EXPLORING INTEROCEPTION

# EXPLORING INTEROCEPTION

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A Thesis Submitted to the School of Graduate Studies in Partial Fulfilment of the Requirements for the Degree Master of Science

McMaster University MASTER OF SCIENCE (2018) Hamilton, Ontario (Psychology)

TITLE: Exploring Interoception AUTHOR: Hannah Kearney, B. Sc. (McMaster University) SUPERVISOR: Professor D.I. Shore NUMBER OF PAGES: ix, 44

**Abstract**

Body ownership is a complicated and multifaceted percept. Although we subjectively perceive body ownership to be a stable component of our identity, recent work has illustrated that body ownership is a dynamic construct that is constantly updated by the integration of current endogenous and exogenous body-related information. The goal of this study was to explore the relation between these endogenous (interoceptive) and exogenous (exteroceptive) channels of information. We investigated this by using a heartbeat perception (HBP) task to measure interoceptive accuracy, and the Rubber Hand Illusion (RHI) to measure malleability of body ownership. Based on prior findings, we hypothesized that the less accurate you are at counting your heartbeats, the more susceptible you will be to the RHI (i.e. the more malleable your sense of body ownership will be). In addition, we were also interested in exploring the relationship between interoception and emotion recognition ability (ERA). In this experiment, we failed to induce the RHI, and thus could not investigate the relationship between endogenous and exogenous body-related information. However, we successfully demonstrated the reliability of the interoceptive accuracy HBP task, as well as demonstrated that interoceptive accuracy is not related to ERA.

**Acknowledgements**

This past year has been hectic. From taking my first statistics course, to supervising my first students, to applying to medical school, I have learned more in this short period of time than I could have ever imagined.

To David, thank you for being flexible and supportive as I navigated the unknown. I couldn't have accomplished any of this without your guidance. I am so lucky to have a supervisor that is as genuine and understanding as you are (although I will continue to put my cutlery in a Ziploc bag).

To my committee members Daniel Goldreich and Louis Schmidt, thank you for being accommodating as the timeline for completing my Master's changed. I appreciate the time you took to help me, and your feedback throughout the year.

To Kaian, thank you so much for all of your help and guidance over the past three years. I couldn't have done any of this without you answering all of my dumb questions.

To my hilarious lab friends on the first floor, thank you for taking me in. I'm going to miss going for coffee walks and not doing work with all of you. I can't wait to see all of the great things you people accomplish.

Also, to Victoria & Chantal–thanks for all of the late night chats and rants. I can't imagine grad school without the two of you.

Finally, I need to thank my family (and Jack) for supporting me even though I'm 98% sure they don't actually know what I do when I'm at school. I'm so lucky to have people like you in my corner.

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## List of Abbreviations and Symbols

| | |
|---|---|
| HBP | Heartbeat Perception |
| RHI | Rubber Hand Illusion |
| ERA | Emotion Recognition Ability |
| MAIA | Multidimensional Assessment of Interoceptive Awareness |
| GERT-S | Geneva Emotion Recognition Test (Short) |

## Declaration of Academic Achievement

This study was conceptually conceived by HK, Kaian Unwalla, and DIS. Data were collected by HK, Anthony Battaglia, Raluca Petria, and Ravjot Rehsi. Data were organized and analyzed by HK and Kaian Unwalla. The thesis was written by HK under the supervision of DIS.

# Chapter 1: Introduction

## 1.1 General Introduction

Successful navigation and interaction with the external world requires that we distinguish between 'self' and other. This distinction depends on a sense of body ownership—or the knowledge that your body belongs to you (Moseley et al., 2008). Body ownership represents a fundamental aspect of our identity that we often assume to be innate, automatic, and durable. Despite our subjective feelings of a stable percept that is gradually updated across our lifespan, clear demonstrations have illustrated that body ownership can be easily disrupted (Cash, 1994; Moseley et al., 2008; Botvinick & Cohen, 1998). Body ownership actually consists of a malleable construct that is dynamic and continuously updated by inputs from endogenous and exogeneous channels of body-related information. The primary goal of the present study was to explore the relation between endogenous and exogenous channels of information, in order to further investigate the impact these inputs have on our sense of body ownership.

Body ownership relies on the integration of multisensory information from the external world, as well as sensory awareness of the body's physiological state (Crucianelli, Krahé, Jenkinson, & Fotopoulou, 2017; Mehling, 2012b; Mussap & Salton, 2006). The channels of information that are integrated to create this construct contain both multisensory signals from the world around us (e.g. exogenous/exteroceptive visual and auditory information), as well as endogenous signals from inside of our body (Mussap & Salton, 2006). Interoception—defined as the sense of the physiological condition of the material body—serves as the primary channel of information for one's internal bodily state (Craig, 2003; Sherrington, 1900). One component of interoception is proprioception, or the perception of the positioning of the physical body in space based on signals from the skin, muscles, joints, and tendons (Sherrington, 1948; Blanke, Slater, & Serino, 2015; Barrett, Quigley, Bliss-Moreau, & Aronson, 2004). Interoception also includes the process of receiving, accessing, and appraising internal bodily signals such as heartbeats, respiration, and satiety (Tsakiris, Jimenez, & Costantini, 2011; Craig, 2009). In order to establish body ownership, exteroceptive and interoceptive channels of information need to convey congruent information during integration (Costantini, Robinson, Migliorati, Dunno, Ferri, & Northoff, 2016). In addition, the multisensory stimuli being integrated must also match our pre-existing cognitive representations of our body in order to establish a coherent bodily experience (Tsakiris & Haggard, 2005; Costantini & Haggard, 2007). Although this constrained matching process ensures that our sense of self remains fairly continuous across time, body ownership can be easily disrupted using illusions such as the Rubber Hand Illusion (RHI) (Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008; Botvinick & Cohen, 1998). During the RHI, synchronous visual and tactile stimulation delivered to still hands can cause the co-occurrence of time-locked multisensory information, evoking a sense of ownership over a prosthetic limb (Botvinick & Cohen, 1998). The RHI is only one example of how body ownership can be disrupted, as it can also be affected by neurological, psychiatric, and psychological conditions (Moseley et al., 2008).

Despite being integral to our day-to-day functioning, our poor understanding of body ownership persists. Although we know that interoceptive and exteroceptive signals contribute to establishing body ownership, the exact relation between these channels of information is unclear (Tsakiris et al., 2011; Crucianelli et al., 2017). It is currently unknown whether interoceptive information is informed by the exteroceptive visual capture of modalities, or if bottom-up processing of interoceptive information assists in calibrating our sense of body ownership (Crucianelli et al., 2017). In addition, recent definitions of interoception have expanded the concept into a multifaceted percept that includes cognitive and affective processes in addition to the perception of bodily signals (Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015; Mehling, Price, Daubenmier, Acrees, Bartmess, & Stewart, 2012a; Bornemann & Singer, 2016). Three dimensions of interoception have been widely accepted: interoceptive accuracy (performance on objective behavioural tests), interoceptive sensibility (self-evaluated assessment of subjective interoceptive ability), and interoceptive awareness (metacognitive awareness of interoceptive accuracy, e.g. confidence–accuracy correspondence) (Garfinkel et al., 2015). This further complicates our understanding of the relation between interoception and exteroception, as it is currently unknown if these three facets of interoception are driven by different processes, or if they are even related to each other (Garfinkel et al., 2015; Farb et al., 2015).

We do know that interoceptive accuracy—measured via a Heartbeat Perception (HBP) task—covaries with the malleability of body representations during the Rubber Hand Illusion (Tsakiris et al, 2011). These tasks were selected as the HBP task is a widely accepted measure of interoceptive accuracy, and because the RHI is a multisensory-induced body ownership illusion (Tsakiris et al., 2011). This study provided the first evidence of interoception playing a role in the integration of visual and haptic information, thus illustrating how interoceptive accuracy can impact the way we experience our body from the outside (i.e. exteroceptively) (Tsakiris et al., 2011). However, Tsakiris and colleagues only studied HBP in female participants, despite there being a large body of work indicating that there may be sex differences in HBP ability (Katkin, 1985; Schandry, 1981; Whitehead, Drescher, Heiman, & Blackwell, 1977; Ehlers & Breuer, 1992; Jones, 1995; Jones, O'Leary & Pipkin, 1984, Katkin, Blascovich & Goldband, 1981; Ludwick-Rosenthal & Neufeld, 1988; Montoya, Schandry & Müller, 1993; Grabauskaite, Baranauskas, Griškova-Bulanova 2017). Thus, in addition to attempting to replicate Tsakiris and colleagues' preliminary findings, our study will use similar numbers of female and male participants. Moreover, our study will additionally explore if emotional intelligence—specifically emotion recognition ability—is correlated with measures of interoception such as the HBP task. We were interested in studying emotional intelligence because it has also been shown to be weakly correlated with interoceptive accuracy (Koch & Pollatos, 2014). Each of the three measures used in this study (HBP task, RHI, and emotional recognition ability) are described in detail below.

### 1.2 Heartbeat Perception Task

Heartbeat perception tasks (HBP) are commonly used to evaluate interoceptive accuracy abilities (Bornemann & Singer, 2016). Due to heartbeats being a discrete signal that can be measured non-invasively, it is fairly easy to determine accuracy of perception (Bornemann & Singer, 2016). Interoceptive accuracy is most commonly assessed using a mental tracking procedure in which participants are asked to count the number of heartbeats that occur during an undisclosed interval of time without taking their pulse (Schandry, 1981; Bornemann & Singer, 2016; Garfinkel et al., 2015). Heartbeat perception using the mental tracking method has been illustrated as having good test-retest reliability (81%) (Knoll & Hodapp, 1992; Mussgay, Klinkenbeger, Rüddel, 1999; Schandry, 1981), as well as correlated with the ability to detect changes in other autonomically innervated organs (Harver, Katkin & Bloch, 1993; Herbert, Muth, Pollatos & Herbert, 2012; Whitehead & Drescher, 1980).

HBP tasks have also been shown to display substantial interindividual differences, contributing to the line of research that suggests that interoceptive awareness is a trait (Domschke, Stevens, Pfleiderer, & Gerlach, 2010; Ehlers & Breuer, 1992; Tsakiris et al, 2011). Conflicting research has indicated that there is a sex difference in HBP ability, with men being more accurate than women (Katkin, 1985; Schandry, 1981; Whitehead et al., 1977; Ehlers & Breuer, 1992; Jones, 1995; Jones et al., 1984, Katkin et al., 1981; Ludwick-Rosenthal & Neufeld, 1985; Montoya et al., 1993; Grabauskaite et al., 2017). However, other research has failed to find sex differences in HBP accuracy (Mussgay, et al., 1999; Pollatos & Schandry, 2004; Franzoi, Kessenich, & Sugrue, 1989).

We hope to resolve the conflict in this literature, as well as further clarify what aspects of interoception may be influenced by sex, by conducting a HBP accuracy assessment using near-equal numbers of healthy female and male participants.

### 1.3 The Rubber Hand Illusion

The Rubber Hand Illusion (RHI) occurs when a prosthetic hand is brushed synchronously with one's unseen hand (Botvinick & Cohen, 1998). By creating synchronous visual and tactile stimulation while keeping both hands static, the co-occurrence of time-locked multisensory information can evoke a sense of ownership over the prosthetic limb (Lewis & Lloyd, 2010). Feelings of body ownership can be quantified behaviourally using proprioceptive drift measures, and subjectively using a self-report embodiment measure (Tsakiris & Haggard, 2005; Longo et al., 2008). Proprioceptive judgements tend to drift towards the location of the rubber hand during synchronous brushing, which has been noted as evidence of malleability in the body scheme (Cadieux, Whitworth, & Shore, 2011; Tsakiris & Haggard, 2005). Use of the embodiment measure has indicated that embodiment experience during the RHI encompasses subcomponents such as feelings of embodiment, agency, and loss (Tsakiris, Prabhu, & Haggard., 2006).

### 1.4 Interoception & Emotional Intelligence

Researchers have long postulated that emotional experience is not possible without the conscious perception of bodily changes (James, 1884; Schacter & Singer, 1962). The perception and feedback of interoceptive signals has been considered an essential aspect in many theories of emotion, as well as a core component of motivational regulation of behaviour and cognition (Cali, Ambrosini, Picconi, Mehling, & Committeri, 2015; Craig, 2003; Singer, Critchley, & Preuschoff, 2009). This is because the process of identification, differentiation, and comparison between self and others is thought to be a prerequisite for understanding others as intentional agents, and the ability to make inferences about their emotions/thoughts/intentions (termed emotional intelligence) (Cascio, Foss-Feig, Burnette, Heacock, & Cosby, 2012; Gallese, 2003).

Emotional intelligence is considered a top-down factor of body ownership, as it relates to the ability to monitor both one's own and others' feelings and emotions, to discriminate among them, and to use this information to guide one's thinking and actions (Salovey & Mayer, 1990). Emotional intelligence can be broken down into four categories: 1) the perception and expression of emotion, which involves identifying and expressing emotions in one's own feelings and thoughts, and also in other people; 2) the assimilation of emotion in thought; 3) the understanding and analyzing of emotions (the ability to label emotions); and 4) the reflective regulation of emotion (Mayer, Caruso, & Salovey, 1999).

Prior findings have demonstrated that higher interoceptive accuracy when assessing bodily sensations is associated with more intense emotional experiences, better identification of one's own emotions, and lower levels of alexithymia (Bornemann & Singer, 2016). Interoceptive accuracy has also been implicated in emotion processing and emotion regulation (Koch & Pollatos, 2014), emotional experience (Barrett, 2004; Wiens, 2005), and empathic abilities (Fukushima, Terasawa, Umeda, 2011).

In the study at hand, we exploratorily examined the relationship between interoception and emotional intelligence through the use of the HBP, RHI and Geneva Emotion Recognition Test-Short (GERT-S). Cardiac sensitivity has been found to be weakly but positively related to interpersonal emotional intelligence and adaptability (Koch & Pollatos, 2014). Other work has also illustrated that the RHI may be driven by empathic function (Asai, Mao, Sugimori, & Tanno, 2011; Durgin, Evans, Dunphy, Klostermann, & Simmons, 2007). Specifically, that cognitive components of empathy, which includes the ability to adopt the perspective of others by imagining their cognitive state based on situational cues, may allow for the generation of anticipation of the RHI experience in ourselves (Rankin et al., 2006; Asai et al., 2011). Emotional components of empathy–including the ability to recognize and comprehend other people's emotions–has also been shown to influence subjective feelings of body ownership during the RHI (Rankin et al., 2006; Asai et al., 2011; Cascio et al., 2012). As well, emotional intelligence has been found to be a predictor of the subjective perception of hand ownership, indicating that higher emotional intelligence may improve multisensory integration in the RHI (Pereplkina, Boboleva, Arina, & Nikolaeva, 2017). Finally, previous research has illustrated a small, but significant advantage for women in emotion recognition (ERA) tasks (Schlegel, Grandjean, & Scherer, 2014). However, many have not found a sex-effect in favour of women (Hall, 1978; Schlegel & Scherer, 2016).

### 1.5 Scope of the Present Study

In this paper, we will discuss one multi-component experiment designed to exploratorily examine the relation between interoceptive and exteroceptive information in the context of body ownership. The primary aim of the present study was to replicate prior findings on the effect of interoceptive accuracy–as measured via a HBP task–on proprioceptive drift and subjective experience during an exteroceptive RHI task (Tsakiris et al., 2011). This study also sought to resolve the conflict in the literature about sex-differences in cardiac accuracy. We hypothesized that higher interoceptive accuracy in the HBP task would correlate with decreased body ownership malleability during the RHI, and that males would be more accurate in the HBP task. The secondary aim of the study was to examine the connection between emotional intelligence—specifically the sub-component of emotion recognition ability—on both interoceptive accuracy during the HBP task and subjective RHI experience (Schlegel & Scherer, 2016; Roberts, MacCann, Matthews, & Zeidner, 2010; Scherer, 2007). We expected that individuals who were better able to recognize emotions in the GERT-S would be more accurate in the HBP task, but potentially more vulnerable to the RHI. We hoped that by conducting both a replication and an exploratory investigation, we would be able to better understand the connection between interoception and exteroception.

## Chapter 2: Methods

*Participants*

51 right-handed participants (23 males), average age of 18.7 years, were recruited from the McMaster University undergraduate psychology subject pool using SONA. Participants were provided with either one course credit per hour or $12 per hour for their participation. All participants had either normal or corrected-to-normal vision and were naïve to the purpose of the study. Written informed consent was obtained prior to beginning the experiment. All procedures were completed in accordance with the Canadian Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans (TCPS2). 8 participants were excluded from data analysis due to absences or technical difficulties that occurred during testing.

*Apparatus and Stimuli*

During the HBP task, participants sat at a table (height of 73.7 cm) with their forearms resting on the tabletop. In order to obtain an exact number of how many heartbeats occurred during each trial, the HRV4Training smartphone application was used (Altini & Amft, 2016). HRV4Training utilizes smartphone-integrated sensors (the camera lens and flashlight) for photoplethysmography (PPG) and has been validated as a reliable measure of heart rate and heart rate variability estimation (Altini & Amft, 2016; Plews, Laursen, & Buchheit, 2017). The application was run on both iOS and Android smartphones. Participants were instructed to press their index finger over the camera and flash of the smartphone in order to obtain an accurate reading. Measurements were recorded once the application deemed the contact with the index finger to be 'optimal'.

For the RHI portion of the experiment, a wooden occluder box was used to obscure the participant's left hand from view (Figure 1). The box had two open faces that were on the side closest to the experimenter and on the side closest to the participant. The rubber hand was composed of a foam core overlaid with a lifelike flesh-coloured exterior. Two identical 60-mm width paintbrushes were used to brush both the participant's hand and the rubber hand. The participant's arms were covered using a navy-blue piece of fabric to obstruct the view of their actual hand and conceal the proximal end of the rubber hand. Participants used coloured pencil crayons to indicate the position of their left index finger on a piece of paper mounted under the occluder after each trial (Figure 2). After marking the location of their left index finger, participants completed an embodiment questionnaire. The self-report measure consisted of a 10-item closed response questionnaire that utilized a 7-point Likert scale, ranging from -3 to +3. Negative values indicated varying levels of disagreement with the statement (-3 representing strongly disagree) and positive values indicated levels of agreement (+3 representing strongly agree). A score of 0 indicated the participant was undecided or indifferent to the statement. Participants were asked to describe their experience during the RHI by rating their level of agreement with statements such as "It seemed like the rubber hand began to resemble my hand," and "It seemed like I could have moved the rubber hand if I had wanted."

*Questionnaires*

Participants completed three questionnaires prior to beginning the experiment. The questionnaires used were the Body Awareness Questionnaire, Multidimensional Assessment of Interoceptive Awareness, and the Geneva Emotion Recognition Test (Short). After completing the questionnaires, participants completed the HBP task before moving on to the RHI.

Body Awareness Questionnaire (BAQ)

The BAQ is designed to quantify attentiveness to bodily functions and processes (Mehling et al., 2009). This self-reporting tool consists of 18 questions rated on a 7-point Likert scale (where 1 = not at all true of me, 7 = very true of me). Items assess vigilance to normative and non-emotive bodily processes, awareness of minute changes in typical functioning, and the ability to predict or anticipate physical or emotional reactions (Shields, Mallory, & Simon, 1989). A high mean score indicates high self-reported sensitivity to cues. Previous studies have demonstrated the BAQ's validity and reliability (Shields et al., 1989).

Multidimensional Assessment of Interoceptive Awareness (MAIA)

The MAIA quantifies an individual's self-reported level of interoceptive body awareness (Mehling et al., 2012a). The measure contains 32 items and uses a 5-point Likert scale (i.e. 0 = never and 5 = always) to score how applicable each statement is to participants' daily lives. Participants were asked to evaluate their abilities in 8 facets of interoception:

Noticing, Not Distracting, Not Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, and Trusting (Mehling et al., 2012a).

Geneva Emotion Recognition Test (Short) (GERT-S)

A shorter adaptation of the GERT, the GERT-S is a computer-administered measure developed to quantify emotional intelligence using emotion recognition ability (Schlegel et al., 2013). The GERT-S consists of 42 items sampled from the full version of the GERT. These items are multimodal portrayals, where facial, bodily, and vocal cues are available, of emotions performed by trained actors (Schlegel et al., 2013). After viewing a short clip, participants select which emotion they believe was depicted (Schlegel et al., 2013). Participants must choose one of fourteen (six positive, eight negative) listed emotions (Schlegel et al., 2013).

*Procedure*

Prior to completing the HBP task, participants were seated at a table and given verbal instructions to not take their pulse during trials. Participants were instructed to place their index finger over the camera and flash of the smartphone device. Verbal start and stop cues were given by the experimenter for each trial. Every participant began with a 15-second practice interval before beginning the four trials. Trials were 30-seconds, 40-seconds, 50-seconds, and 100-seconds in length. Immediately following each trial, participants were instructed to write down the number of heartbeats they counted, and to rate their confidence on a Likert scale from 1-7 (where 1 = no confidence and 7 = very high confidence). The actual number of heartbeats—obtained via PPG—was documented by the experimenter after each trial. No feedback was given to the participant on the length of the interval or their accuracy. Trials were counterbalanced between participants.

In between the HBP task and the RHI, participants completed a tactile temporal order judgement (TOJ) task. Participants held one tactile vibrator in each hand during the task, which were held so that the thumbs were in contact with the buttons. Half of the experiment blocks were completed with hands in an uncrossed posture, and half with hands crossed right over left. Each trial consisted of two short vibrations, one to each thumb. Participants pressed the button corresponding to the hand that was stimulated first, regardless of hand posture. If participants did not provide a response within three seconds, both devices would vibrate three times. Trials would resume once the participant pressed both buttons. Before beginning the experimental blocks, participants received verbal instructions and then completed two blocks of sixteen practice trials, one in each hand posture. On each trial, the participant was responsible for selecting which stimulus had been presented first by pressing the respective button. During the hands crossed block, hands were crossed right over left and the arms remained touching. After practicing, participants completed four blocks (that each consisted of 64 trials) and alternated between crossed and uncrossed postures every block. The starting posture was counterbalanced between participants to control for order effects. The data from this portion of the study will not be included in this thesis.

For the RHI segment of the experiment, participants were asked to sit facing the occluder. They were then prompted to put their left-hand palm-side down inside of the occluder and to assume the same hand posture as the rubber hand. The experimenter then positioned the participant's hand inside the occluder at one of two positions: position A, 34.5 cm to the left of the middle of the occluder and position B, 11.5 cm to the left of the middle of the occluder. At this time, participants were given a coloured pencil crayon to use to mark the location of their left index finger after the trial was complete. The experimenter then draped a navy cloth over their arms and shoulders to create the illusion that the rubber hand was their own left hand. Prior to beginning the brushing, verbal instructions were given to look only at the rubber hand during the brushing, and to refrain from moving either of their actual hands during the trial.

Each participant underwent two experimental blocks that consisted of two trials each. All trials were 30-seconds in length. In one block, the participant had their left hand aligned in position A, and the rubber hand aligned in position B. In the other block, the participant had their left hand aligned in position B, and the rubber hand aligned in position A. Each block consisted of one trial with synchronous brushing, and one trial with asynchronous brushing. Block and trial order were counterbalanced between participants.

Synchronous brushing consisted of the two paintbrushes being brushed in the same direction, whereas asynchronous brushing consisted of the two paintbrushes being brushed in 180-degree opposite directions. Both hands were brushed for 30 seconds before participants were asked to indicate the location of their left index finger by drawing a vertical line on a sheet of paper affixed under the occluder using their right hand. After drawing the line, participants then completed an embodiment questionnaire. Once the questionnaire was completed, participants moved on to the next trial.

Participants returned between one and seven days later to complete the experiment a second time. All measures were administered in the same order. Modified verbal instructions were provided by the experimenter to the participant before beginning each measure.


Figure 1: Photograph taken from the experimenter's point of view. The experimenter sat across the table from the participant. The participant's left hand was placed under the occluder (seen here in section B), and the rubber hand was placed on the table's surface (seen here in section A). Two 30-second trials were conducted with the hands in the position seen here, and two 30-second trials were conducted with the real hand is section A and the rubber hand in section B. Blocks of trials were counterbalanced across participants.

Figure 2: After each 30-second trial, the participant had to mark the location of their left index finger on a piece of paper mounted under the occluder.

# Chapter 3: Select Results

## 1.1 Interoceptive Accuracy Calculations

Interoceptive accuracy was calculated according to the following transformation:

$$\frac{1}{4}\Sigma(1-\frac{(|recorded\ heartbeats-counted\ heartbeats|)}{recorded\ heartbeats}$$

Using this equation, interoceptive accuracy on the HBP task was calculated as a mean score of the four different time intervals. Scores varied between 0 and 1, with scores closer to a value of 1 indicating small discrepancies between recorded and counted heartbeats (i.e. a higher level of interoceptive accuracy). Individual statistics were calculated as interoceptive accuracy is usually considered a trait, and thus may be subject to interindividual differences (Tsakiris et al., 2011).

## 1.2 Interoceptive Accuracy & RHI Proprioceptive Drift

Proprioceptive drifts were calculated as the difference between the post-synchronous trial location judgements and the post-asynchronous trial location judgements. Positive values represent a mislocalization towards the rubber hand.

Four planned one sample t-tests (hand position A/B, session 1/2) comparing mean proprioceptive drift to zero were conducted, and proprioceptive drift was not significantly different from zero in any of the conditions ($p = .101–.756$). These non-significant comparisons indicate that proprioceptive drift was not measured in any of the hand positions.

Due to our failure to establish proprioceptive drift during the RHI, we have omitted any analyses examining the relation between the RHI task and other measures in this paper.

### 1.3 Interoception Analyses

Data was analyzed using descriptive statistics, bivariate Pearson correlations, independent samples t-tests, Fisher's Z-tests, and repeated-measures ANOVAs. An alpha value of .05 was used as the significance criterion unless multiple variable correlations were computed, in which case Bonferroni corrections were then used.

#### 1.3.1 Interoceptive Accuracy

Interoceptive accuracy—as measured by the HBP task—on Day 1 was positively correlated with accuracy on Day 2 ($r = .542$, $p < .000$, $n = 51$), indicating that interoceptive accuracy was consistent over time (Figure 3). When split by sex, interoceptive accuracy on Day 1 was also positively correlated with accuracy on Day 2 (Males: $r = .617$, $p = .002$, $n = 23$; Females: $r = .478$, $p = .010$, $n = 28$). The difference between these correlations was not statistically significant ($Z = 0.67$, $p = .503$), illustrating that both males were not more reliable than females. In addition, a paired samples t-test demonstrated that there was no significant difference in HBP accuracy scores between Day 1 ($M = .670$, $SD = .155$) and Day 2 ($M = .697$, $SD =.156$) for the whole subsample; $t(-1.321)$, $p = .192$. In combination with the significant correlation ($r = .542$, $p < .000$, $n = 51$), this non-significant t-test indicates that participants' performance was stable across session days. Paired sample t-tests were also non-significant when participants were split by sex ($p = .272–.412$), indicating that both female and male participants' accuracy scores were stable.

### 1.3.2 Interoceptive Sensibility

Overall interoceptive sensibility—as measured by participant's confidence ratings on a post-trial questionnaire—was significantly correlated between Day 1 and Day 2 ($r = .760$, $p < .000$, $n = 51$) (Figure 4). Interoceptive sensibility was also correlated between days for females ($r = .756$, $p < .000$, $n = 28$), and males ($r = .754$, $p < .000$, $n = 23$). The difference between these correlations was not statistically significant, $Z = -0.02$, $p = .984$. These results indicate that interoceptive sensibility ratings for both the whole subsample and both sex groups were similarly reliable across session days.

### 1.3.3 Repeated Measures ANOVA

HBP accuracy scores were submitted to a 2x2x4 ANOVA with the between-participants factor of sex (male vs. female), and within-participant factors of day (Day 1 vs. Day 2), trial length (30s vs. 40s vs. 50s vs.100s). Greenhouse-Geisser corrections were made when appropriate, and adjusted p-values were reported. There was a significant within-subjects main effect of trial length, $F(3, 147) = 6.618$, $p < .000$, indicating that as trials got longer, participants' accuracy scores worsened. A non-significant between-subjects effect of sex was also observed, $F(1, 49) = 2.939$, $p = .093$, demonstrating that interoceptive accuracy scores did not differ significantly between sexes (i.e. there was no sex difference). A post-hoc power analysis was also performed for sample size estimation based on the data from this study. The projected sample size needed for an effect size of 0.8 and an alpha of .05 is approximately N = 42 for each sex group.

### 1.4 Multidimensional Assessment of Interoceptive Awareness (MAIA)

After applying a Bonferroni correction for multiple comparisons, interoceptive accuracy in the HBP task was not correlated with any of the eight interoceptive awareness MAIA scales on either day (correlation coefficients and p-values can be found in Table 1 & 2). This suggests that participants' interoceptive accuracy abilities were not related to the eight facets of interoceptive sensibility as measured by the MAIA.

The MAIA consisted of 32 items ($\alpha = .888$), indicating that there is a high level of internal consistency for this scale. Scores in each of the eight sub-sections of the MAIA were observed to be strongly positively correlated between sessions (Table 3). There was no significant difference between correlations for males and females, with the exception of the *Emotional Awareness* sub-scale ($Z = 2.09$, $p = .0366$). The non-significant differences indicate that males and females scores were similarly reliable across sessions in 7 of the 8 sub-scales, and the significant difference suggests that female scores were significantly more reliable in the *Emotional Awareness* sub-scale.

### 1.5 Geneva Emotional Recognition Test-Short

There was a significant positive correlation between GERT-S scores on Day 1 and Day 2 across all participants, $r = .633$, $p < .000$, $n = 51$ (Figure 5). Emotion recognition scores were also positively correlated for both males ($r = .515$, $p = .012$, $n = 23$), and females ($r = .705$, $p < .000$, $n = 28$) when analyzed separately. However, the difference between these correlations were not significant, $Z = -1.03$, $p = .303$. This indicates that both females and males, as well as the sample as a whole, had reliable emotion recognition scores across time. In an independent samples t-test, there was a significant difference in the scores between females ($M = .6428$, $SD = .0895$) and males ($M = .5766$, $SD = .0879$) on Day 1 ($t(49) = 2.651$, $p = .011$), but not Day 2 ($p = .301$). These results suggest that there may not be a sex difference in emotion recognition ability if the task is repeated (i.e. males may benefit from a small practice effect).

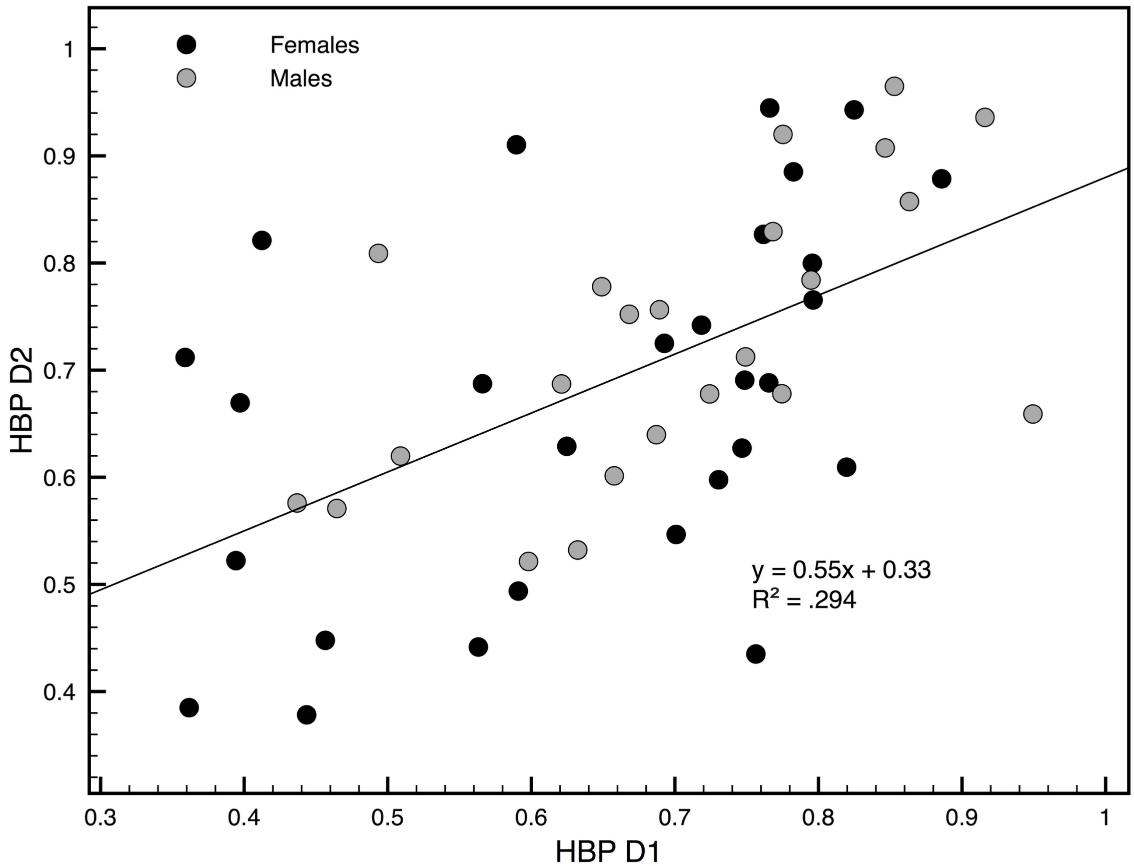


Figure 3: Overall interoceptive accuracy reliability as measured by the HBP task. Interoceptive accuracy on Day 1 was significantly correlated with interoceptive accuracy on Day 2 ($r = .542$, $p < .000$, $n = 51$). There was no difference in reliability between sex groups.

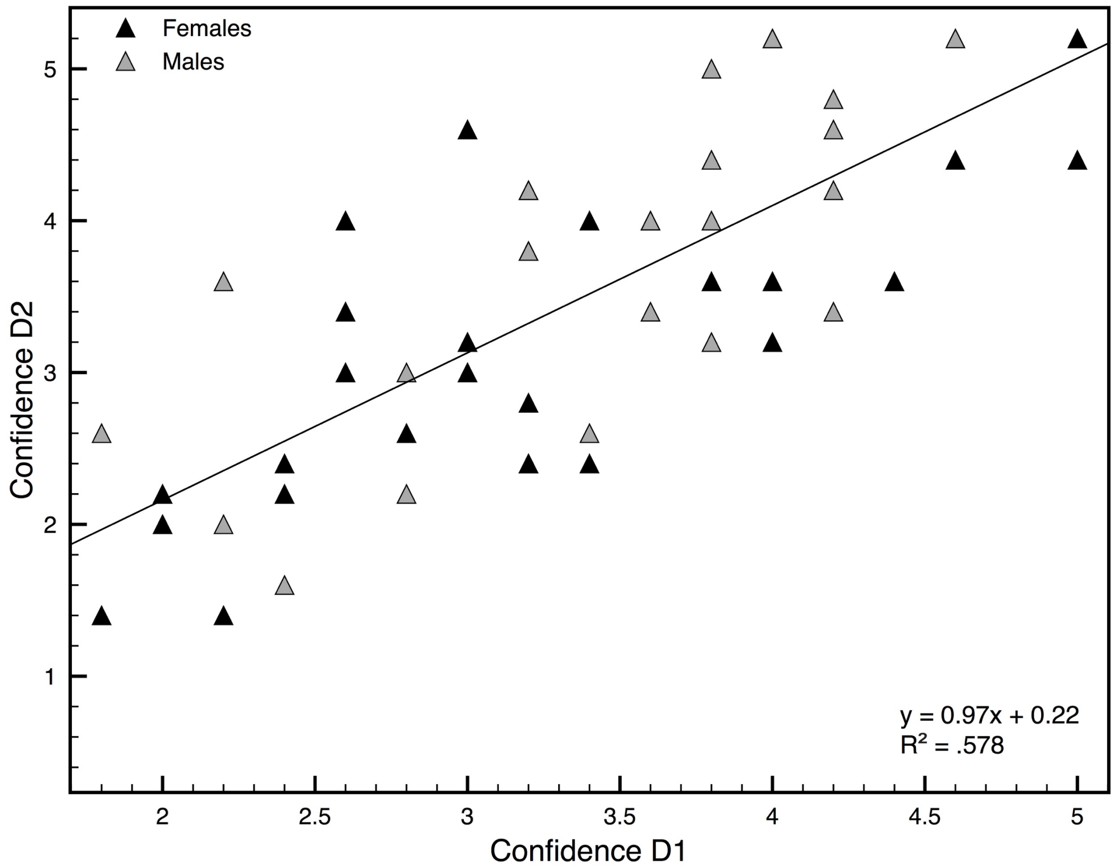


Figure 4: Overall interoceptive sensibility reliability as measured by self-rated confidence after each HBP task trial. Interoceptive sensibility on Day 1 was significantly correlated with interoceptive sensibility on Day 2 ($r = .760$, $p < .000$, $n = 51$). There was no difference in sensibility reliability between sex groups.

| Scale (Questions) | Both genders | | Males | | Females | |
|---|---|---|---|---|---|---|
| | r | p | r | p | r | p |
| Noticing | .332 | .017 | .177 | .420 | .405 | .032 |
| Not-Distracting | .064 | .654 | -.017 | .940 | .065 | .744 |
| Not-Worrying | .183 | .199 | -.224 | .304 | .355 | .063 |
| Attention Regulation | .184 | .196 | -.045 | .838 | .314 | .103 |
| Emotional Awareness | .082 | .565 | -.077 | .725 | .299 | .122 |
| Self-Regulation | .251 | .075 | -.048 | .829 | .437 | .020 |
| Body Listening | -.046 | .750 | -.192 | .379 | .090 | .649 |
| Trusting | .287 | .041 | -.026 | .906 | .439 | .019 |

Table 1: Correlation coefficients and corresponding p-values between Day 1 MAIA scores and Day 1 accuracy on the HBP task. Significance after applying a Bonferroni Correction for multiple comparisons are in Bold.

| Scale (Questions) | Both genders | | Males | | Females | |
|---|---|---|---|---|---|---|
| | r | p | r | p | r | p |
| Noticing | .203 | .153 | -.104 | .637 | .496 | .007 |
| Not-Distracting | -.121 | .396 | -.376 | .077 | .043 | .0827 |
| Not-Worrying | .198 | .164 | -.029 | .896 | .284 | .143 |
| Attention Regulation | .110 | .443 | -.072 | .744 | .230 | .240 |
| Emotional Awareness | .143 | .317 | .006 | .978 | .415 | .028 |
| Self-Regulation | .164 | .250 | -.141 | .522 | .388 | .041 |
| Body Listening | .094 | .512 | -.083 | .708 | .189 | .337 |
| Trusting | .173 | .224 | -.407 | .054 | .414 | .028 |

Table 2: Correlation coefficients and corresponding p-values between Day 2 MAIA scores and Day 2 accuracy on the HBP task. Significance after applying a Bonferroni Correction for multiple comparisons are in Bold.

| Scale (Questions) | Both genders | | Males | | Females | |
|---|---|---|---|---|---|---|
| | r | p | r | p | r | p |
| Noticing | .472 | **<.000** | .621 | **.002** | .398 | .036 |
| Not-Distracting | .652 | **<.000** | .694 | **<.000** | .611 | **<.000** |
| Not-Worrying | .801 | **<.000** | .769 | **<.000** | .812 | **<.000** |
| Attention Regulation | .788 | **<.000** | .750 | **<.000** | .824 | **<.000** |
| Emotional Awareness | .820 | **<.000** | .905* | **<.000** | .703* | **<.000** |
| Self-Regulation | .736 | **<.000** | .738 | **<.000** | .740 | **<.000** |
| Body Listening | .767 | **<.000** | .710 | **<.000** | .816 | **<.000** |
| Trusting | .868 | **<.000** | .922 | **<.000** | .851 | **<.000** |

Table 3: Correlation coefficients and corresponding p-values between Day 1 and Day 2 MAIA scores. Significance after applying a Bonferroni Correction for multiple comparisons are in bold. Asterisk denotes significantly different male-female correlations.

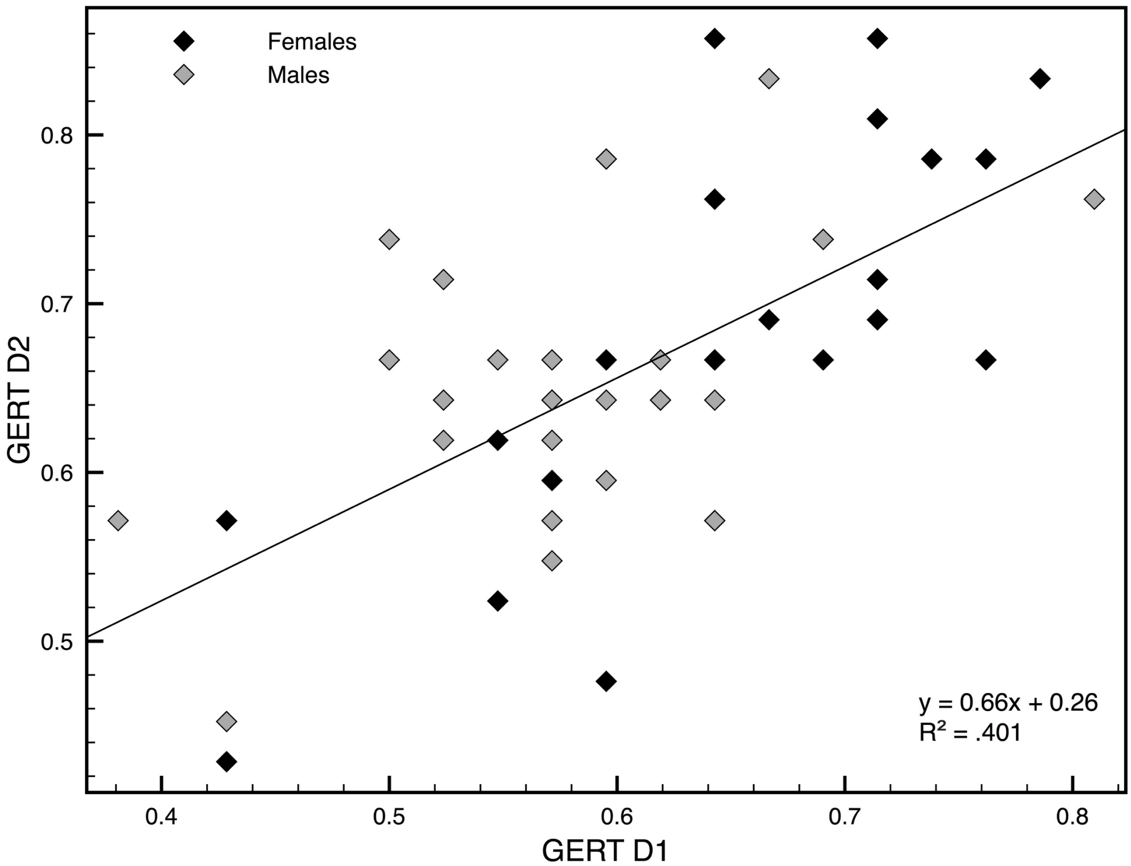


Figure 5: Overall emotion recognition reliability as measured by the GERT-S. ERA on Day 1 was significantly correlated with ERA on Day 2 ($r = .633$, $p < .000$, $n = 51$).

## Chapter 4: Discussion

The primary aim of this study was to explore the association between endogenous (interoceptive) and exogenous (exteroceptive) information in the context of body ownership. This was achieved through the use of a HBP task to measure interoceptive accuracy, and the use of the RHI as a measure of body ownership malleability. The secondary aim of the present study was to exploratorily investigate the influence of emotional intelligence—specifically the facet of emotion recognition ability—on interoceptive accuracy and subjective RHI experience.

Unfortunately, we failed to measure proprioceptive drift during the RHI task and were thus unable to address the main objective of this paper. Although this was unexpected, this result may be due to a combination of task-related factors. For example, the incorporation of the rubber hand into one's own bodily experience has been shown to depend on the matching of visual and tactile stimulation (Asai et al., 2011). Thus, it is possible that by using experimenters who do not have extensive practice inducing the RHI, we were unable to consistently provide participants with truly synchronous stimuli. In addition, induction of the RHI has been shown to be modulated by congruency between the rubber hand and the actual hand (Tsakiris et al., 2011; Tsakiris, Longo, & Haggard, 2010; Asai et al., 2011). Incongruities between the viewed and felt body part—such as visual, postural, and volumetric differences—can result in a reduced illusory experience (Tsakiris et al., 2011; Tsakiris et al., 2010; Asai et al., 2011). Since we used a light coloured, average female-sized hand for all participants, visual incongruities may have also contributed to our failure to establish a consistent RHI.

That being said, we were still able to use the HBP task to evaluate interoceptive accuracy. Like many others, we illustrated that interoceptive accuracy has good test–retest reliability (Knoll & Hossap, 1992), and failed to demonstrate a sex difference in interoceptive accuracy (Mussgay et al., 1999; Pollatos & Schandry, 2004; Franzoi et al., 1989). Interestingly, we demonstrated a main effect of trial length, indicating that participant's ability to accurately mentally track heartbeats decreased as trial length increased. To our knowledge, mental tracking ability as a factor of trial length has not been studied extensively in adults. However, this finding is similar to related literature that demonstrated that typically developing children are worse at sustaining attention to internal cues (e.g. mental tracking for longer periods of time) than children with ASD (Schauder, Mash, Bryant, & Cascio, 2015).

We also tested if interoceptive accuracy on the HBP task was related to interoceptive awareness as measured by the MAIA. We did not replicate the most recent finding of a negative correlation between interoceptive accuracy and the *Body Listening* scale of the MAIA (Grabauskaite et al., 2017). However, we successfully replicated older studies that did not find associations between questionnaire scores and interoceptive accuracy (Meessen et al., 2016; Dudley & Stevenson, 2016). The failure to find a correlation between interoceptive accuracy and interoceptive sensibility—despite both measures being highly reliable—suggests that these two facets of interoception may be driven by distinct processes and not actually be interrelated. In addition, we also demonstrated that all eight sub-sections of the MAIA were reliable between sessions, and that females and males were equally reliable (with the exception of the *Emotional Awareness* scale).

As a final investigative component of our experiment, we showed that emotion recognition ability—as measured by the GERT—was reliable for the whole subsample, as well as for each of the sexes. Although we did find that females had higher GERT scores—and thus better ERA—on Day 1, this sex difference was not found during Day 2. Unfortunately, this result does not help us resolve the conflict in the literature about sex differences in ERA (Schlegel et al., 2014; Hall, 1978; Schlegel & Scherer, 2016). We speculate that we did not observe a sex difference because males scores increased slightly on Day 2—potentially indicating that they benefited from a small practice effect when the task was repeated. In addition, we also failed to demonstrate that interoceptive accuracy on the HBP task was correlated with interpersonal emotional intelligence (Koch & Pollatos, 2014).

This exploratory endeavor into the relation between interoception and exteroception leaves us with more questions than answers, highlighting the need for further research into this topic. Future studies should focus on how sex differences play a role in interoception, but also how interoceptive and exteroceptive signals are integrated to establish body ownership. Interoception forms the basis for psychological identity and bodily self-consciousness, and the effect of interoception on exteroceptive body representations should be considered as a possible contributing factor to the development and maintenance of eating disorders (Longo et al., 2008). By viewing oneself from an appearance-based and self-objectifying perspective, the integration of bodily experiences (from both within and from the outside) may be severely impaired (Tsakiris et al., 2011). Previous findings indicate that individuals with Anorexia have reduced interoceptive awareness, and that individuals with unstable perceptual body image are the most easily and convincingly affected by illusions such as the RHI (Pollatos et al., 2008; Mussap & Salton, 2016). Future studies should consider testing individuals with eating disorders or body perception disorders in order to compare how interoception differs between them and the general population. In addition, future work should investigate if all aspects of interoception are disrupted in this clinical population by using a multi-faceted evaluation tool such as the MAIA.

The present study demonstrated that there are no sex differences in interoceptive accuracy, and that interoceptive accuracy is not correlated with interoceptive awareness or emotion recognition ability. However, these results represent the interindividual differences of a very small sample with unbalanced sex groups. Additional research is needed to fully explore the multidimensionality of interoception, and to discover the mechanisms for each facet of interoception that has already been defined. This paper prompts the importance of the continued study of these cognitive processes that shape how we navigate the world and interact with those around us.

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