more representational level; it is how a system represents itself as embodied. Three conditions must be satisfied for a system to reach 2E: first, its behaviors and intelligence can be understood by describing it as a representational system, second, the system must have a single, coherent self-representation of itself as "being an embodied agent" (Metzinger 2014), and finally, the way the system uses its self-model helps us understand its intelligence and behaviors in functional terms. In more basic terms, the body in itself cannot actively induce behavior, but it can be used as a tool, a predictive model that filters data in accordance to its own boundary conditions (geometrical and dynamic, among others). Second-order embodiment is necessary for a system to learn new behavior. While 1E is purely adaptive, 2E uses the body model to predict potential novel solutions to problems posed by the environment, and the physical body tests those solutions. In the real world, 1E can be seen in single celled organisms (exhibiting purely instinctive and adaptive behaviors), while 2E is seen in more advanced organisms like dogs and cats.

3E is found in conscious machines, where the physical system models itself *as* embodied and *maps* the representational content of this model onto conscious experience. Thus, a system that has third order embodiment not only has an internal representation of its body, but it consciously experiences itself as embodied. This experience creates a phenomenal self model, and the sense of selfhood stems from this model. We are able to identify with the content that is produced by 3E because we experience our body models as real rather than representational. Metzigner describes this process as "transparent" (Metzinger 2014). The subjective state of identification assigns a unique role to the physical body among all other potential bodily representations held within the system. This is where the interoceptive aspects of the phenomenal self model come into play. The system must be aware of its own internal sensations in order to identify with the correct system, as in, the physical body. Metzinger posits that in order to fully grasp third order embodiment, one must first understand a comprehensive theory of consciousness. These levels of embodiment can be easily incorporated into Seth's beast machine theory: since humans have the conscious experience of embodiment, they are able to form a subjective experience.

After understanding the three different levels of embodiment, it is crucial to understand how they are related to one another. Metzinger defines the relationship between 1E, 2E, and 3E as a "grounding relation" (Metzinger 2014). A grounding relation connects a phenomenal property to the low level dynamics of a conscious system. In other words, the phenomenal self stems from its grounding relation to first order and second order embodiment. Phenomenal properties like selfhood must be understood as a representational structure, and this representation must be understood as a graded process.

Based on the theories surrounding selfhood, embodiment, and consciousness (Seth, Cassanto, and Metzinger), our sense of selfhood is linked to our sense of body ownership. It is a common assumption that our sense of body ownership is concrete, where we are constantly locked inside our own bodies and there is no way to separate ourselves from our bodies. But, as Metzinger posits, our selfhood is a graded process, thus our sense of body ownership is a graded process as well. Body ownership is extremely malleable, and this can be seen through experimental manipulations such as the rubber hand illusion and full body illusions. Changes in body ownership can also be seen in out of body experiences. The leading hypothesis surrounding the investigation of bodily ownership is that the ownership of our bodies stems from multisensory integration (Ehrsson 2012). The experience of being in our bodies is an evolutionary adaptation in which we need to be able to distinguish and identify ourselves within the sensory environment (Ehrsson 2012).

The Rubber Hand Illusion

A common technique for studying the malleability of our bodily ownership is the rubber hand illusion (RHI). This illusion was first reported by Matthew Botvinick and Jonathan Cohen (1998). The RHI involves placing a participant's hands on a table, with one arm/hand hidden from view. An artificial (usually rubber) arm/hand is placed next to the hidden one but within view. The experimenter then synchronously strokes the visible rubber hand and the hidden real hand (e.g., with a paint brush). Eventually, due to the consistency of the visual and tactile input, the participant begins to experience the rubber hand as their own. There is a plethora of research utilizing this technique. Previous research has revealed that the rubber hand illusion can induce ownership of a supernumerary limb (Guterstam, Petkova, Ehrsson 2011), but this can only be accomplished if the limbs are in anatomically congruent positions relative to the physical body and with synchronous tactile stimulation. The rubber hand illusion also has multiple limitations, the most striking limitation being voluntary movement. As soon as the participant moves their real hand, the illusion of owning the rubber hand breaks down immediately due to the inconsistency in sensory-motor feedback. Previous research has confirmed that moving the real limb during the illusion breaks the illusion (see Reader, Trifonova, Ehrsson 2021). However, new technology is being developed in order to combat this limitation. A new, computer controlled robotic hand could help alleviate the problem of voluntary movement disrupting the rubber hand illusion (Caspar et al 2015).

Interoception and the Rubber Hand Illusion

Previous research has begun to uncover how interoceptive awareness relates to susceptibility to the rubber hand illusion (Crucianelli et al 2017; Horváth et al 2020; Tsakiris et al 2011; Suzuki et al 2013). This previous research provides contrasting evidence as to the role that interoceptive awareness plays in our sense of body ownership. The first study to explore the individual differences in interoception in relation to the rubber hand illusion was conducted by Tsakiris and colleagues in 2011. They measured participants' interoceptive awareness using the Mental Tracking Task (Schandry 1981). They then had the participants go through the rubber hand illusion and measured the strength of the illusion objectively using a proprioceptive measure (participants indicated where their left index finger was located by pointing on a ruler) and through skin temperature. They also measured the subjective experience of the illusion using a questionnaire. They found an inverse relationship between interoceptive awareness and the strength of the illusion, participants with low interoceptive awareness experienced a stronger illusion, and those with high interoceptive awareness experienced a weaker illusion.

The conclusions of Tsakiris and colleagues (2011) are rather intriguing; however, these results were not easily replicated. Two studies attempted to replicate these findings (Crucianelli et al 2017; Horváth et al 2020). Using the same task as Taskiris (2011), they were unable to identify interoceptive awareness as a modulator for the strength of the rubber hand illusion (Crucianelli et al 2017). Furthermore, they found that proprioceptive processing impacts the rubber hand illusion while interoception is entirely unrelated (Horváth et al 2020). However, there is further evidence that the mechanisms for proprioception are separate from the mechanisms for body ownership (Rohde, Luce, Ernst, 2011).

Previous research has also incorporated interoceptive signals into the elicitation of the rubber hand illusion. A 2013 study conducted by Keisuke Suzuki and colleagues explored the integration of both exteroceptive and interoceptive signals in the rubber hand illusion. Their study also focused on the individual differences in interoception. Their results regarding individual differences fall in line with the results of Tsakiris et al (2011). They found that the subjective and objective measures of the strength of the full body illusion were correlated with the level of interoceptive awareness. However, while they noticed a distinctive trend between interoceptive awareness and illusion strength, this result did not reach significance.

All in all, the role that interoceptive awareness might play in our sense of body ownership is still relatively unclear. This could be due to the paradigms previous research has used. Interoception is a holistic perception, it involves the entire body. These studies were all looking at how interoception interacts with the rubber hand illusion, which is a manipulation of only one part of the body. They then attempt to generalize their results to body ownership as a whole, but such generalizations remain speculative because they did not manipulate the participants' entire body. The participants were still able to feel the rest of their body as their own during the rubber hand illusion. Therefore, it is not surprising that their interoceptive awareness would not modulate the strength of the illusion on one part of their body, as the rest of their body was still "intact". This could potentially explain much of the conflicting evidence in this area of research, and the most direct way to reconcile this issue is to look into the effect of interoception on a full body illusion.

Mindfulness and the Rubber Hand Illusion

Previous research has investigated the role of attention and mindfulness in the rubber hand illusion. It is known that the rubber hand illusion involves multisensory integration brought upon by visuo-tactile stimulation, but less is known about the role higher cognitive functions play during the illusion. A study by Yeh and colleagues (2017) sought to investigate this very issue. They measured three factors of individual differences in attention: mind wandering, attentional shift, and attentional control. They measured these factors after the rubber hand illusion and analyzed them with linear regression models. Their results indicate that participants with less shift cost and higher attentional shift scores experienced a faster and stronger illusion. They were able to conclude that higher cognitive functions must be taken into account when exploring the strength of the rubber hand illusion. These results show that attention is a factor to be considered when exploring body ownership, thus making it an important aspect of the current study.

Two studies investigated the relationship between mindfulness and body ownership using the rubber hand illusion (Cebolla et al. 2016; Xu et al. 2018). Both studies sought to investigate the experiences of body ownership and interoceptive awareness in expert meditators and non-meditators. They both measured interoceptive awareness subjectively using the multidimensional assessment of interoceptive awareness (MAIA) questionnaire. Participants were immersed in the rubber hand illusion, and the strength was measured subjectively using an embodiment questionnaire (Cebolla et al.

2016), and objectively using proprioceptive drift (Cebolla et al. 2016; Xu et al. 2018). Cebolla et al. (2016) found that expert meditators reported significantly less agency over the rubber hand, as reflected in their proprioceptive drift scores. They further found that lower senses of agency over the rubber hand were associated with higher scores on mindfulness and body awareness. They provide evidence for the importance of body awareness and mindfulness in cognitive processes of embodiment. The results of Xu et al. (2018) followed very closely to those of Cebolla et al. (2016). They found that long-term meditators reported weaker ownership over the rubber hand than non-meditators. They also found a significant relationship between the MAIA “not distracting” subscale (where they are not easily distracted by strong bodily sensations) and weak rubber hand ownership in meditators. But when they combined non-meditators and meditators into one group, they found no relationship between the MAIA and the RHI. In contrast to Cebolla and colleagues, Xu et al, (2018) found no difference in proprioceptive drift between expert meditators and non-meditators. They explain that this could be a result of the inclusion of an asynchronous condition, which was omitted in Cebolla’s (2016) study.

Another study focused on the relationship between meditation and body ownership using the rubber hand illusion, but this study focused on state mindfulness versus trait mindfulness (Guthrie et al. 2022). They investigated the impact of state and trait mindfulness, induced by body scan meditations, on multisensory integration involved in the rubber hand illusion. State mindfulness was induced by a 20-minute body scan meditation. Trait mindfulness was cultivated over a period of 14 days, in which subjects performed a 10-15 minute body scan daily. A control group practiced relaxed listening. Mindfulness and body ownership were subjectively measured using questionnaires. Interestingly, they found that participants in the state mindfulness group experienced a stronger illusion than those in the control group. However, the illusion was weaker in the trait mindfulness group. They explained that the strange finding in the state mindfulness group could be associated with a stronger visuotactile-proprioceptive multisensory conflict produced by the body scan meditation. These participants reacted strongly to the conflict between what they were seeing and what they were feeling, therefore they experienced a stronger illusion. However, participants in the trait mindfulness group learned to accept this conflict, leading to a weaker illusion. This could be a result of the non-judgmental practices of mindfulness, where participants were less judging of their own body, thus they experienced an increased saliency of body ownership.

The above studies provide conflicting evidence for the relationship between mindfulness and body ownership. Once again, the general limitation of these studies is likely the specific paradigm employed, there may be stronger evidence towards a relationship between mindfulness and body ownership if a full body illusion is used. The current study hopes to reconcile this conflicting information by incorporating interoceptive awareness and state mindfulness (using a body scan meditation) into a full body illusion paradigm, assessing ownership of the entire body instead of one singular part.

Full Body Illusions

Full body illusions (FBI) were first reported in 2007 (Ehrrson 2007). They are accomplished by situating a mannequin body with cameras pointing downwards from where the head would be, recording the body from an artificial first-person perspective. The participant wears a head mount display and angles their head as if they are looking down towards their torso. However, instead of seeing their own torso, they see the artificial torso. The most common procedure for eliciting the full body illusion is visuo-tactile stimulation. The experimenter strokes the participant with a brush while stroking the mannequin body at the same time. The participant sees the mannequin body being stroked as they are feeling the strokes on their real body. Soon enough, the participant can report that they feel as if the mannequin body is their own body, and thus the full body illusion is successfully achieved. These are the factors that are necessary and sufficient to elicit the full body illusion, but there is also evidence that the full body illusion can be elicited when the body is being looked at from a third person perspective as well as a mirror reflection (Preston et al 2015). There is a plethora of recent literature surrounding the full body illusion paradigm. Several of these studies have manipulated the size of the body (e.g. van der Hoort, Ehrsson 2016), the age of the body (Banakou, Groten, Slater 2013), the gender of the body (Taciskowski, Fust, Ehrsson 2020), among other things. This paradigm has also been used to transport people into the body of famous people, namely Albert Einstein (Banakou, Kishore, Slater 2018).

Bjorn van de Hoort and Henrik Ehrsson conducted groundbreaking FBI research in the early 2010s. One of the most popular of their studies involves manipulating the size of the artificial body. They manipulated the size of the illusory body to be either as small as a doll or as large as a giant, and examined how the perceived body size affects judgments on the size of external objects. They found that participants perceived objects to be larger when the fake body they were owning during the illusion was small, and vice versa, objects were smaller when the fake body they were owning was large. These effects disappeared when the illusion was disrupted by asynchronous touches. They concluded that a central body representation directly influences visual object size perception, where the body space is linked to the external space.

A 2013 study conducted by Banakou and colleagues explored the extent to which embodying the form of a child can change attitudes. They studied this through immersive virtual reality, where participants embodied the body of a toddler, then a scaled down adult body. They found no significant differences in the level of bodily ownership between the two conditions. They also found that in the toddler condition, participants had a stronger association with self-child, where they categorized more child-like attributes to themselves when in a toddlers body. They finally found that there were large size overestimations in both conditions. They concluded that body ownership not only influences perceptual processing, but our perceptual system can change in such a way where we are able to experience something in the way a child experience it.

A recent 2020 study conducted by Tacikowski, Fust, and Ehrsson explored gender identity and how it can be updated through a full-body illusion, specifically a full body-sex change. They found that moment to moment perception of one's body can update subjective feelings of masculinity or femininity. Further experiments showed that ongoing perception of one's body informs the strength of associations between the self and gender. Finally, they found that perception of masculine or feminine traits as one's own updates stereotypical gendered beliefs in one's personality. They concluded that there is a dynamic and immediate link between perception of one's body and aspects of their gender identity.

Another study conducted by Banakou, Kishore, and Slater (2018) was interested in changes that result from the embodiment of a different person. Specifically, they sought to investigate whether embodying the form of a highly intelligent person, Einstein, would result in changes in performances on cognitive tasks. They were also interested in seeing if embodying the body of an older person would reduce age-related biases. They found that body ownership levels were high, and surprisingly, greater intelligence scores and reduced age bias in the Einstein condition. They concluded that body type carries meaning that has implications in perceptual processing, attitudes, and cognitive processing in the person experiencing it.

The above studies are a small portion of the literature surrounding full body illusions. Many of them are exploring the boundaries in which the illusion could be successful. They manipulate parts of the body itself, rather than targeting the functions that form the basis of selfhood, specifically interoceptive awareness. There is very little literature that explores the mechanisms that are incorporated into the full body illusion. More specifically, the differences that contribute to the illusion on an individual level have yet to be fully explored. There are a couple of studies that have looked at the relationship between interoception and full body illusions.

Interoception and Full Body Illusion

There have been a few studies that have incorporated interoceptive signals into the body ownership illusions (Betka et al 2020; Crucianelli et al 2022; Heydrich et al 2018). Instead of looking at levels of interoception for each participant, these studies adapted the procedure to elicit the full body illusion to include interoceptive signals.

These methods included visuo-thermal stimulation (Crucianelli et al 2022), visuo-cardio stimulation (Heydrich et al 2018), and visuo-respiratory stimulation (Betka et al 2020).

The 2022 study conducted by Crucianelli and Ehrrson investigated how thermosensation modulated body ownership using the rubber hand illusion. They examined this by manipulating visuo-thermal congruency while participants experienced the rubber hand illusion. 40 subjects participated in each of the two experiments: the visuo-thermal congruency test and a control test. In Experiment one, participants were induced into the rubber hand illusion through visuotactile stimulation. Then they experienced visuo-thermal stimulation, where they observed the rubber hand being stroked by either a fake ice cube or a hand warmer while their real hand was being stroked by a thermode, matching the temperature of the object stroking the fake hand. In experiment 2, they investigated whether the RHI was due to actual embodiment of the artificial limb, or if it was merely due to visuo-thermal stimulation. They performed the same RHI with the cool temperature condition since it elicited the strongest illusion, but the rubber hand was in a non-anatomical position. So if the visuo-thermal illusion and the RHI were linked, they would not observe an illusion. If they were not linked, then they would still observe the thermal part of the illusion. Results went as expected, they observed a stronger illusion when the temperatures were congruent, and they did not observe a RHI in experiment 2. This means there is an additional rule to the RHI, thermal signals were incorporated with the visual and proprioceptive signals from the arm to produce a rubber hand illusion. While this experiment did not utilize a full body illusion (again, a possible limitation of these kinds of experiments), it still has important findings towards how interoceptive signals are incorporated into part-body ownership, and can possibly be extended to full body ownership.

Heydrich and colleagues examined how interoceptive signals modulate body ownership in the full body illusion (2018). Thirteen participants participated in this study, their heartbeats were measured and that was reflected in a visual cue in the virtual body. The virtual body had an "aura" that reflected the beats of the participants' heartbeat. They found that participants identified more strongly with the virtual body in the synchronous heartbeat condition. This shows that both exteroception and interoception are integrated into the representation of our entire body.

Betka and colleagues (2020) used a similar procedure to Heydrich's study, but instead of the aura of the illusory body glow in sync with the participants heartbeat, the aura was tied to the participants' breath rate. They studied how respiratory signals are incorporated into bodily self consciousness. They used the same synchronous-asynchronous conditions, where the aura either flashed synchronously with the participants' breath rate, or it was asynchronous. They found that participants experienced a stronger illusion in the synchronous conditions. This study provides yet more evidence that interoceptive signals are also incorporated in the multisensory integration that occurs during body ownership illusion. Based on these studies, it becomes clear that interoception is an important factor to take into consideration when conducting studies that involve a full body illusion. Thus it is crucial to find how individual differences of interoception affect bodily self consciousness.

Mindfulness and Full Body Illusion

Until now, there does not seem to be any research studying the roles that attention and mindfulness play in the full body illusion. There are several studies (mentioned above) that have studied attention in relation to the rubber hand illusion. At this time, no studies to date have attempted to extend the results of the rubber hand illusion to full body illusion paradigms. Therefore, a good direction for further research is to study the relationship between attention and body ownership using a full body illusion. This can be accomplished by focusing on state mindfulness that is directed inward towards the body and how inducing state mindfulness can affect the strength of a full body illusion.

The Link

Mindfulness, interoceptive awareness, and body ownership are linked to each other on a neurological basis. A review by Gibson (2019) highlighted the links between mindfulness and IA and gave a contemporary approach to how these factors should be studied in conjunction with one another. He accomplished this by identifying the neural networks that link these two phenomena together, namely the interoceptive network. The interoceptive network spans multiple brain regions including the insular cortex, cingulate cortex, the inferior frontal gyrus, and the sensorimotor cortex. It also has connections to the amygdala, hypothalamus, hippocampus, and the brainstem. However, the key region of the interoceptive network is the insula, which integrates information from the body. Several portions of the insula are involved in this integration, the information is represented in the posterior portion of the insula and is “re-represented” in the mid and anterior portions of the insula. This re-representation involves multisensory integration of body sensations and exteroceptive signals to provide a representation of the entire state of the body. The anterior portion of the insula also integrates information from the higher cognitive functions to maintain homeostasis. The interoceptive network has been shown to engage not only in interoceptive awareness, but emotional regulation and processing due to its intimate relation with body sensations. Thus, the interoceptive network and the insula provide the neural basis for the representation of the body along with awareness of the body, which, as described above, helps create the conscious experience of the self.

While the interoceptive network has the incredibly complex function of representing the body, it is also involved in many other higher level cognitive functions: attention, decision making, intention, body movement, expectations, and subjective trustworthiness, among others. More broadly, the interoceptive network and the insula are structures that engage in human awareness of the present moment, which coincidentally is the defining feature of mindfulness literature. Gibson has reviewed how mindfulness modulates these structures. He focused on a couple of studies conducted by Farb et al. (2007, 2013) which sought to identify the underlying neural circuits involved in mindfulness. They operationalized mindfulness using experimental focus: “sensing what is occurring in one’s thoughts, feelings, and body state”. They found that participants who engaged in this kind of mindfulness training had increased connectivity within the interoceptive network (2007). In 2013, they found that their control group who did not engage with mindfulness training had activation in the dorsomedial prefrontal cortex (DMPFC). While the function of this particular brain region is unclear, it is consistently engaged in inferring mental states. Conversely, those that did engage in mindfulness training showed deactivation in this cortex and had increased connectivity between the posterior and anterior portions of the insula, resulting in increased insula activation. They concluded that the deactivation in the DMPFC during mindfulness and IA create a more expansive form of sensory attention.

Gibson further unpacks these findings to fully explain the relation between the DMPFC and the insula. The DMPFC processes higher-cognitive functions and relays information to the anterior portion of the insula. Mindfulness training essentially decouples the DMPFC from the insula, allowing the anterior portion of the insula to fully attend to the internal signals from the body, which can help explain the changes to body awareness, attention, and emotional regulation that are reported after mindfulness training.

The Present Study

The goal of the present study was to assess how interoceptive awareness and attention moderate the strength of full body illusions. The illusion was elicited by synchronous (visual & tactile) stimulation of the real and fake body (with asynchronous stimulation as the control). This study assessed how individual differences in interoceptive awareness affect the susceptibility to the full body illusion. Further, this study sought to gain answers to whether our degree of bodily awareness stems from a trait (interoceptive awareness) or a state (attention). Attention was be manipulated through mindfulness-based techniques that have been developed to promote state mindfulness towards bodily awareness. This was a 2 x 2 x 2 mixed subjects design, with three independent variables: stimulation synchronicity, interoceptive awareness, and attentional priming. The dependent variable was the strength of the illusion (measured subjectively via questionnaires and objectively via skin conductance responses to a threatening stimulus). It was expected that participants with high interoceptive awareness would experience a weaker illusion, the attentional intervention group would experience a weaker illusion, and the asynchronous control condition would fail to elicit the illusion.

Chapter 2: Methods

Participants

Twenty participants were recruited from Reed College and the greater Portland area (faculty and alumni), 18-69 years old. One participant was excluded after they failed the control questions on the body ownership questionnaire. Thus, nineteen participants were included in the analyses. Participants were English speakers, had normal or corrected to normal vision, and had no pre-existing disorders related to body image or depersonalization. Six participants identified as male, ten identified as female, and three as non-binary or other gender identities. The distribution of ethnicity was as follows: twelve white, three Asian, two Hispanic, and two other or mixed ethnicity participants. Fourteen participants were right-handed and five were left-handed. Every participant gave informed consent before they participated, and all procedures were approved by the Reed College IRB.

Materials

The illusion was elicited by having the participants wear a head mount display (Oculus quest 2) which displayed a pre-recorded video of a mannequin body from a first-person perspective (see Figure 1). The video was recorded using Insta360 ONE X2 camera for a fully immersive experience. Before the illusion, participants had their heart rate measured using a heart rate monitor (iHealth wireless pulse oximeter) attached to the participants' fingertip. Participants were connected to a skin conductance monitor

(Mindfield eSense Skin Response) during the illusion. The visuo-tactile stimulation was accomplished using a pointer stick.

Apparatus

This study was conducted at Reed College in the psychology building. The space in which the experiment was conducted had 4’x8’ of empty floor space. The mannequin was set up against an opposite wall from the experimental space. The windows were covered with blackout shutters to make sure the video had the same lighting conditions as the real time experiment. This also ensured that it didn’t matter what time of day the participants came in, as artificial lighting was the only source of light in the room. The mannequin was present in the room during the experiment, facing the participant. The investigator stood between the mannequin and the participant to elicit the illusion properly.

Measures

Demographics

A brief demographic questionnaire was administered to all participants. This included standard questions regarding age, gender, race, and handedness. It also included more specific questions related to body ownership, including experience with virtual reality, role playing games, and hypnosis. These answers were analyzed to uncover any other factors that may contribute to body awareness.

Interoceptive Awareness

Each participant completed the Mental Tracking Task (Schandry 1981) to measure their interoceptive awareness. This task has solid test-retest reliability (Tsakiris et al 2011), thus it has been proven as a reliable measure for interoceptive awareness. Participants were instructed to silently count their heartbeats at various time intervals: 25s, 35s, 45s, and 60s. The time intervals were given randomly in order to avoid any order effects, and they were asked to report their counted heart rate after each trial. While they were counting their heart rate, it was being recorded by a heart rate monitor attached to their fingertip, which was hidden from view to avoid any cheating. Their recorded heart rate was compared with their reported heart rate to produce an IA score. The following transformation is used to produce this score: $\frac{1}{4}\Sigma(1 - \frac{|recorded - counted|}{recorded})$. The scores fell between zero and one, with scores closer to one indicating high interoceptive awareness, and those closer to zero indicating low interoceptive awareness. The scores were then divided using a median split (based on previous research) into Low and High IA groups.

Body Ownership: Subjective

Body ownership was measured subjectively with the Body Ownership Questionnaire. This questionnaire was adapted from a standardized questionnaire created by Gonzalo-Franco and Peck (2018). Certain questions were omitted because they were irrelevant to this study (voluntary movement, etc.). This questionnaire consisted of 22 questions, with 3 of the questions being foil questions. It was divided into 5 subscales: ownership, tactile sensations, location, appearance, and response (see appendix A) These subscales were combined with one another to produce a total embodiment score. Gonzalo-Franco and Peck provided the arithmetic for how these scores were calculated:

Ownership: (Q1 – Q2) – Q3

Tactile Sensation: (Q4 – Q5) + Q6 +Q7

Location: Q8 – Q9 + Q10

Appearance: Q11 + Q12 + Q13 + Q14

Response: Q15 + Q16 + Q17 + Q18 + Q19

Total: $\frac{\left(\frac{ownership}{3}*2\right)+\left(\frac{tactile\ sensation}{4}\right)+\left(\frac{Location}{3}*2\right)+\left(\frac{appearance}{4}\right)+\left(\frac{response}{5}\right)}{9}$

Body Ownership: Objective

To objectively measure the strength of the illusion, a threat test was used. This test has been used extensively in previous studies using RHI and FBI (e.g. Ehrsson 2007; Preston et al. 2017; Preuss et al. 2018). When participants are immersed in the illusion, the false body is approached with a knife. The response to the knife-threat was measured by recording the participant’s skin conductance.

Procedure

Participants were divided into two groups: the standard illusion group and the attentional intervention group (see Figure 5). Those in the standard illusion group experienced a typical illusion. They participated in the MTT, then they were asked to participate in a foil task of listening to a short story before they experienced the illusion. This was to ensure that there was no improved state mindfulness from the interoceptive awareness task. They were instructed to stand and look down at their body, but instead of viewing their real body they were viewing a mannequin body through the head mount display. Once they were situated and immersed in virtual reality, the illusion began (see Figure 2). The participants viewed a pre-recorded video of the mannequin body being stroked by a plastic pointer stick (see Figure 3), and while they were viewing the video their real body was stroked at the same time (in the synchronous condition). The stimulation lasted for three and a half minutes at a rate of 60 bpm. After the visuotactile stimulation, the participants were subjected to a threat test, where they saw the mannequin body being “sliced” with a knife (see Figure 4). In the asynchronous control condition, the visual stimulation (seeing the mannequin touched) and the tactile stimulation (the touch on their real body) occurred at different times. This was to ensure that the illusion was elicited properly in the synchronous condition, participants were not meant to experience the illusion in the control condition. The order of the two conditions was not counterbalanced across participants, every participant experienced the synchronous condition first to ensure the threat test had the best chance of being successful. Seeing the threat test once would prime participants to expect the knife in the second condition, so running the synchronous condition first eliminated this possibility. The attentional intervention group had a very similar procedure to the standard illusion group, however instead of listening to the story, they participated in a 20-minute body scan meditation. This was a guided meditation, they listened to a youtube video created by experienced meditators, and the experimenter left the room to give them privacy. This intervention was meant to promote state mindfulness, where attention was directed towards the body right before they were immersed in the illusion. They then participated in the same illusion procedure as the standard illusion group.

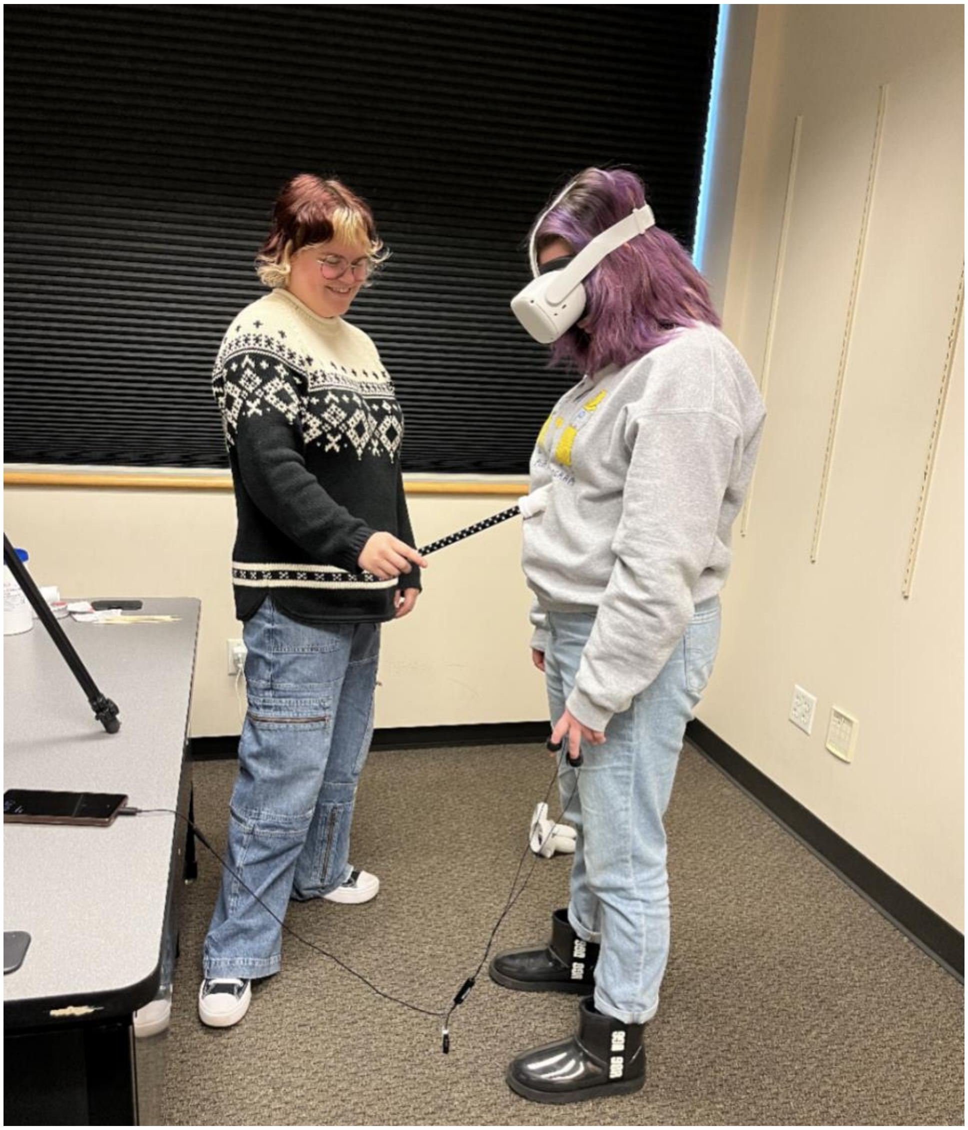

Figure 2: Experimental Setup.

Participants wore the Oculus Quest 2 headset and were instructed to look down at their body. See Figure 3 for a first-person perspective from the viewpoint of the participant. Participants stood still in one spot in the room, facing the mannequin (not seen, on the opposite side of the table). Participants were connected to the skin conductance monitor with electrodes strapped to the index and middle finger of their non dominant hand. They were instructed to assume the position of the mannequin as closely as they could, and they were instructed to stand as still as they could. Visuotactile stimulation was accomplished with a pointer stick. Not seen, experimenter wore headphones that played a metronome rhythm of 1 hertz or 60 bpm and they matched the pacing of the stimulation by viewing the video displayed on the headset through an external laptop.

Figure 3: Headset View of the Mannequin in Each Visuotactile Condition.

This is how each participant viewed the mannequin body. They were instructed to get themselves situated in the VR space and then look down; they did not see the mannequin body until their head was positioned in the right way (refer to Figure 1 for example).

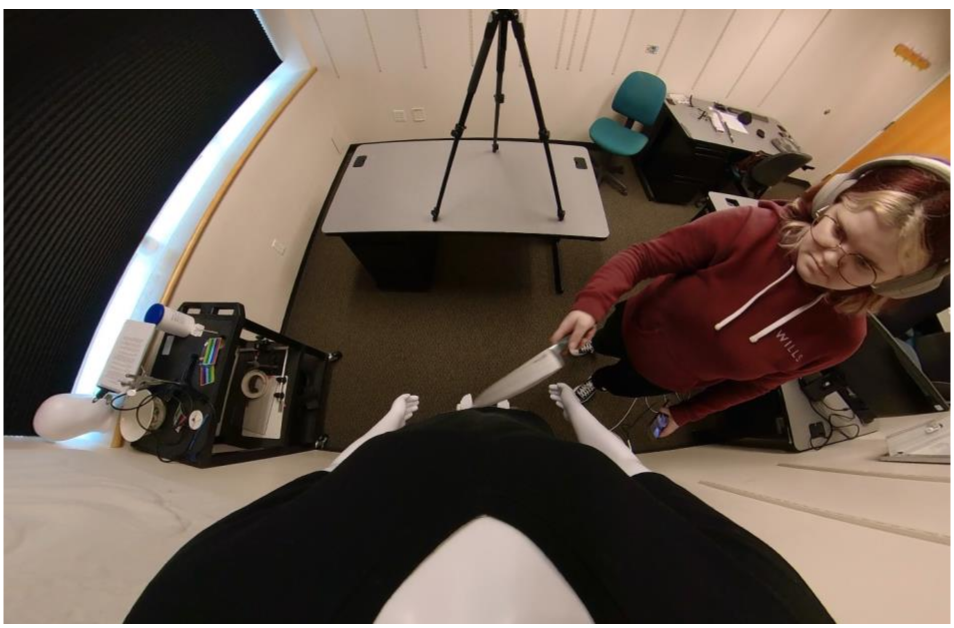

Figure 4: Threat Test.

The mannequin body was "sliced" by a knife after the 3.5 minutes of visuotactile stimulation.

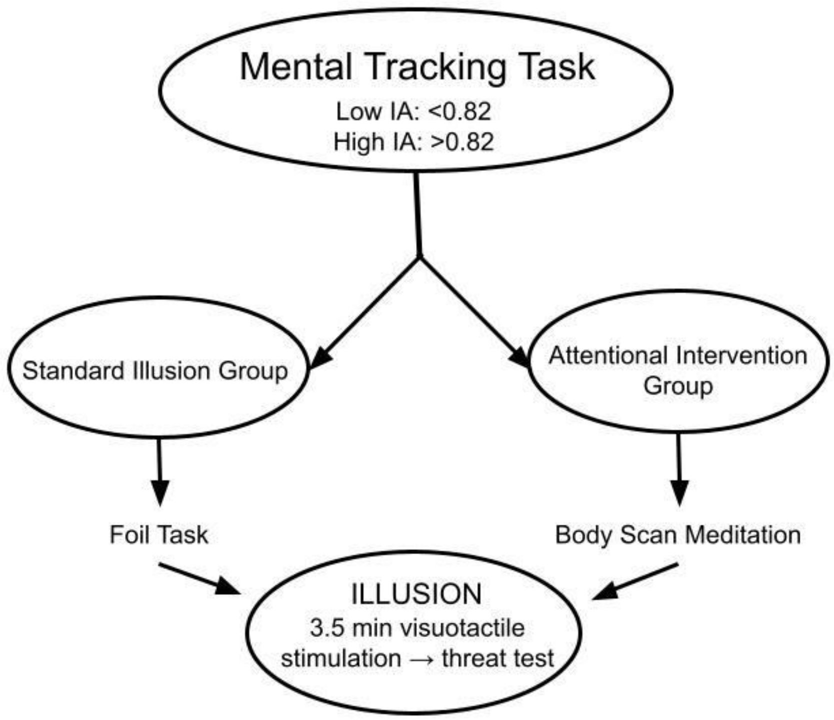

Figure 5: Conditions Layout.

All participants completed the mental tracking task, split into two equal IA groups based on their performance on this task. Then, participants were split into the control and attentional intervention group, where they performed a task before the illusion. All participants experienced the illusion, with three and a half minutes of visuotactile stimulation followed by a threat test with a knife, and their skin conductance (μS) was measured.

Chapter 3: Results

Visuotactile Conditions

The first phase of tests was run to answer the question: *"was the illusion successful?"* The only participant that was excluded from this analysis was the participant who failed the control questions, therefore a total of 19 participants were included in this analysis. A total embodiment score was calculated from the Body Ownership Questionnaire (Gonzalo-Peck 2018), by calculating and balancing the average score of each subcategory (refer to methods section for arithmetic), then taking the total average of all categories. Figure 6 shows the embodiment scores organized by illusion condition. A paired samples t-test was conducted to compare the embodiment scores for the synchronous and asynchronous conditions. Participants reported significantly more embodiment in the synchronous condition ($M = 0.38$, $SD = 0.7$) than the asynchronous condition ($M = -0.05$, $SD = 0.55$), $t(18) = 3.118$, $p = 0.003$, $d = 0.715$. To validate the results from the subjective reports, the objective measure (skin conductance changes during the knife-threat) were compared between the same two conditions (synchronous vs. asynchronous touch). Due to equipment malfunctions, only 15 participants had usable skin conductance data. μS was recorded during resting state and during the threat test, and the difference between these scores were calculated and compared across conditions using a paired samples t-test. Figure 7 shows the difference in SCR recordings organized by illusion condition. Participants had a significantly larger difference in μS in the synchronous condition ($M = 0.92$, $SD = 0.36$) than the asynchronous condition ($M =$

0.27, SD = 0.23), $t(14) = 5.699$, $p < 0.001$, confirming that the full body illusion was successful.

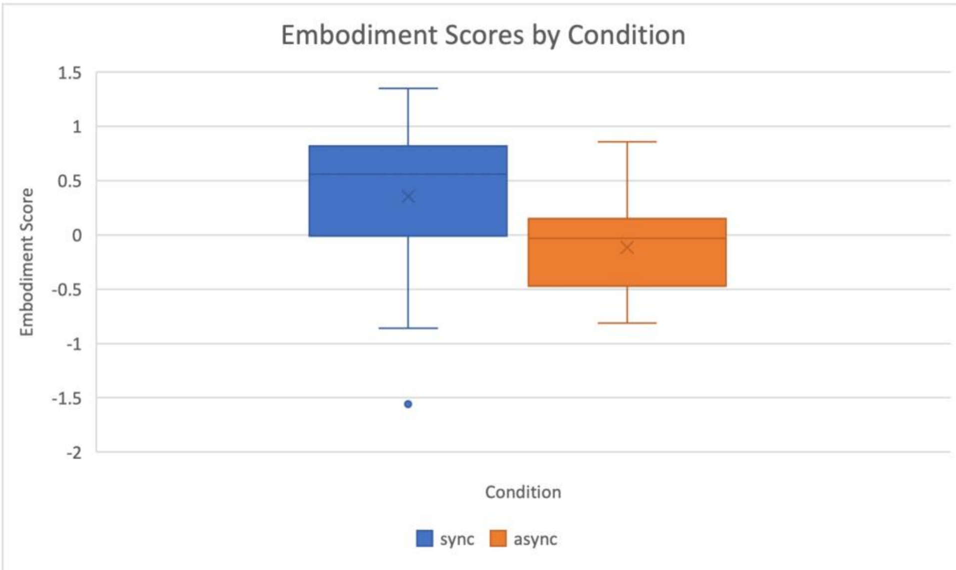

Figure 6: Embodiment Scores in Each Visuotactile Condition

Visuotactile condition: synchronous and asynchronous.

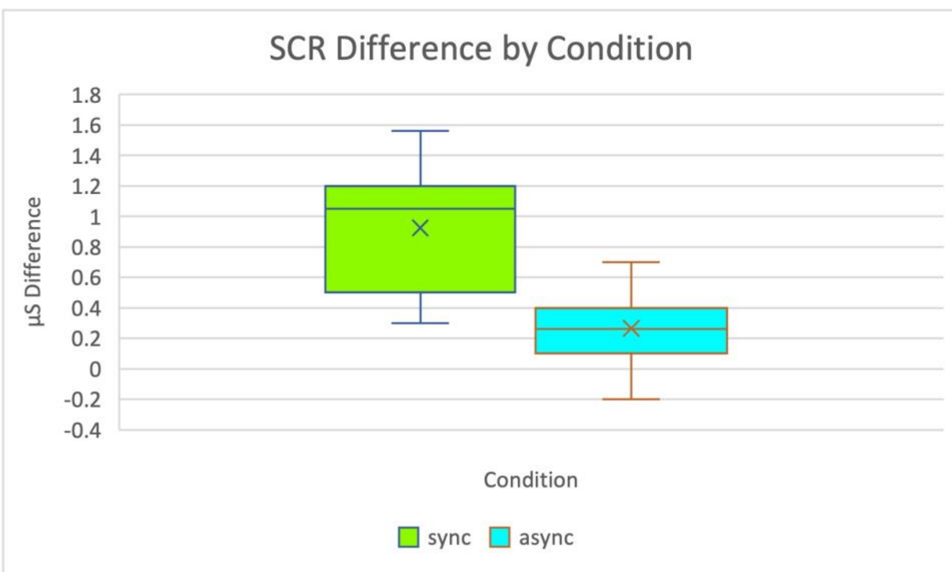

Figure 7: Skin Condutance Scores in Visuotactile Condition

Difference in skin conductance scores (µS) taken at baseline and during the threat test in each visuotactile condition (threat – baseline).

Subjective data was then broken down by each subcategory (ownership, tactile sensation, location, appearance, and response). Figure 8 shows the average score for each category, organized by condition. Participants had significantly higher scores for tactile sensation (M = 1.2, SD = 1.14, t(18) = 2.881, p = 0.01), appearance (M = 0.46, SD = 1.34, t(18) = 4.438, p < 0.001), and response (M = -0.11, SD =2.03, t(18) = 2.185, p = 0.043) in the synchronous condition than the asynchronous condition. The other two categories, ownership and location, did not show any significance.

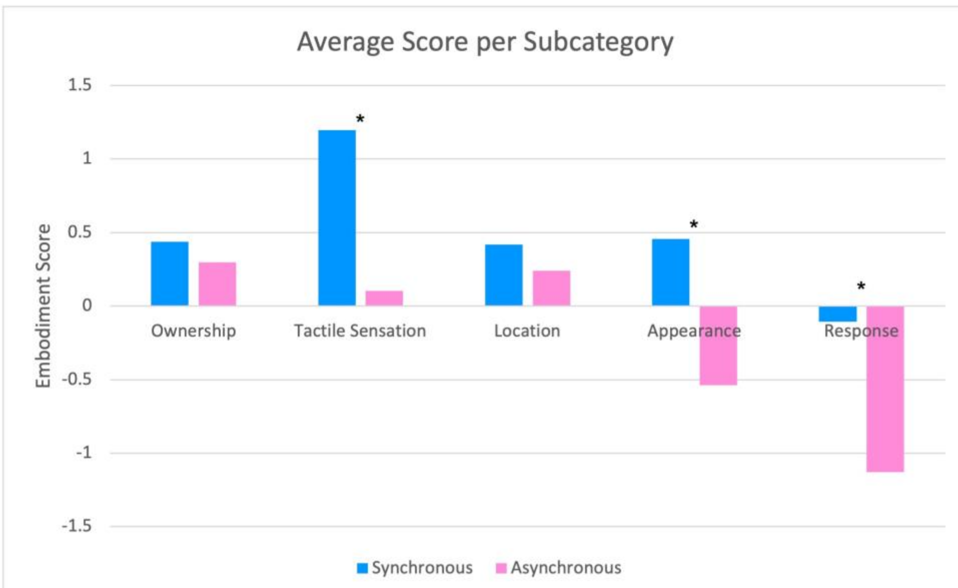

Figure 8: Embodiment Subcategories

Average score for each subcategory of the body ownership questionnaire, organized by visuotactile condition

Interoceptive Awareness

The next phase of data analysis was aimed at answering the question "*does interoceptive awareness modulate body ownership?"* Participants were divided into two groups, low IA and high IA, based on their performance on the interoceptive awareness task (M = 0.755, SD = 0.19). These groups were split using a median split, participants whose scores fell above 0.82 were categorized as high IA, and those whose scores fell below 0.82 were categorized as low IA. An independent samples t-test was used to compare embodiment scores between the low IA and high IA groups. Figure 9 shows the distribution of embodiment scores organized by IA group. There was no significant difference in embodiment scores between the high IA (M = 0.4, SD = 0.82) and low IA (M = 0.31, SD = 0.62) groups, t(18): 0.496, p: 0.687. These results are consistent with the objective scores, as there was no significant difference in μS during the threat test between the high IA (M = 0.85, SD = 0.41) and low IA (M = 0.98, SD = 0.34) groups, t(14): -0.645, p: 0.265, d: -0.334. Figure 10 shows the distribution of skin conductance scores organized by IA group.

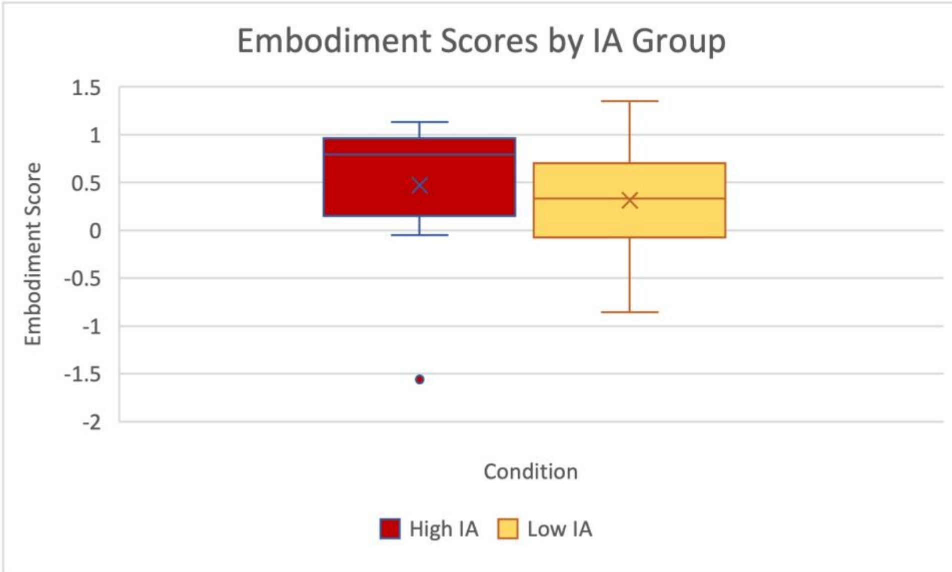

Figure 9: Embodiment Scores in Each IA Group.

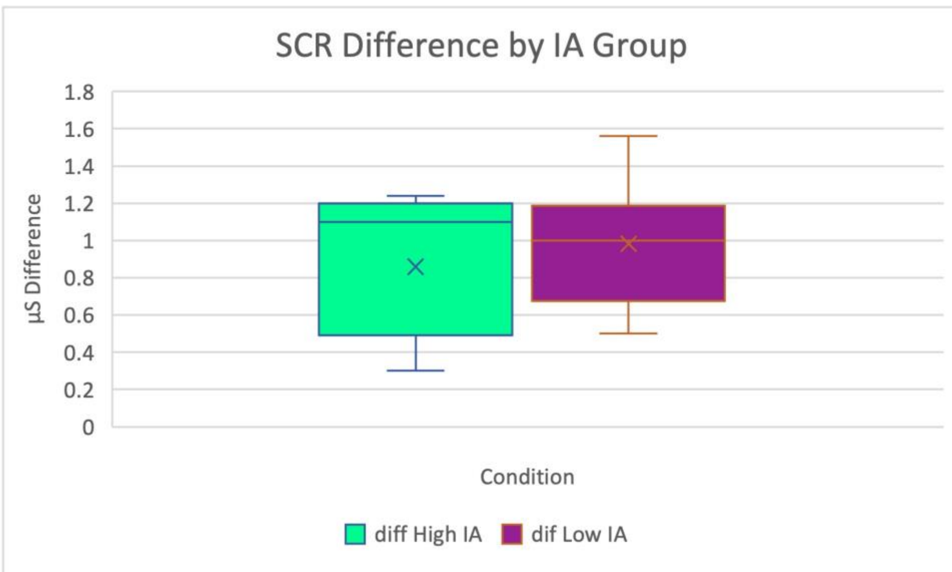

Figure 10: Skin Conductance Scores in Each IA Group.

Attentional Intervention: Body Scan Meditation

The final phase of analysis was to answer the question "*does attention modulate body awareness?"* Participants with an even subject number were assigned to the standard illusion (control) group, while those with an odd subject number were assigned to the body scan group. Figure 11 shows the distribution of embodiment scores organized by attention group. An independent samples t-test was conducted to compare the embodiment scores between the two groups. There was no significant differences in embodiment between the body scan (M = 0.54, SD = 0.61) and control (M = 0.24, SD = 0.79) groups, t(18) = 1.141, p = 0.866, d = 0.510. These results are consistent with the objective scores, as there was no significant difference in μS during the threat test between the body scan (M = 0.94, SD = 0.38) and control (M = 0.91, SD = 0.37) groups, t(14) = 0.141, p = 0.89, d = 0.073. Figure 12 shows the distribution of skin conductance scores organized by attention group.

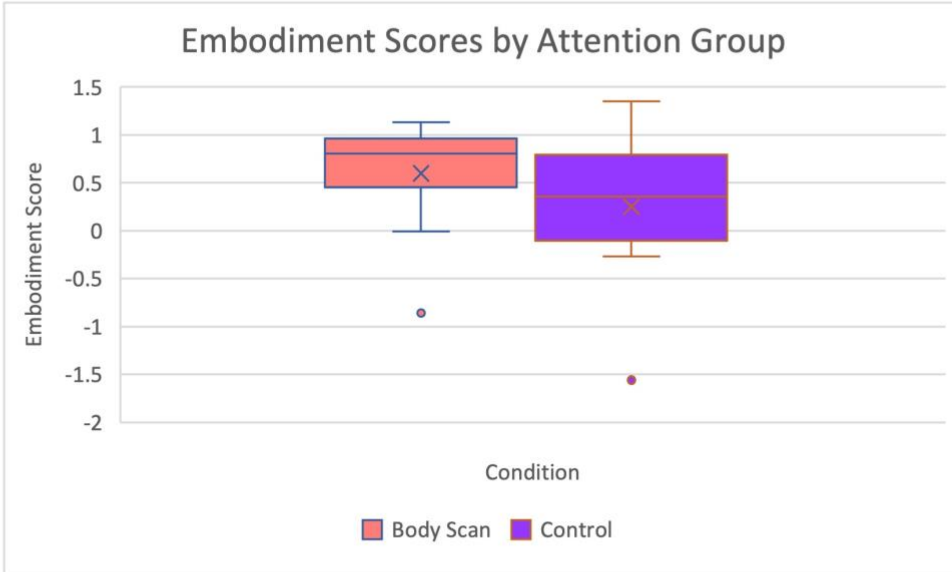

Figure 11: Embodiment Scores in Each Attention Group

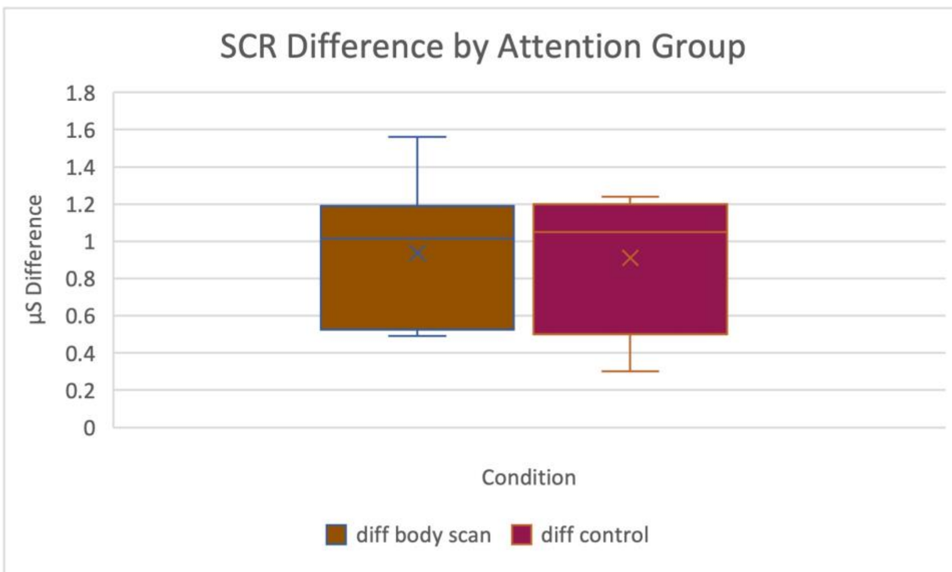

Figure 12: Skin Conductance Scores in Each Attention Group.

The number of subjects in this study were too low to run a MANOVA, which would be the correct test to uncover any interaction between interoceptive awareness and attention. Thus, a repeated-measured ANOVA was conducted to uncover any interaction between interoceptive awareness and attention. All nineteen participants participated in the mental tracking task and half of the participants participated in the body scan meditation. See appendix B for a table displaying the results of this test. There was no significant interaction between these two factors as modulators for the subjective and objective strength of full body illusions.

Demographics

A linear regression was conducted to uncover any possible predictors for the subjective strength of the illusion. Possible predictors included familiarity with virtual reality video games, ability to suspend one's belief, and experience with role playing games such as D&D. None of the demographic factors predicted the embodiment scores (see Appendix B for table).

Chapter 4: Discussion

Modulation of the Illusion

The aim of the present study was to assess how individual factors contributed to the strength of full body illusions to uncover the mechanisms that modulate our sense of body ownership. This study looked at interoceptive awareness and attention. Specifically, I wanted to assess how individual differences in interoceptive awareness related to the strength of full body illusion, and if directing attention towards the body (increasing state mindfulness) would have an affect on the strength of the illusion. Thus, this study aimed to uncover if body ownership stems from a trait (interoceptive awareness) or a state (state mindfulness). The results of this study do not support the hypothesis that those with high interoceptive awareness would experience a weaker illusion and those who participated in the body scan meditation would also experience a weaker illusion. Instead, both factors did not significantly affect the subjective or objective strength of the illusion, at least in the current sample of participants. As for the illusion itself, the visuotactile synchronicity was successful for inducing full body ownership. Participants reported a stronger illusion in the synchronous condition than the asynchronous condition, meaning the visuotactile synchronicity successfully induced an illusion while there was no illusion induction through visuotactile asynchronicity. Participants also had a significantly weaker response to the threat test in the asynchronous condition, which is further confirmation that the synchronous condition was successful in eliciting the illusion.

The nonsignificant affects of interoceptive awareness on full body illusions is consistent with those of Horváth et al (2020). They found that interocpetive awareness, measured by cardioceptive accuracy, had no significant impact on the results of RHI. The results of this study and the present study contrast with those of Tsakiris et al (2011), who found a significant relationship between interoceptive awareness and the strength of the RHI. Further, the results of the present study corroborate those of Horváth et al (2021), who claimed that interoceptive accuracy had no relationship to body awareness. The present study hoped to address the conflicting results in relation to the rubber hand illusion by using a full body illusion. However, these results show that it is possible that interoceptive awareness does not modulate our sense of body ownership no matter if it is part-body or full-body ownership.

This is interesting when considering studies that have incorporated interoceptive signals into full body illusions, including breath rate (Betka et al. 2020) and cardiac signals (Heydrich et al. 2018). Both studies concluded that interoceptive signals can also induce a successful illusion without exteroceptive haptic signals. It would make sense that, given that interoceptive signals are incorporated into the multisensory integration to produce a full body illusion, that interoceptive awareness would have some affect on our sense of body ownership. However, based on the results of the present study, that does not seem to be the case; interoceptive awareness did not modulate the strength of full body illusions. A possible explanation of this comes with a predictive model of multisensory integration proposed by Ernst and Banks (2002). In this model, certain sensory information dominates multisensory integration, usually visual signals. When information from difference sources is integrated, the sources are considered with different weights when inducing an illusion (Ernst and Banks, 2002). The present study used exteroceptive signals to elicit the illusion and analyzed the strength of the illusion based on the perception of interoceptive signals. It is possible that there was sensory competition between these two modalities during the illusion, and the exteroceptive signals of the visuotactile stimulation dominated over the trait perception of interoceptive signals at the time. This competition could be eliminated by exclusively using interoceptive signals for the illusion. By measuring trait interoceptive awareness and eliminating the interoceptive and exteroceptive competition in multisensory integration, it is possible that a relationship between interoceptive awareness and body ownership could be revealed. However, at this point it seems that exteroceptive signals dominate full body illusions, thus exteroception may dominate our sense of body ownership over interoception.

As for the relationship of state mindfulness and full body illusions, the results of the present study are consistent with those of Guthrie et al (2022). They found that brief induction of state mindfulness through a 20-minute body scan meditation increased the strength of RHI. While the present study did not find this exact relationship, it certainly did not dispute these findings. A recent study published by Schroter et al (2023) had similar findings, where brief induction of state mindfulness did not influence the RHI. The present study aimed to assess whether state mindfulness would have an affect on full body illusions, but like the previous results, it seems as though state mindfulness does not have an influence on our sense of part-body or full-body ownership. This study, in conjunction with the results of the previous two, essentially eliminate state mindfulness as a factor in body ownership.

However, a study conducted by Xu et al (2018) found that expert meditators experience a significantly less intense RHI than non-meditators. These results indicate that it could be possible that trait mindfulness would have more of an affect on body ownership illusions than state mindfulness. This makes sense when considering the neurobiological link between mindfulness and body awareness. Gibson (2019) highlighted that mindfulness training decouples the dorsomedial prefrontal cortex from the anterior portion of the insula, allowing the insula to directly attend to body awareness. Taking these factors into consideration, it is possible that trait mindfulness, induced with extensive mindfulness training, would have a stronger relationship with body ownership than state mindfulness. Trait mindfulness could not be explored in the present study based on the demographic information provided by the participants. Only one participant practiced meditation outside of the study, but they indicated that they did not do it frequently, therefore they would not have been a good subject for analyzing trait mindfulness. Future studies should consider investigating trait mindfulness with full body illusions, and potentially how these factors interact with interoceptive awareness.

This study did not find any significant interaction between state mindfulness and interoceptive awareness, even though there is neurobiological evidence that these pathways are linked (Gibson 2019). This could be because this study focused on state mindfulness rather than trait mindfulness, as discussed above. The link between the interoceptive network and mindfulness that Gibson showcased may only be activated with long term mindfulness training. Short term training may not activate these areas significantly enough to allow the insula to directly attend to the body without being mediated by the DMPFC. Once again, future studies should focus on trait mindfulness rather than state mindfulness to fully understand the relationship between mindfulness and interoception beyond the neurobiological level.

Limitations

The present study had several limitations. One of the most critical limitations was the technical difficulties involved with obtaining the objective measure (skin conductance) and inducing the illusion with precisely synchronized tactile stimulation. The ESense Mindfield Skin Conductance monitor was the only option available for an affordable, portable skin conductance monitor, however it was difficult to get a good connection with the electrodes provided. The problem was resolved by connecting the electrodes directly to the skin without attaching them to the straps provided, however this solution was found after running several subjects, therefore valuable data was lost due to technical difficulties. If this study were to be run again, I would conduct more extensive research into portable skin conductance monitors and choose more reliable equipment. Another limitation of this study pertained to inducing the illusion itself through synchronizing live touching of the participants' bodies with pre-recorded touching of the mannequin's body. In order to induce the illusion, I had to be able to see what the participant was seeing in the headset, so I knew when to start and stop the stimulation. This was accomplished by casting the image from the headset to an external laptop that I could see. Unfortunately, the casting had an indeterminate amount of time delay between what the participant was seeing on the headset and what I was seeing on the laptop. I did my best to mitigate for this by pacing the stimulation with a metronome and having the participant cue me to start the metronome based on what they were seeing. However, human error occurred occasionally and sometimes the synchonization was slightly off, which could have resulted in a weaker illusion than what might have been possible with exactly synchronized touches. Not many participants reported a strong illusion, and this could be the reason why. Resolving the delay issue is rather difficult with the equipment I used for this study, but if future studies could find a way to have a livestream directly from the camera situated above the mannequin to the headset the participant is wearing, the illusion could be induced in real time by stroking the mannequin and the participant at the same time, rather than having to sync up with a pre-recorded video. Another limitation with the illusion could have been with the length of the stimulation. I made an educated guess based on previous research that three and a half minutes would suffice to induce the illusion, however if I had made the stimulation phase last longer, I could have had more success with the illusion. However, while weaker than reported in previous studies, the illusion was successful regardless of these limitations. Mitigating these limitations in future research could give even stronger results.

Another limitation of this study was with the subjective measure. There were no significant results for the ownership and location subcategories of the body ownership questionnaire. However, the answers to these questions followed the trend of the other categories, where the ownership and location scores were higher for the synchronous condition than the asynchronous condition. This trend just did not reach significance. Also, these answers mirrored the reports of a weak illusion in the synchronous condition. Based on conversations conducted after each condition, the participants reported feeling as if they were in another part of the room during the asynchronous condition. While the subjective and objective results indicate that there was no illusion in the asynchronous condition, it is possible that the immersive quality of the VR space caused participants to feel as if they were on the other side of the room even without the illusion. This is potentially why the difference in location scores between the synchronous and asynchronous condition did not reach significance. The lack of statistical significance in the ownership category could be because the questions were confusing to the participant. A couple of the questions in this category were inverse of each other, and this inverse quality could have confused the participants. If this questionnaire is used in future studies, it might be helpful to either reword the questions in these categories or substitute them with other less confusing questions. Further, if I were to conduct this study again, I would somehow quantify state mindfulness. Several measures have been created to measure state mindfulness, however the reliability of these measures is still in dispute. A reliable measure was used by Guthrie et al (2022) to measure the five facets of mindfulness: observing, describing, acting with awareness, non-judging, and non-reacting. This is a potential measure that can be used to quantify state mindfulness after the body scan meditation. If future studies aim to measure the increase of mindfulness brought by the meditation practice, they should consider using this measure.

Why this? Why now?

Our sense of body ownership has been extensively studied using the rubber hand illusion. It is only in recent years that technological developments have allowed this sense to be studied using full body illusions (Seth 2021). This paradigm has become a popular way to testing body ownership, however these recent studies have focused mostly on pushing the boundaries of the illusion (see Banakou, Kishore, Slater 2018 or van der Hoort and Ehrsson 2016 for examples). Recent literature has yet to uncover the individual factors that contribute to the multisensory integration that occurs during full body illusions. The present study has provided more evidence towards how interoception and attention integrate into our sense of body ownership. Even though this study did not uncover statistically significant modulations of body ownership based on these factors, it is still important to study the modalities that make up body awareness and ownership. If future research works to uncover these factors, the full body illusion paradigm could be adapted to specifically target these mechansims, ultimately leading to stronger illusions. This now begs the question*: "why do we want strong full body illusions?"*

Body illusions have been utilized for several different clinical applications. The most used application of body illusions is to help mitigate phantom limb pain (see Vassantachart et al. 2022 for review). Phantom limb pain (PLP) is typically seen in amputees, where they report burning, stabbing, or gnawing pain that extends down to the region where the limb used to be (Vassantachart et al. 2022). A few studies have investigated phantom limbs and PLP in using a full body illusion paradigm (Pazzaglia et al 2019; Schmalzl and Ehrsson 2011; Schmalzl et al 2011). These studies provide preliminary evidence that illusory manipulations influence phantom limbs, specifically relating to 'telescoped' limbs, or phantom limbs that are perceived as withdrawn into the stump. These body illusions have both induced (Schmalzl and Ehrsson 2011) and revoked (Schmalzl et al 2011) telescoping. The rubber hand illusion has been used to help control phantom limb sensations from disconnected body parts (Pazzaglia et al 2019). These studies have shown the potential clinical applications for body illusions for phantom limb sensations and PLP, and by having stronger and more salient illusions, these illusions can be an effective non-invasive method of rehabilitation for amputees.

Full body illusions transport people into different bodies, and these bodies look far different to what people are used to when they look down at their torso. This has more clinical applications when it comes to disorders stemming from the perception of one's body. Full body illusions can be used as treatment for eating disorders (Ferrer-Garcia et al 2018; Keizer et al 2016; Serino, Polli, Riva 2019). There is some preliminary evidence that induction of a full body illusion is associated with reduction of body image distortion and dissatisfaction (Ferrer-Garcia et al. 2018). Full body illusions also have the potential to reduce overestimation of body size in patients with anorexia nervosa (Keizer et al 2016). These changes have been linked to multisensory integration (Serino, Polli, Riva, 2019), where patients with eating disorders like anorexia nervosa have disturbances in multisensory integration. Clinical cases like Serino, Polli, and Riva (2019) demonstrate the potential that full body illusions have as treatment for anorexia nervosa. If this treatment is effective for this particular disorder, it is likely that a stronger full body illusion paradigm can be extended to treat other disorders related to disrupted body image and disordered eating. Full body illusions also have the potential to help with gender related distress, as seen in gender swap body illusions (Petkova and Ehrsson 2008; Slater et al. 2010; Tacikowski, Fust, Ehrsson 2020), where this distress could be lessened with a stronger illusion paradigm.

The clinical applications of full body illusions do not stop here. Body illusions, including the rubber hand illusion and full body illusions, can be used to help understand multisensory integration in patients with neurological disorders or injuries. A recent study has provided preliminary evidence that full body illusions have helped to highlight the importance of the temporoparietal junction in cases of epilepsy (Heydrich et al. 2011). Another study used the full body illusion technique for motor rehabilitation for patients who have suffered a stroke (Matamala-Gomez et al. 2020). Full body illusions have also been used to reduce chronic pain: including sciatica, fibromyalgia, IBS, and back pain, by up to 37% (Pamment and Aspell 2016). These studies have opened the door for clinical applications for treatment of neurological disorders and injuries. Perfecting the full body illusion paradigm by breaking it down into the essential senses that integrate for body ownership will provide a highly effective non-invasive form of therapy and rehabilitation for a wide variety of disorders.

Conclusion

The present study aimed to assess individual factors that contribute to our sense of body ownership using a full body illusion. The specific factors explored here were interoceptive awareness and attention. Based on the results of this study, neither interoceptive awareness nor attention have a significant affect on the strength of full body illusion. This reveals that interoception and attention may not be primary factors that contribute to multisensory integration in full body illusions, opening the door for future studies to uncover the modalities that dominate our sense of body ownership. If we are able to pinpoint these modalities, the full body illusion paradigm can be perfected to become an effective non-invasive form of therapy and rehabilitation for a myriad of neurological and mental disorders.

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Appendix A: Body Ownership Questionnaire

Questionnaire adapted from Gonzalo-Franco and Peck (2018) to fit the context of this study and omit questions that are irrelevant to this study.

Body Ownership Questionnaire

Please select your level of agreement with each of the following statements

"During the experiment there were moments in which…"

Q1: I felt as if the body I saw when I looked down was my body

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q2: It felt as if the body I saw was someone else

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q3: It seemed as if I might have more than one body

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q4: It seemed as if I felt the touch of the stick in the location where I saw the mannequin body touched

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q5: It seemed as if the touch I felt was located somewhere between my physical body and the mannequin body.

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q6: It seemed as if the touch I felt was caused by the stick touching the mannequin body.

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q7: It seemed as if my body was touching the stick

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q8: I felt as if my body was located where I saw the mannequin body.

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q9: I felt out of my body

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q10: It felt as if my physical body was drifting towards the mannequin body or the mannequin body was drifting towards my physical body.

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q11: It felt as if my real body was turning into a mannequin

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q12: At some point it felt as if my body was taking on the posture or shape of the mannequin body

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q13: At some point it felt as if the mannequin body resembled my real body, in terms of shape, skin tone, or other visual features

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q14: It felt as if I was wearing different clothes from when I came into the laboratory

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q15: It felt as if my body could have been affected by the knife

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q16: I felt a panic sensation in my body when I saw the knife

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q17: When the threat happened, I felt the instinct to flinch

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q18: It felt as if my body had been approached with a knife

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q19: It felt as if I might be harmed by the knife

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q20: It looked as if my body was no longer human (i.e looked like an animal)

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q21: When I saw the stick moving, I felt it touching the back of my leg

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Q22: It felt as if my body had three arms

Strongly Disagree (-3)	Disagree (-2)	Somewhat Disagree (-1)	Neither Disagree nor Agree (0)	Somewhat Agree (1)	Agree (2)	Strongly Agree (3)

Appendix B: Supplemental Analysis Figures

Repeated Measures ANOVA ▼

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Illusion Strength	1.384	1	1.384	3.936	0.073
Illusion Strength ∗ IA Group	0.113	1	0.113	0.320	0.583
Illusion Strength ∗ Attention Group	0.226	1	0.226	0.642	0.440
Illusion Strength ∗ IA Group ∗ Attention Group	0.182	1	0.182	0.517	0.487
Residuals	3.867	11	0.352		

Note. Type III Sum of Squares

Between Subjects Effects ▼

Cases	Sum of Squares	df	Mean Square	F	p
IA Group	1.967e−5	1	1.967e−5	4.938e−5	0.995
Attention Group	0.144	1	0.144	0.361	0.560
IA Group ∗ Attention Group	0.094	1	0.094	0.236	0.637
Residuals	4.383	11	0.398		

Note. Type III Sum of Squares

Appendix figure 1: Repeated measures ANOVA results. Test was conducted to find any interaction between interoceptive awareness and attention. No significant results were found.

Linear Regression

Model Summary - Embodiment Score

Model	R	R^2	Adjusted R^2	RMSE
H_0	0.000	0.000	0.000	0.718
H_1	0.656	0.430	−0.076	0.745

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
H_1	Regression	3.766	8	0.471	0.849	0.586
	Residual	4.990	9	0.554		
	Total	8.757	17			

Note. The intercept model is omitted, as no meaningful information can be shown.

Coefficients

Model		Unstandardized	Standard Error	Standardized[a]	t	p
H_0	(Intercept)	0.364	0.169		2.152	0.046
H_1	(Intercept)	1.541	1.460		1.056	0.319
	Q1 (yes)	−0.086	0.456		−0.190	0.854
	Q3 (no)	0.631	0.875		0.721	0.489
	Q3 (yes)	−0.137	0.883		−0.155	0.880
	Q5 (yes)	0.005	0.743		0.007	0.995
	Q6 (no)	−1.197	0.883		−1.355	0.208
	Q6 (yes)	−1.006	1.087		−0.925	0.379
	Q7 (yes)	−1.025	0.911		−1.125	0.290
	Q8 (yes)	−0.528	0.466		−1.132	0.287

[a] Standardized coefficients can only be computed for continuous predictors.

Appendix figure 2: Linear Regression for Demographic predictors. This test was run to uncover any possible predictors based on demographic information. None of the demographic responses predicted embodiment scores in the synchronous condition.