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QUANTIFYING PERCEPTION OF THE INTERNAL:

Investigating the temporal stability of temperature perception as an interoceptive measurement

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Abstract

Interoception refers to the sensation of internal bodily signals. When studying sensory perception, one needs measurements for assessing individual abilities. Individual interoceptive abilities have mostly been measured by a heartbeat counting task, however recent criticism towards the validity of the task has surfaced. A limiting factor remaining for interoceptive research is the lack of standardized valid measurements for individual abilities. In this context, new measurements have been proposed, such as a thermal matching task. In the present study, I examine the reliability of the new thermal matching task, as well as the relationship between skin-mediated interoceptive sensations and cardiac interoception. The thermal matching task was found to be temporally stable on the dorsal forearm, but not on the dorsal hand or palm. Furthermore, participants were significantly better at the task on the dorsal forearm compared to dorsal hand and palm. There were also differences in the task between genders, however whether this is due to gender effects or associated confounding variables remains unclear. The thermal matching task shows potential to be included as a measure for thermal perception in an interoceptive context. Future research should address the relationship between the thermal matching task and other measurements of thermal perception.

Keywords: Interoception, interoceptive accuracy, thermal perception, reliability

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1. Investigating the Reliability of Temperature Perception as an Interoceptive Measurement

1.1. Background of the Concept Interoception

The first use of terms relating to interoception occurred more than over one-hundred years ago. Sherrington (1906) used terms such as “interoceptive receptor fields” and “interoceptors” to describe the perception of the viscera, or the internal. Sherrington (1906) contrasted this with exteroception, or perception of the external, and proprioception, or feeling of bodily position. Between these respective categories, Sherrington (1906) split human perception based on the origin of the stimulus. Sensations such as seeing and hearing were unsurprisingly categorized as exteroception, while muscle tension is the key component of proprioception. However, the first use of the term “interoception” occurred first during the 1940 (Ceunen, Vlaeyen, & Van Diest, 2016), although the term was based on the definitions by Sherrington (1906). The interoception as described by Sherrington (1906) was as such limited to sensations originating from the visceral organs, such as heart, lungs, and gut. Today the view on perception is not as clear cut. It is more common to categorize sensations not on their origin, but either by their function or their neuroanatomy. Further, integration is constant across sensations regardless of which of Sherrington’s (1906) receptive fields they belong to. As such, the boundaries between what is interoceptive and exteroceptive is not as clear cut as initially proposed. Interoception is now more of an umbrella term for the phenomenological experience of the present body state, rather than only perception of visceral organs (Ceunen, et al., 2016).

The origin of this shift in the definition of interoception can be partially traced back to two papers written by Craig (2002, 2003). Almost one hundred years after the publishing of Sherrington’s *The integrative action of the nervous system*, Craig (2002, 2003) proposed a remodelling of interoception. Craig (2002, 2003) suggested that interoception should cover not only visceral sensations, but rather all signals reflecting the homeostatic need of the body. With this change in definition of interoception, many sensations previously thought of as exteroceptive were reclassified as interoception. These were for example pain, itch, sensual touch, and temperature. These sensations were previously considered as a part of the exteroceptive modality of touch but are now thought of as interoceptive. This might seem counter-intuitive, but they relay important homeostatic information to the brain about the condition of the body (Craig, 2002, 2003). Not only are they functionally connected to the maintenance of homeostasis, but these new sensations also in part have common neuroanatomy with the classical visceral sensations (Critchley & Garfinkel, 2017). Seth (2013) supports the expansion of interoception and writes “one of the most relevant features of the world for a particular organism is the organism itself” (p. 567). In addition to this, there is a close connection between interoceptive sensations (such as the ones presented earlier) and emotional experiences (Craig, 2002; Wiens, 2005). Damasio (1994) argues a strong link between maintenance of homeostasis and emotional experiences, and a consequence of this is that survival coincides with a reduction of unpleasant bodily states. The link between the reclassified sensations and emotions is not obvious at first. To illustrate this, Craig (2008), used the example of a shower in two different settings. In the first, imagine on a cold winter day how, rewarding a warm shower can be. Yet, on a warm summer day, a cold shower will be equally rewarding. The sensation of temperature is therefore heavily reliant on the bodily needs (Craig, 2008).

Interoception has changed further than only regarding the sensations thought of as interoceptive. Garfinkel, Seth, Barrett, Suzuki, and Critchley (2015) proposed three dimensions of interoception, something further expanded upon by Garfinkel et al., (2016a). The authors argued that interoception is more than only sensory perception of homeostatic bodily signals. In addition to the basic sensory perception, the new model of interoception also includes our conscious processing of internal bodily signals, as well as beliefs of our own perception. This view of interoception is reflected in the three dimensions suggested by Garfinkel et al., (2015, 2016a). These three dimensions are (interoceptive-) accuracy, sensibility, and awareness. Interoceptive accuracy refers to the traditional approach of studying interoception, that is, behavioural study of objective performance in an interoceptive task. Interoceptive sensitivity refers to the self-reported sensitivity to bodily signals, often measured by questionnaires such as *body perception questionnaire* (Porges, 1993; as used in for example Garfinkel et al., [2016a]), *Body awareness questionnaire* (Shields, Mallory, & Simon, 1989; as used in Fiene and Brownlow, [2015]) or *Multidimensional Assessment of Interoceptive Awareness* (Mehling et al., 2012). Lastly, interoceptive metacognitive awareness refers to the relationship between the two previous dimensions and reflects the individual’s awareness to their own perception (Garfinkel et al., 2015, 2016a).

There seems to have been an underlying assumption that interoception is unitarily perceived, regardless of the particular modality studied. However, this is not fully agreed on (Murphy, Brewer, Hobson, Catmur, & Bird, 2018). Suggesting a unitary perceptive ability shared between classical exteroceptive modalities would be arbitrary. However, such a function is not known regarding interoception. Different methodologies have further limited comparable results between studies (Ferentzi, Drew, & Köteles, 2016). For example, performance between cardiac and gastric interoception has been found to correlate by Herbert, Muth, Pollatos, & Herbert (2012), however, Ferentzi et al., (2018a) were unable to replicate this finding. The idea of modality-specific interoceptive ability has recently gained support, (Crucianelli et al., in preparation; Ferentzi et al., 2018a) with studies indicating a lack of correlation between different interoceptive modalities. Support to this idea spans several interoceptive modalities, although studies are sparse on the topic. Garfinkel et al., (2015) found two different cardiac tasks to correlate, and Ferentzi et al. (2018a) found similar results but within gastric perception.

Interoception as a topic is very much still under development. Khalsa et al., (2018) demonstrate an increase in the amount of publications on interoception, from about 50 articles per year around 2005, to over 300 per year in 2015. As such, terminology may differ in older papers. The definitions established by Garfinkel et al. (2015, 2016a) will be used throughout this essay. Further, this essay is only concerned with interoceptive accuracy and objective measures. Being able to accurately measure the interoceptive ability of an individual is important, as without an objective measurement, one is left only with the subjective self-report. Further, the metacognitive awareness-dimension is directly dependent on comparing the subjective self-report with an objective measurement (Zamariola, Maurage, Luminet, & Corneille, 2018).

1.2. Interoception beyond only Homeostasis

As mentioned earlier, interoception is strongly related to emotional experiences. All the interoceptive sensations carry affective information used to direct behaviour to optimally maintain homeostasis (Craig, 2002; Wiens, 2005). Emotional experiences are connected to a bodily feeling, reflected even in common expressions such as “butterflies in the stomach” or “skipping a heartbeat” (Critchley & Garfinkel, 2017). Further, it has been shown that experimental manipulation of interoceptive signals induce a fear response (Makovac et al., 2015). While interoception is classically thought of as only afferent, meaning one way from the body to the brain, Seth (2013) argues interoception to be involved in both bottom-up and top-down processes, as the afferent stimulus directly causes not only an emotional shift, but also a behavioural change. Seth (2013) argues that the emotional experiences, or subjective states, arising from interoception are essential for a coherent sense of self. In addition to this, several clinical conditions with affective components show a link to altered interoceptive abilities (Quadt, Critchley, & Garfinkel, 2018).

Damasio (2003) argues that interoceptive signals are essential in the formation of sense of self, as they provide the brain with the knowledge of the status of the body. Gao, Ping, and Chen (2019) argue that the formation of body ownership is moderated in part by interindividual differences to stimuli originating from inside the body. Further support for the involvement of interoception in the formation of a coherent self comes from studies employing the rubber hand illusion paradigm (RHI). In the illusion, participants have their own hand stroked by a brush hidden that is hidden out of view. During the stroking, the participant is watching a rubber hand in front of them being stroked in synchrony with their own hand. This produces a sense of ownership over the rubber hand as if it were the persons own real hand (Botvinick & Cohen, 1998; Ehrsson, Holmes, & Passingham, 2005). The rubber hand illusion is primarily an exteroceptive task, dependent on the multisensory integration between visual, tactile, and proprioceptive signals. Crucianelli, Metcalf, Fotopoulou and Jenkinson (2013) found that the strength of the rubber hand illusion is enhanced when stroking occurs at velocities which elicit sensual touch, or CT-optimal velocities (expanded upon in section 1.3) relative to higher or lower stroking velocities. This indicates some role of interoceptive signals on the feeling of ownership of the rubber hand. Suzuki, Garfinkel, Critchley and Seth (2013) found that synchronous cardio-visual feedback using augmented reality strengthened the rubber hand illusion compared to asynchronous feedback. However, the link between interoception and susceptibility to the rubber hand illusion remains unclear, as results differ across studies. Tsakiris, Tajadura-Jiménez and Costantini (2011) found interoceptive accuracy to be negatively correlated with susceptibility to the RHI, arguing that poor interoception strengthens susceptibility to the RHI. This finding was replicated by Schauder, Mash, Bryant, and Cascio (2015). In contrast to this, Crucianelli et al. (2013) did not find any relationship between interoceptive accuracy and the sense of ownership of the rubber hand. Taken together, it seems interoception has some involvement in the formation of self. However, the full extent of this is still unclear as the task RHI paradigm is mainly exteroceptive and proprioceptive. Further, a link between specifically cardiac accuracy and the feeling of the self is limited and inconclusive.

1.3. Neurobiology of Interoception

The primary cortex associated with interoception is the insula (Craig, 2002, 2003). The insula is a part of the brain located beneath the sylvian fissure (Gasquoine, 2014; Nieuwenhuys, 2012), and is completely obscured from lateral view by other cortices. The insula has sometimes been referred to as the fifth cortex (Stephani, Fernandez-Baca Vaca, Maciunas, Koubeissi, & Lüders, 2010), and is further divided into anterior and posterior regions.

Contrasted with the other primary cortices, development of knowledge regarding the insula was slow, primarily due to its location, together with the lack of isolated insular lesions (Uddin, Nomi, Hébert-Seropian, Ghaziri, & Boucher, 2017). Its role was mostly limited to gustatory perception, much like the way Sherrington (1906) defined interoception. However, the insula has since been shown to be involved in several other processes alongside its gustatory function. Findings indicate the importance of the insula in viscerosensation, thermal- and pain perception (Stephani et al., 2010), but also in higher-order cognitive functions (Uddin et al., 2017). These include both self-awareness (further expanded upon in section 1.3) as shown by Karnath and Baier (2010), as well as socio-emotional processes such as emotional processing (Uddin et al., 2017).

The interoceptive function of the insula corresponds to all the three earlier discussed aspects. Many of the modalities reclassified as interoception (Craig, 2002, 2003) show insular activity. Furthermore, conscious attention directed towards interoceptive signals have also shown insular activity (Critchley, Wiens, Rohstein, Öhman, & Dolan, 2004). To further elaborate this, the insular activity (as measured by fMRI) was linearly correlated to interoceptive accuracy (or objective performance, as discussed earlier in section 1.1 on the dimensions of interoception). Lastly, the insula has been proposed to be the main integration point of bodily signals, and these signals are argued to be important for self-awareness (Craig, 2009; Damasio, 2003). Further, Suzuki (2012) argues that the insula is involved in the conscious perception of emotions, which is heavily dependent on the homeostatic needs of the body.

The peripheral component of interoception is dependent on the interoceptive modality, as well as the mediating organ. While the modalities classified as interoceptive are many, the present essay only considers the visceral organ of the heart and the peripheral organ of the skin. More specifically, skin-mediated interoception limited to dynamic innoxious temperature perception. The cardiac signals are generated by baroreceptors that sense pressure and correspond to individual heartbeats, as opposed to a continuous signal. The baroreceptors are located in the aorta and carotid sinus (Garfinkel & Critchley, 2016; Schulz & Vögele, 2015). These relay the heartbeat signals via the vagus nerve onto the nucleus of the solitary tract in the brainstem, from where the signals reach the insula (among others) through thalamocortical projections.

Temperature is perceived by thermoreceptors, which are free nerve endings dispersed across the body (Waldman, 2009). There are several types of nerve-endings, with different sensitivity ranges (either warm or cold) and thresholds (either high or low, depending on the intensity of the temperature needed to signal) (Dhaka, Viswanath, & Patapoutian, 2006; Eliav & Gracely, 2008). Most of the thermoreceptors are phasic neurons, meaning they fire intensively for a short interval before habituation occurs (Waldman, 2009). From the respective thermoreceptor, the afferent signal enters the spinal cord at the dorsal horn and ascends through the lateral spinothalamic tract. The spinothalamic tract then terminates in the posterior thalamus, before being further projected to higher-order cortical areas such as the insula, anterior cingulate cortex, orbitofrontal cortex and somatosensory cortex, among others (Craig, 2002; Critchley, & Harrison, 2013; Stern et al., 2017). There is a division in the conduction velocity between warmth and cold nerve fibers. Heat perception is primarily transmitted along unmyelinated axons (with a low velocity), whereas cold perception is transmitted on myelinated axons (with a higher velocity) (Feher, 2017). It seems agreed upon that on the first sensory step, warmth and cold perception are different, although whether temperature perception is divided or unitary is not clear (Dhaka et al., 2006; Iannetti et al., 2003). There is support for both arguments, such as differences in sensitivity towards change between increasing and decreasing temperatures (Heldestad Lilliesköld & Nordh, 2018). However, Green and Akirav (2007) found perception of warmth and cold to highly correlate.

In addition to the earlier discussed thermal perception, the C-tactile fibers have shown preferential activity to stroking at neutral temperatures (32º), as compared to cold (18º) or warm (42º) (Ackerley et al., 2014). In addition, their firing patterns are different depending on if cooling or warming occurs (Ackerley et al., 2018). The C-tactile (or CT) fibers are unmyelinated, low-threshold mechanoreceptors found in hairy skin, that are stimulated by slow moving soft touch (Nordin, 1990; Olausson, Wessberg, Morrison, McGlone, & Vallbo, 2010; Vallbo, Olausson, Wessberg, & Norrsell, 1993). CT-afferent activity follows an inverse U-shape dependent on stroking velocity, with peak activity at three cm/s. Stroking between one and ten cm/s has been labelled as CT-optimal. In addition to the thermal involvement of the CT-afferents, CT activity has been shown to linearly correlate with subjective pleasantness (Löken, Wessberg, Morrison, McGlone, & Olausson, 2009). These fibers have been attributed to carrying the interoceptive sensation of sensual touch. Further, this type of touch has been suggested to carry an important social function, both for social bonding and communication (Morrison, Löken, & Olausson, 2009).

The link between body temperature and homeostasis is well defined, as described in depth over 50 years ago by Benzinger (1969). Thermoregulation is both a conscious behavioural process, such as preference towards a certain temperature (acquired for example by dressing accordingly) and an automatic response, such as sweating or shivering (Benzinger, 1969). Romanovsky (2014) argues that the glabrous skin present on the palm or foot sole is specialized in determining the specific heat of an object, as the body parts where this skin type is present are the typical contact parts. In contrast, the hairy skin is suggested to provide the brain with the necessary information for thermoregulation, as the hairy skin represents a more stable, environment-independent thermal information. Fealey (2013) argues that afferent neuronal pathway from thermoreceptors combines core (body) with shell (skin) temperature to provide thermal feedback to the brain. Skin-temperature is as such an integral component of thermoregulation. Further, Fealey (2013) argues that thermal discomfort, as well as the anticipation of thermal discomfort guide behaviour. Further, biological response (such as an increase in sweat gland activity) has been shown to follow afferent stimulus (thermal stimulation) in clinical studies. (Fealey, 2013).

1.4. Quantifying Interoception

Regardless of which sensory modality is investigated, standardized measurements are used to compare individual abilities, both cross-individuals and within individuals over time. The lack of standardized measurements for quantifying interoception has been one of the main limiting factors when studying interoception. The consequence of this is the extent to which results of one study could be transferred onto a new field is limited (Ferentzi et al., 2016). Standardized measurements of the interoceptive abilities of a person could potentially serve additional behavioural measurements for several clinical conditions. Clinical conditions such as anxiety, depression and autism spectrum disorder have all been linked to altered interoceptive abilities (Quadt et al., 2018). Standardized measurements are currently under development for several of the modalities of interoception. These include new measurements for studying gastric interoception (Ferentzi et al., 2018a; van Dyck et al., 2016) as well as respiratory interoception (Garfinkel et al., 2016b), and thermal interoception (Crucianelli, Enmalm, & Ehrsson, in preparation).

1.4.1. Cardiac interoception and the heartbeat counting task. While modalities included within the term interoception have increased, this is not reflected in standardized measurements for the newer modalities. In line with the classical definition of interoception as only encompassing visceral organs, these are also the modalities with the most established tests. One of the main tasks used when studying interoception is the heartbeat counting task (Schandry, 1981). In the task, participants are asked to silently count their own heartbeats between two given cues, without manually taking their pulse. Upon receiving a stop-cue, the participant reports the counted amount of heartbeats, which is compared to the real amount of heartbeats for the given period, as monitored by the researchers. A value between zero and one is then calculated corresponding to the accuracy of the counting relative to the real heartbeats, with values closer to one indicating a higher accuracy.

Criticism towards the heartbeat counting task was raised over 20 years ago by Ring and Brener (1992, 1996) who suggested that strategies and beliefs may underlie performance. This critique has recently gained more support, and further concerns regarding the validity of this task have been raised (Brener & Ring, 2016; Ring & Brener, 2018; Ring, Brener, Knapp, & Mailloux, 2015). The task has several issues associated with it. One such issue it that scores appear biased based on participant knowledge of normal heart rhythm (Brener & Ring, 2016). Furthermore, performance in the task seems to be influenced by strategies to detect heartbeats. These include detecting heartbeats in specific body parts or relying on estimates. Further, when participants were asked to count only truly felt heartbeats, participant's reported heartbeats were drastically reduced (Desmedt, Luminet, & Corneille, 2018). Zamariola et al., (2018) measured the heartbeat counting task in a large sample (*n*=572) and found 95% of reports where underestimations of the amount of heartbeats. The authors reason these under-reports may be due to several affecting factors, such as beliefs about heartbeat at rest and individual decision thresholds. In addition to this, scores were reduced for longer time intervals, whereas heartbeats remain relatively non-changing during such a short duration. This is speculated to be due to the task's reliance on attention (Murphy, Brewer, Hobson, Catmur, & Bird, 2018). This critique is not unique towards only the heartbeat counting task as other cardiac tasks, such as the heartbeat tracking task, also show similar issues (Brener & Ring, 2016).

1.4.2. Thermal interoception and the thermal matching task. Crucianelli et al., (in preparation) introduced an interoceptive battery which covers several interoceptive modalities, in order to more accurately describe the interoceptive abilities of an individual. Included in the interoceptive battery is a new measurement of skin-mediated interoception, the thermal matching task. Participants are shown a reference temperature by a short stroke with a thermode (a small probe capable of delivering thermal stimuli). Following the reference temperature, the participant is then asked to match it with one of the temperatures stimulated after. The task employs a modified version of a staircase design which is commonly used in psychophysics (Cornsweet, 1962), as temperature changes occur either with an increasing or decreasing scale. The temperature changes between strokes occur between strokes in discrete steps of two degrees (the procedure is further expanded upon in section 2.2.). There is support indicating differences between warming and cooling perception (Hua, Strigo, Baxter, Johnson, & Craig, 2005). The extent to which this task is dependent on beliefs or strategies is not known yet due to only one paper employing it (Crucianelli et al.,).

1.4.3. Relationship between cardiac and skin-mediated interoception. As discussed in section 1.1, the relationship between different interoceptive modalities is relatively uncharted. Studies investigating a link between cardiac interoception and skin-mediated interoception have been inconclusive. As discussed earlier (Section 1.2), there have been varying results regarding interoception and the rubber hand illusion. Out of these studies, Crucianelli et al. (2013) found no link between affective touch and cardiac accuracy. On the contrary to this, Crucianelli et al. (in preparation) found a link between thermal perception on the forearm (skin containing CT-afferents) and cardiac accuracy. This relationship was not found on the palm (CT-deprived skin). Further, a link between pain sensitivity and interoceptive accuracy has not been found (Werner, Duschek, Mattern, & Schandry, 2009). The lack of relationship between cardiac interoception and skin-mediated interoception is further supported by Agostinho, Canaipa, Honigman, and Treister (2019) who found no link between thermal-induced pain and cardiac accuracy.

1.5. Rationale for the Present Study

As mentioned, there is a demand for new standardized measurements of interoception (Murphy et al., 2018). Crucianelli et al. (in preparation) proposed a broadening of the standard interoceptive measurements. In addition to the classical heartbeat counting task (Schandry, 1981), the “interoceptive battery” included several externally generated interoceptive signals. Examples of these include affective touch, thermal perception measured either using a static method-of-limits (MOL) procedure or the thermal matching task, and pain perception (also measured by MOL). While affective touch has been studied rigorously (McGlone, Wessberg, & Olausson, 2014) and MOL has relatively well-established reference data (Heldestad, Linder, Sellersjö, & Nordh, 2010; Heldestad Lilliesköld & Nordh, 2018), the properties of the thermal matching task remains unclear. If the thermal matching task is to be used as an interoceptive measurement, the temporal stability (as measured by test-retest reliability) needs to be determined. In addition to this, the inconclusive relationship between cardiac interoception and skin-mediated interoception can be further studied using the task. Further, as Crucianelli et al., (in preparation) found differences between the body sites (dorsal forearm vs palm) the role of body site and skin-type will be further explored. In particular, the present study will employ the thermal matching task on three body sites, being the dorsal forearm, dorsal hand, and palm. The dorsal forearm and dorsal hand both contain hairy skin, with CT-afferents present, in contrast to the glabrous skin of the palm (Olausson et al., 2010; Vallbo et al., 1993). The CT-afferents show preferential activation to stimulation similar to the task (Ackerley et al., 2014, 2018). Further, perception of thermal stimulation differs across body sites (Mancini et al., 2014), and as such, the present study will also investigate potential differences across sites.

1.5.1. Aim and hypotheses. The aim of the present paper is to determine the reliability of the thermal matching task across the three body sites, as well as the relationship between the thermal matching task and cardiac accuracy. In order to assess the test-retest reliability of both the thermal matching task and classical heartbeat counting task, the full study will be done on two identical sessions.

There are several hypotheses in the present study. First, I hypothesize the cardiac accuracy to be temporally stable (Ferentzi, Drew, Tihanyi, & Köteles, 2018b). Further, the thermal matching task is hypothesized to be temporally stable on the dorsal forearm and dorsal hand (skin containing CT-afferents). In addition to this, thermal accuracy is hypothesized to be significantly better on the aforementioned sites compared to the palm. Lastly, I also hypothesize that thermal accuracy (specifically with decreasing temperatures) to correlate with cardiac accuracy, in line with Crucianelli et al., (in preparation).

2. Method

2.1. Participants and Sampling

33 participants were recruited, with an age range of 18-31 (*M* = 24.7, *SD* = 3.2*)*, of which 30 completed both experimental sessions. Reasons for not completing both sessions were sickness (*n* = 1) and cancellation of data collection (*n* = 2). The sample was gender balanced (15 males, 18 females). The study was approved by the Swedish Ethical Review Authority, and all participants gave written consent. The study was conducted in accordance with the declaration of Helsinki. Recruitment was done using social media and Karolinska Institutet advertising. Participants were reimbursed a total of 400 SEK for their participation (200SEK/session) at the end of the second testing session. Inclusion criteria comprised: (a) Being between 18-40 years old (as temperature perception seems to change with age, shown in Harju, 2002; Heldestad Lilliesköld & Nordh, 2018, among others), (b) being right-handed, (c) having no history of neurological or psychiatric conditions, (d) not taking psychoactive drugs or medication, (e) fluency in English, (f) No large scars, tattoos or other visible marks

on their left hand and forearm, (g) no skin condition or other medical condition with resulting skin condition (such as psoriasis).

2.2. Experimental Tasks

Heartbeat counting task: Participants were seated by a table opposite of the experimenter. Heartbeats were measured using a Biopac MP150 Heart Rate Oximeter, attached to the participants' left index finger (non-dominant hand). The heart rate oximeter was connected to a PC with AcqKnowledge software (version 4.0), which recorded the heartbeats after pre-set time intervals using the "count peaks" function. A five-minute heart rate baseline reading was measured before trials commenced. Participants were asked if they felt their pulse in their finger from the monitor, and if they did, the monitor strap was loosened. The heartbeat counting task established by Schandry (1981) was employed, whereby participants were instructed to silently count their own heartbeats between two verbal cues (start/stop) without manually taking their own pulse or feeling their chest, but rather try and "sense" their heartbeat from within. A total of three trials were done, at 25, 45 and 65 seconds respective, in a randomized order (Crucianelli et al., in preparation; Crucianelli, Krahé, Jenkinson, & Fotopoulou, 2018). Before the first trial, a practice trial of 15 seconds was done. No feedback on the participants performance was given, and no information about the duration of the trials was provided. Upon being given the "stop"-cue, participants verbally reported the perceived number of heartbeats for the trial. A 30 second break was taken between trials.

Thermal matching task: For the thermal stimulation, a thermode (a small probe capable of delivering thermal stimuli) attached to a thermal stimulator (Somedic MSA thermal Stimulator) was used. This task was completed on three body sites: left dorsal forearm, left dorsal hand, and left palm, in a randomized order. The skin temperature of the participant on these three sites was measured before testing using a non-contact thermometer (Microlife NC150). Participants were first stroked with the thermode at a reference temperature. The reference temperatures used were 30°C, 32°C and 34°C respectively, given in a randomized order. Participants were then asked to try and match the temperature of this stroke with one of the strokes that followed. Velocity of strokes was 4 cm/s and total contact time two (2) seconds. This was done in an increasing or decreasing order in discrete steps of two (2) degrees, starting 8°C above or below the reference temperature (for a total of nine strokes). Stroking continued until participants verbally indicated to have identified the reference temperature, or when 8°C in the opposite direction of the starting temperature was reached. This was then repeated in the other direction (increasing/decreasing) for the same reference temperature. Upon completing the matching task in increasing and decreasing order, the process was repeated for a new reference temperature. A schematic of the process is illustrated in figure 1. Upon completion of the task for one body site, participant repositioned their arm/hand and the process was repeated on the other two body sites (i.e. left dorsal forearm/dorsal hand/palm).

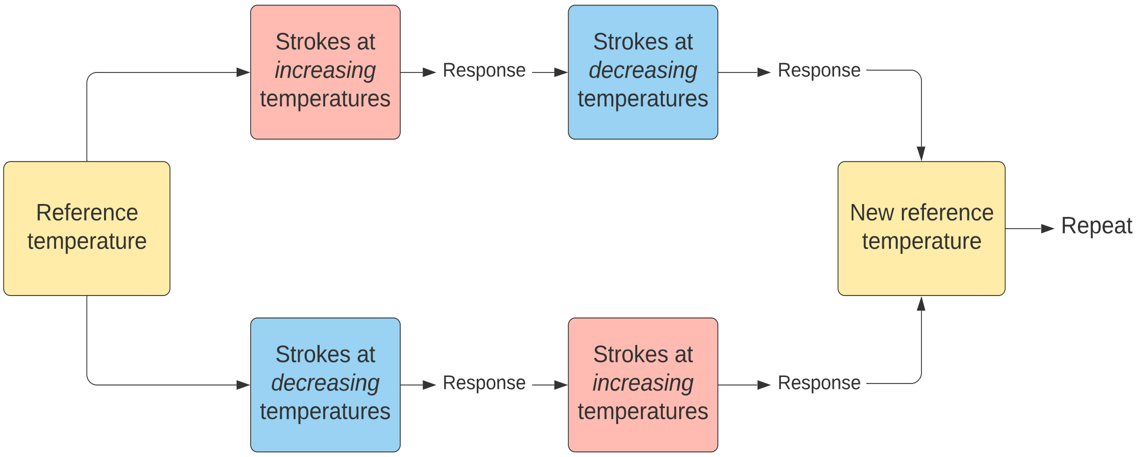

Figure 1. Schematic of procedure of the thermal matching task. Upon receiving the reference temperature, participants were stroked with either increasing or decreasing temperatures Upon giving a response the process was repeated in the other direction, increasing, or decreasing respectively. Upon completion of both trials, the participants received a new reference temperature and the process was repeated.

2.3. Experimental Procedure

This procedure was part of a larger investigation on interoceptive modalities. However, this thesis will only focus on the first two components of the study (the order of the tasks in this study was kept constant). Specifically, the heartbeat counting task was always the first task to be completed, given the evidence showing potential influences of emotional experiences and other interoceptive tasks (e.g. Corneille, Desmedt, Zamariola, Luminet, & Maurage, 2020; Werner, Mannhart, Reyes Del Paso, & Duschek, 2014; Zamariola et al., 2018). Further, to determine test-retest reliability, the experimental procedure is repeated after 24 hours. This ensures no major changes in the menstrual cycle of females, known to affect body temperature (Buxton & Atkinson, 1948; Nagashima, 2015). This also allows us to control for other potential confounding variables such as fatigue and even daylight, which seems to affect thermal perception (Chinazzo, Wienold, & Andersen, 2019). In addition to this, room temperature and body temperature will be controlled.

The study consisted of two identical sessions, lasting about 1h and 30 minutes each. Upon being seated in the first session, participants were given the information sheet and asked to sign the consent form. Then, they provided demographic information (such as age, weight etc). The heartbeat oximeter was then placed on the participants' left-index finger, and a baseline pulse was calculated for five (5) minutes. During these minutes, the participants were instructed in the heartbeat counting task (as described in section 2.2). During the baseline measurement, a practice trial of 15 seconds was offered. When the baseline measure was done, the three experimental trials were done in a randomized order but kept constant for each participant across sessions.

Upon completion of the heartbeat counting task, the participants were instructed in the thermal matching task (as described in section 2.2). Upon verbal confirmation that the participant had understood the instruction, they were blindfolded. A reference temperature was given (30°C, 32°C and 34°C), followed by strokes starting at ±8 °C of the shown reference temperature, increasing or decreasing until a response was given. The process was then repeated in the opposite direction. Upon completion of both directions, a new reference temperature was shown, and the process repeated for that temperature instead. The order of the reference temperatures and staircase direction was randomized but kept constant for each participant across sessions. The process was repeated for all three reference temperatures on all three sites. The entire process was repeated for session two with identical order of the individual trials.

2.4. Plan of Analysis

A modified version of the formula originally used by Schandry (1981) is used to calculate interoceptive awareness as measured by the heartbeat counting task. By using this formula, a value between 0 and 1 is acquired proportional to the accuracy of the counted heartbeats (relative to the correct number of heartbeats). The same formula as that used in Crucianelli et al. (2018) and Crucianelli et al. (in preparation) will be used, which takes three trials into considerations. This will produce one value for each session per participant. The formula is as follows:

$$Interoceptive\ accuarcy_{Cardiac} = \frac{1}{3}\sum(1 - \frac{|recorded\ heartbeats - counted\ heartbeats|}{recorded\ heartbeats})$$

A modified version of the same formula will be used for the thermal matching task. Similar to the classical heartbeat counting task formula, this formula takes into consideration the distance from the correct value, albeit adapted to the design of the task. The modified formula uses the same principle as the original formula and produces values between 0 and 1, proportional to the accuracy of the thermal matchings. The formula is as follows:

$$Interoceptive\ accuarcy_{Thermal} = (1 - \frac{(\sum|reference\ temperature - reponse\ temperature|)/2}{12})$$

In this formula, the numerator consists of the amount of errors done in the thermal matching task (calculated by taking half of the absolute difference between the response temperature and reference temperature). The errors done are valued to be of equal regardless of whether the participants over- or underestimate the reference temperature. Further, this process also values errors equally regardless of the true reference temperature. The denominator is the amount of possible errors, in this case 12 steps, as the scales were considered separate. A total of three trials per site are done (as there are three reference temperatures) and given the furthest distance from the reference temperature is four steps, the maximum amount of possible errors is 12. In total, six values per session will be produced for the thermal task, across the factors scale and body site.

A repeated-measures ANOVA will be conducted with the scores calculated by the above described formulas. Post-hoc analysis of significant main effects or interactions will be done. Order effect of the thermal matching task will be considered. Furthermore, temporal stability of the respective tasks (and their respective components) will be determined using correlational analysis. Correlational analysis will be done to determine potential correlations across tasks the tasks, as well as within the thermal matching task across the body sites.

3. Results

3.1. Heartbeat Counting task

Cardiac accuracy measured by the heartbeat counting task across both sessions were (*M* = 0.67, *SD* = 0.19). There was no main effect of session, *f* (1, 3) = .208, *p* =.650. For session one (*M* = 0.66, *SD* = 0.19), and for session two (*M* = 0.69, *SD* = 0.19). There was a main effect of gender, *f* (1, 3) =5.187, *p*=.026, with men (*M* = 0.74, *SD* = 0.20) being significantly better than women (*M* =0.63, *SD* =0.18). No significant differences in scores were found between the three time-intervals, *f (*1, 187) = .299, *p* =.585.

3.2. Thermal Matching task

Data from one participant was excluded due to failure to comply with task instruction. Thermal accuracy for the entire task was (*M* = 0.81 (*SD*=0.13). For session one, the mean was 0.80 (*SD*=0.13), and for session two the mean was 0.82 (*SD*=0.12). There was no main effect of session, *F* (1, 28) =1.603, p=.216. There was no main effect of scale, *F* (1, 28) =.057, *p*=.814, therefore all future analysis was done with averaged scores for both scales. There was a main effect of body site, *F* (2, 27) = 3.755, *p*=.002, $\eta_p{}^2$=.219. Post-hoc analysis (with Bonferroni adjusted alpha levels of α=0.017) revealed significant differences between the dorsal forearm and dorsal hand, *t* (62) =2.883, *p*=0.003. There was also a significant difference between dorsal forearm and palm, *t* (61) =3.606, *p*=0.001. Further there was no difference between dorsal hand and palm, t (61) =1.433, p=.157 (see figure 2). There was no main effect of order of the starting site, *F* (2, 373) =.277, p=0.758 and no main effect of gender, *t* (374) =-.444, *p*=.657.

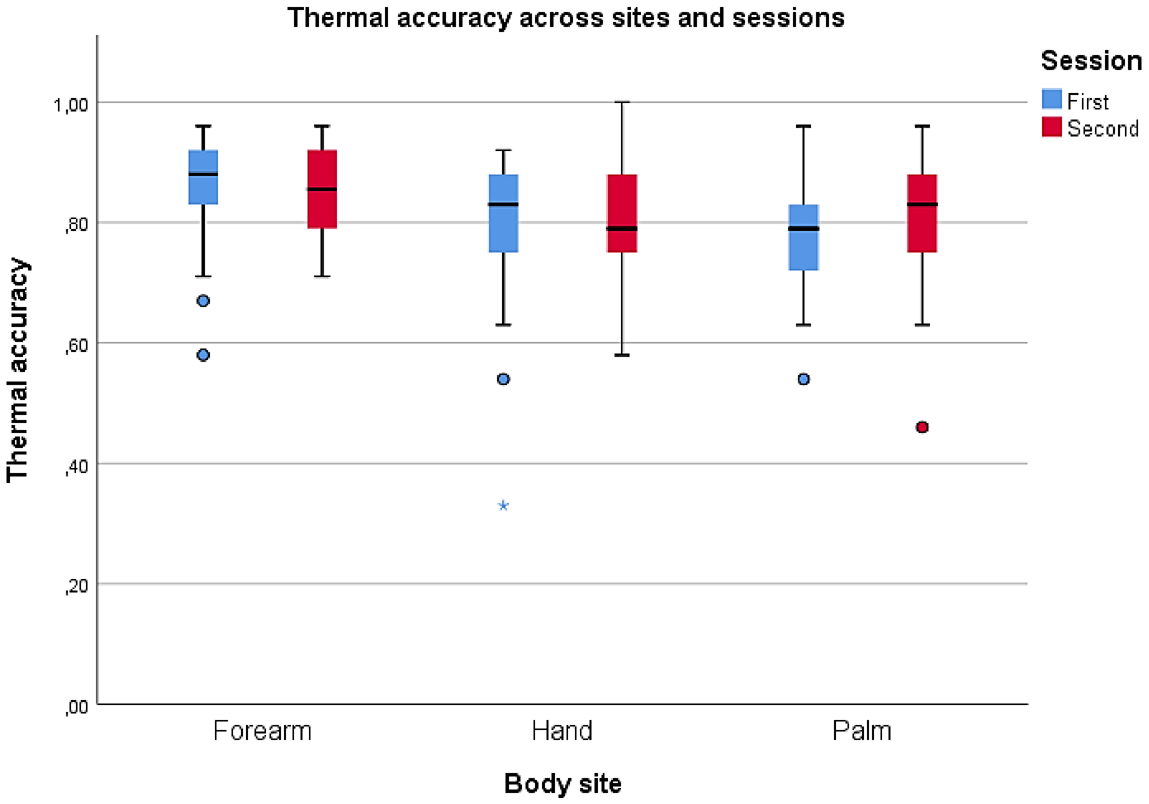

Figure 2. Boxplots of the thermal accuracy on the three body sites, split across sessions. Scores are averaged for the two scales. There was a main effect of body site, F (2, 27) = 3.755, p=.002, $\eta_p{}^2$*=.219, as the participants were significantly better on the dorsal forearm than both dorsal hand and palm. There was not difference between the latter.*

3.3. Correlational Analysis

3.3.1. Temporal stability. Correlational analysis showed that the heartbeat counting task was temporally stable, as scores were positively correlated across session (*r* (28) = .604, *p*=.000, see figure 3). As there was a main effect of gender on the task (as described in section 3.1), cross-session correlations were assessed for both genders. Temporal stability for males was significant (*r* (11) = .704, *p* =.007), but not for females (*r* (15) = .451, *p* = .069), illustrated in figure 4.

Correlational analysis across sessions showed that thermal accuracy, as measured by the thermal matching task was temporally stable on the dorsal forearm (*r* (28) =.430, *p*=.018 see figure 5). Thermal accuracy was not temporally stable dorsal hand (*r* (28) =.247, *p*=.189), nor palm (*r* (27) =0.184, *p*=.341). Temporal stability for the two tasks (across all three body sites) is displayed in table 1. As there was a main effect of gender on the heartbeat counting task, correlational analysis was done split for gender on the thermal matching task as well. The cross-session correlation for thermal accuracy was not significant for males on either site: forearm (*r* (11) =.308, *p* =.306); dorsal hand (*r* (11) =.496, *p* =.085); palm (*r* (11) =.407, *p* =.167). For females thermal accuracy was temporally stable on forearm (*r* (15) =.515, *p* =.035), but not on dorsal forearm (*r* (15) =.116, *p* =.656), or palm (*r* (15) =-.252, *p* = .347). The temporal stability of the task on forearm split for gender is illustrated in figure 6.

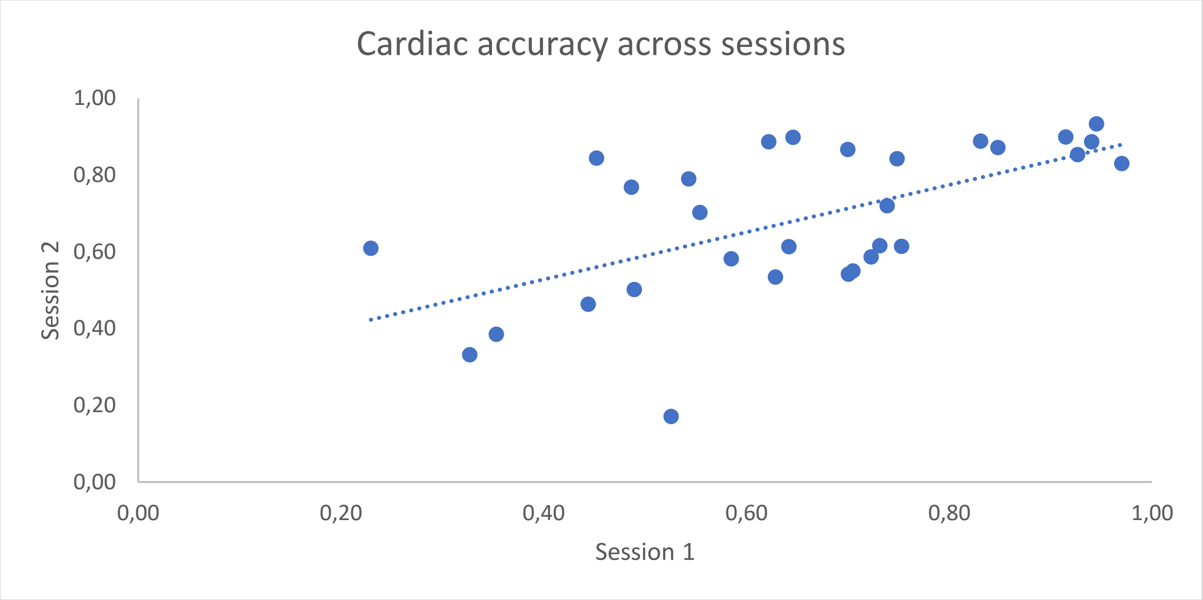

Figure 3. Cardiac accuracy correlated across the two sessions. The correlation is significant, r (28) = .604, p=.000.

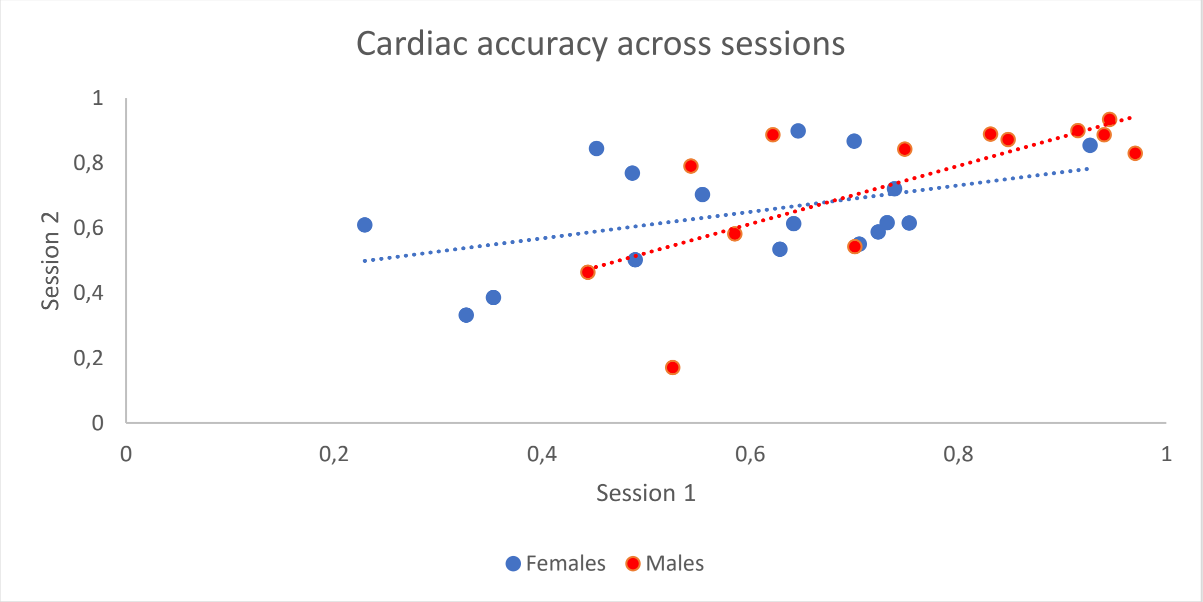

Figure 4. The temporal stability of the heartbeat counting task split for gender. The correlation is significant for males (r (11) = .704, p=.007) but not for females (r (15) =.451, p=.069).

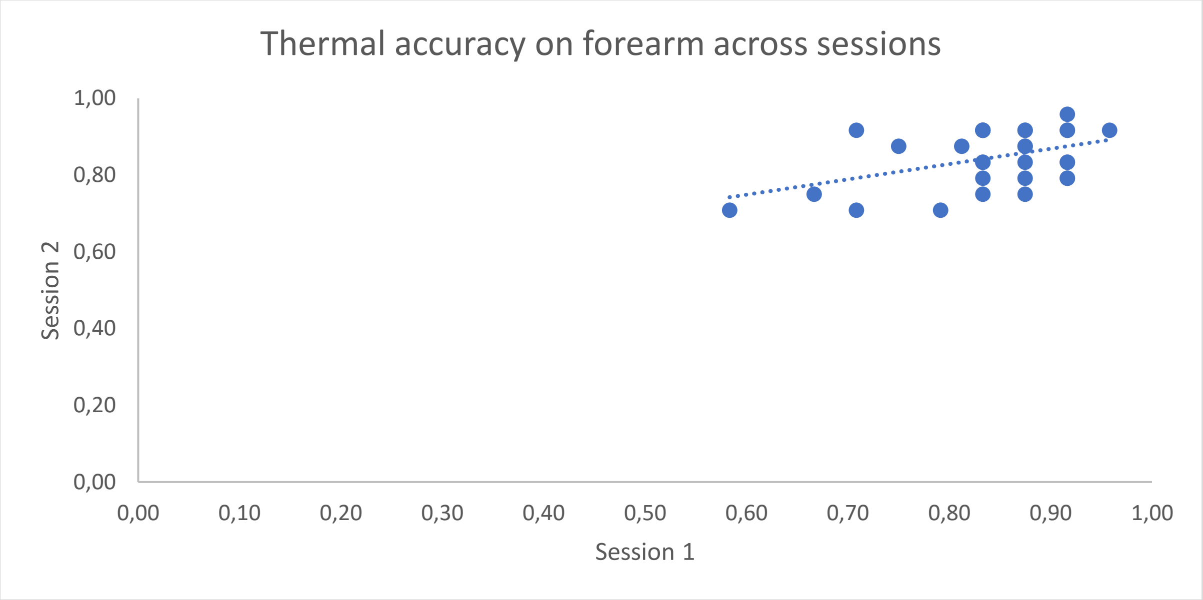

Figure 5. Thermal accuracy on forearm across sessions. Scores are averaged for the two scales. The correlation is significant, r (28) = .430, p=.018.

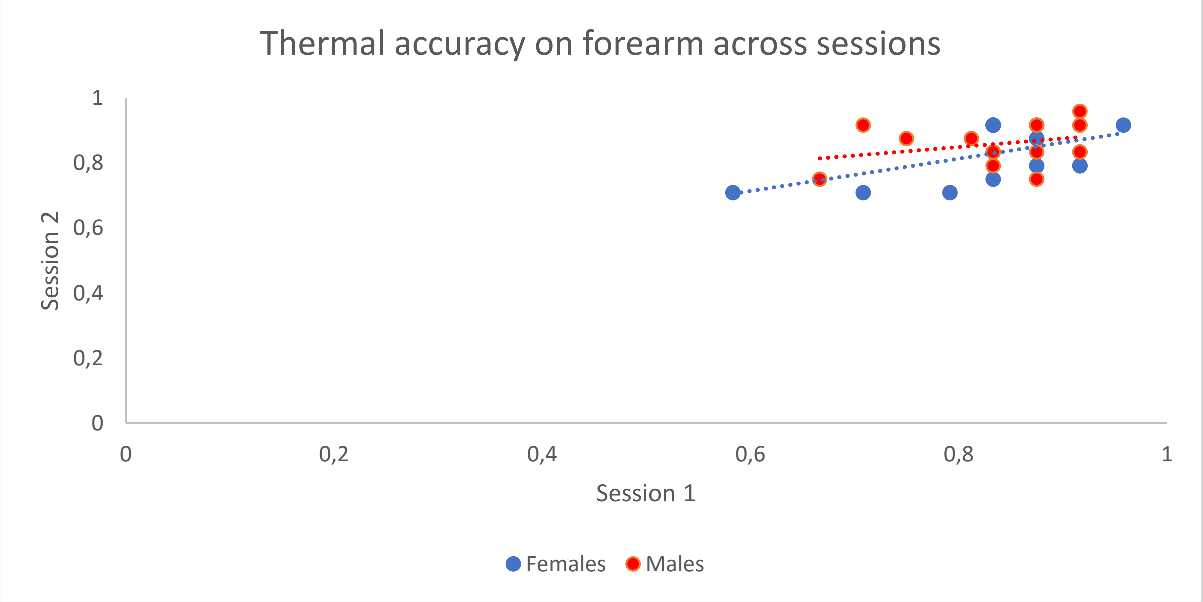

Figure 6. Thermal accuracy on forearm across sessions, split for gender. Thermal accuracy scores are averaged for the two scales. The correlation was not significant for males (r (11) =.308, p = .306) but significant for females (r (15) = .515, p = .035).

3.3.2. Cross-task correlations. Cardiac accuracy was not correlated with thermal accuracy on either of the three body sites (Session 1; dorsal forearm: *r* (31) = .050, *p*=.784, dorsal hand: *r* (31) = -.266, *p*=.644, palm: *r* (30) =-.038, *p*=.838. Session 2; dorsal forearm: *r* (28) =-.113, *p*=.551, dorsal hand: *r* (28) =.044, *p*=.816, palm: *r* (28) =-.220, *p*=.242, illustrated in figure 7). Thermal accuracy was correlated within the task on the dorsal forearm and palm in session one, (*r* (30) =.415, *p*=.018). Furthermore, thermal accuracy on hand and palm were correlated within both sessions (*r* (30) =.551, *p*=0.001 and *r* (28) =464, *p*=.010 for session one and two, respectively). All correlations are displayed in table 1. No cross-task correlations were significant when split for gender, see Appendix.

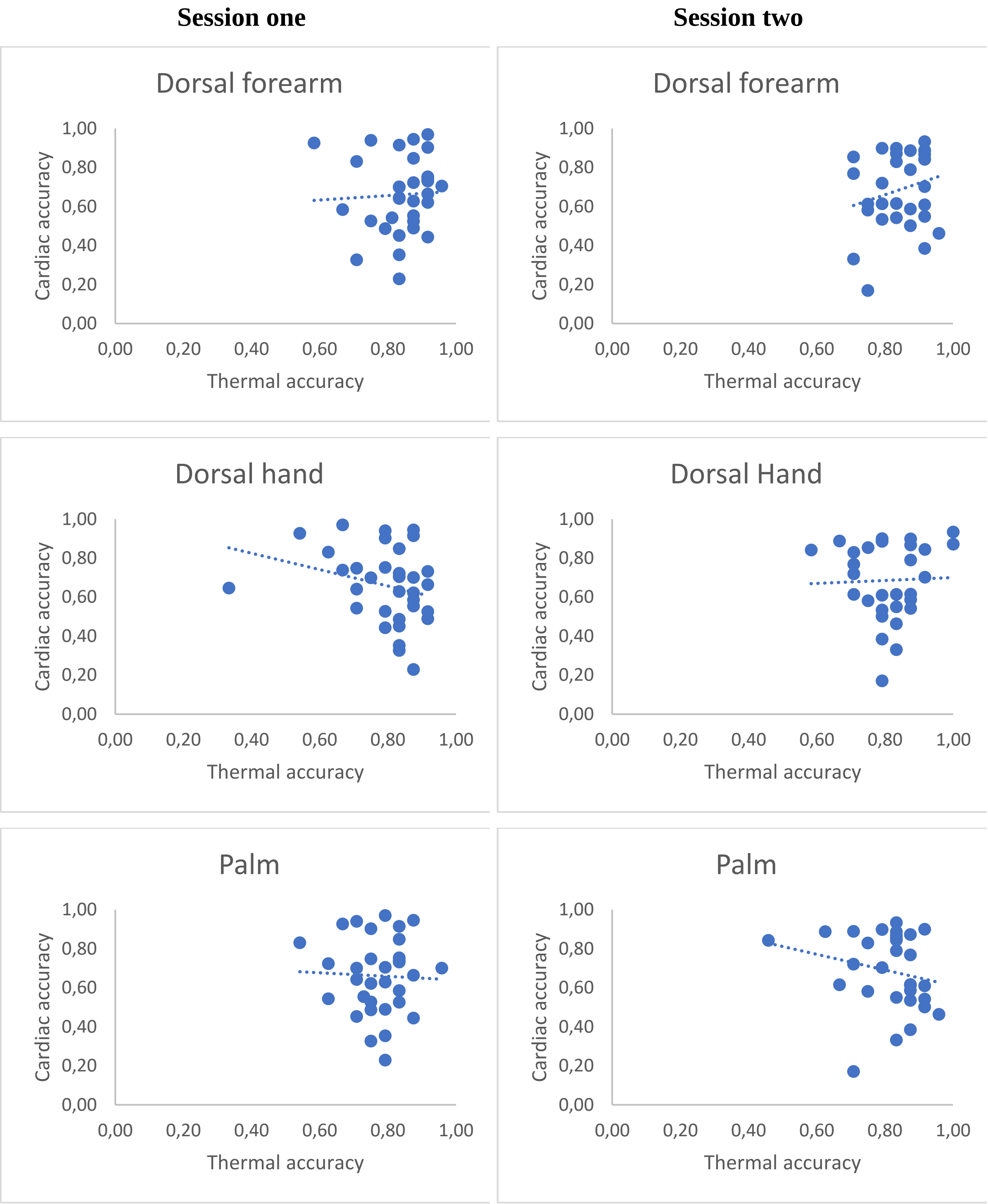

Figure 7. Cardiac accuracy correlated with thermal accuracy on the three body sites for both sessions. Thermal accuracy is averaged for both scales. All correlations are non-significant.

*Table 1. Correlations for both tasks across all three body sites. The first value corresponds to the r-value, and the second correspond to the p-value. *Significant at alpha =.005, **Significant at alpha =0.01. Orange colour is cardiac accuracy, as measured by the heartbeat counting task. Green is thermal accuracy, as measured by the thermal matching task. Darker colour represents session one, while lighter colours represent session two. Light blue cells highlight the correlations of interest, such as temporal stability or cross-task correlations within the sessions.*

	Cardiac Session 1	Cardiac Session 2	Forearm Session 1	Forearm Session 2	Hand Session 1	Hand Session 2	Palm Session 1	Palm Session 2
Cardiac Session 1	1							
Cardiac Session 2	,604** ,000	1						
Forearm Session 1	,050 ,784	-,113 ,551	1					
Forearm Session 2	-,088 ,644	,226 ,231	,430* ,018	1				
Hand Session 1	-,266 ,135	-,424* ,020	,289 ,103	,114 ,549	1			
Hand Session 2	-,022 ,906	,044 ,816	,172 ,364	,239 ,204	,247 ,189	1		
Palm Session 1	-,038 ,838	-,326 ,084	,415* ,018	-,111 ,567	,551** ,001	,245 ,201	1	
Palm Session 2	-,230 ,221	-,220 ,242	-,127 ,505	-,043 ,823	,244 ,195	,464** ,010	,184 ,341	1

4. Discussion

In the present study the temporal stability of the thermal matching task was evaluated, a new measurement of interoception suggested as a part of an interoceptive battery (Crucianelli et al., in preparation). The relationship between cardiac accuracy and the perception of temperature as an externally generated skin mediated interoceptive modality was further examined. In line with previous findings from the research group, it was found that people were significantly better at matching temperatures on the dorsal forearm compared to the palm, however no other significant differences were found between the body sites studied. Furthermore, the present study indicates thermal accuracy to be moderately temporally stable across 24 hours when conducted on the dorsal forearm, but not when done on more distal parts of the arm (i.e. dorsal hand and palm). The classical heartbeat counting task (Schandry, 1981) was also found to be temporally stable, with results in line with other papers investigating the task (Ferentzi et al., 2018b). However, in contrast with previous data collected in the lab the present study did not find a positive correlation between cardiac accuracy and thermal accuracy on the forearm. Crucianelli et al. (in preparation) is the only study to date using the method and this paper provides crucial reference data for future usage of the task.

4.1. Cardiac Interoceptive Accuracy

The total sample average and standard deviation of the heartbeat counting task are in line with other papers employing the same heartbeat counting task (Garfinkel et al., 2015; Crucianelli et al., in preparation; Crucianelli et al., 2018). Cardiac accuracy was found to be temporally stable across 24 hours. The result is in line with other papers investigating the stability of the task. Ferentzi et al., (2018b), found cardiac accuracy to be stable across an eight-week period, something the presented data supports. There was no a priori hypothesis about the effects of gender, however a main effect of gender was found in the present study. There was as also a difference in temporal stability between genders, as the task was only significantly correlated cross sessions for males, although the correlation was approaching the significance threshold in females. However, the small sample size of the female only group (*n* = 17) may affect the significance value, as the correlation was moderate yet non-significant. Earlier papers have found varying results regarding gender (Grabauskaitė, Baranauskas, & Griškova-Bulanova, 2017). Grabauskaitė et al. (2017) attributed the earlier lack of consensus on the role of gender to methodological differences and unbalanced samples. Additionally, Grabauskaitė et al., (2017) found males to be significantly better on the task, something that the results support, as male scores on the task were significantly higher than women's scores. Grabauskaitė et al., (2017) speculates this difference to be due to the biomechanical properties of the heart as males have higher stroke-volume and stronger heart contractions than females. This would potentially also explain a difference in temporal stability between the genders.

The experimenter paid close attention to ensuring the pulse was not felt from the heart rate oximeter monitor by the participant, by asking them whether they could feel their pulse on their index finger before instructions were given. However, a potential confounding variable is that this sensation could have arisen after asking the question without participants informing the experimenter about it.

4.2. Thermal Interoceptive Accuracy

As discussed in the introduction, the lack of standardized measurements has been one of the limiting factors when studying interoception, particularly when studying the interoceptive dimension of accuracy. There seems to be growing support towards the notion that interoceptive accuracy cannot be measured only by one measurement alone, mainly cardiac tasks (Ferentzi et al., 2018a). The present data provide support for this argument.

The total sample average and standard deviation of the thermal matching task are in line with the only study using the method to date (Crucianelli et al., in preparation). The thermal matching task was found to be temporally stable on the dorsal forearm, but not on the dorsal hand or palm. The correlation across sessions (temporal stability) was significant, but lower compared to the heartbeat counting task. The assumption that direction of temperature change (scale) has any effect on thermal matching was not supported, as there was no significant effect of scale. Further there were no interactions between scale and body site or scale and session. As such, the correlational analysis was done with the averaged scores for the two scales for all participants. This applied to correlations both within the thermal matching task across the body sites, but also the cross-task correlations (further expanded upon in section 4.3). There were also correlations of thermal accuracy across the three body sites, mainly between the dorsal hand and the palm, within both sessions. We observed no main effect of body site starting order on thermal accuracy. Furthermore, there was no main effect of gender, however, the main effect of gender on the heartbeat counting task warrants gender consideration in correlational analysis.

The present study found a main effect of body site. Thermal perception has been found to vary across body sites, which the present data support. The present study found participants to be significantly better on the thermal matching task on the forearm compared to both the dorsal hand and the palm. The dorsal hand granted higher thermal accuracy than the palm, although this difference was nonsignificant. Mancini et al. (2014) found thermally induced pain acuity to be greater on the arm proximal and gradually declined on the further distal parts of the arm. However, Mancini et al., (2014) found a difference in pain acuity between the dorsal hand and palm, with the palm having lower acuity threshold (i.e. better sensitivity). The present study did not observe a similar finding with thermal matching. Further, Gerrett et al. (2015) investigated thermal sensation ratings across body sites. Concerning the three body sites of the present study, Gerrett et al. (2015) found the dorsal forearm to produce the highest thermal sensations for warm stimulation, regardless of gender. For cold in females, the dorsal forearm granted similar values to that of the palm, both of which were higher than the dorsal hand. In males, there was no difference between the three sites for cold stimulations. The dorsal hand granted higher thermal sensations for warmth than the palm for both genders. For cold stimulation, the dorsal hand produced similar values to that of the palm in males and lower values compared to the palm in females (Gerrett et al., 2015). Contrary to these findings, method-of-limit studies of thermal detection thresholds indicate that temperature change needed for detection are similar across the body sites investigated (Heldestad Lilliesköld & Nordh, 2018). As such, it seems thermal perception varies strongly and inconclusively across body sites. The present study indicates that distance from the body may be an important factor in the thermal matching task. Support for this argument is provided by the significant difference of thermal accuracy between the dorsal forearm and both the dorsal hand and palm. It is also supported by the correlations between the dorsal hand and palm within both sessions. As such, future studies should consider studying more proximal body parts.

One aim was to investigate the role of the CT-afferents and body site. The CT-afferent fibers have shown to be involved in slow moving strokes at neutral temperatures (Ackerley et al., 2014) in experiments using similar designs to the present study. The a priori hypothesis that participants would be significantly better on skin containing CT-afferents was not confirmed. Participants were found to be significantly better on the task on the forearm compared to the palm, in line with previous findings from the research group. However, unlike previous studies using the thermal matching task, the present study also examined the thermal matching task on another CT-afferent body site, the dorsal hand. There was a significant difference in thermal accuracy between dorsal forearm and dorsal hand, with dorsal forearm yielding higher accuracy scores. However, there was no significant difference between the dorsal hand and palm. There currently exists no accurate method to measure the density of the CT-afferents (Liljencrantz & Olausson, 2014), and as such it is unsurprising that the relative density of these afferents is not well known. The CT-afferent density may vary between the dorsal forearm and dorsal hand, and it is possible that the difference in thermal accuracy is a consequence of this difference. Microneurography studies have found CT-afferents to be present to a similar extent to other mechanoreceptors (such as the Aβ-fibers) in the lateral antebrachial cutaneous nerve (Liljecrantz & Olausson, 2014), close to the dorsal forearm site in the present study. It is reasonable to assume that the density of the CT-afferents differs between the dorsal hand and dorsal forearm, similar to how other mechano- and thermoreceptors vary across body sites (Gerrett, Ouzzahra, & Havenith, 2015; Liljecrantz and Olausson, 2014). As such, the present study is unable to conclusively determine the CT-afferents as uninvolved in the thermal matching task.

The thermal matching task was found to be temporally stable on a group level when done on the dorsal forearm, but not on the other two sites. The main effect of body site together with the differences in temporal stability relative to method-of-limits indicates that different sensory and cognitive components are involved in the thermal matching task. However, splitting the group by gender revealed differences in temporal stability. For males, neither site showed a significant cross-session correlation, but in females the forearm was a temporally stable body site. The correlation is modest yet non-significant and could stem from the small sample size requiring stronger correlations to be significant. The finding of this gender effect contrasts with other studies, that found no significant difference between genders in thermal perception over time (Heldestad et al., 2010). However, Sarlani, Farooq, and Greenspan (2003) found gender differences in thermally induced pain. There are some findings indicating a potential difference in thermal perception, such as differences in perception of cooling temperatures (Yasuoka, Kubo, Tsuzuki, & Isoda, 2015). Whether or not the present gender effect is true or a consequence of an associated confounding variable, such as body composition and mass effect the task was not controlled for in the present study. These factors have been shown to affect thermoregulation (Kaciuba-Uscilko & Grucza, 2001), and could potentially explain this difference.

The experimenter paid close attention to keeping the contact pressure of the thermode constant between participants. However, a potential confounding variable regarding the thermal matching task is that participants could press the contact site towards the thermode (mainly done on the palm), which was not controlled. Thermally induced pain is inhibited by active contact, i.e. active grasping of the source by the participant compared to passive perception (Green, 2009). The extent to which this affects innoxious temperature perception is not fully clear, but it could nevertheless be a source of variance within the thermal matching task (as mentioned, mainly on the palm).

4.3. Cross-task Correlations

There were no correlations between the cardiac accuracy and thermal accuracy on either of the three body sites. The absence of a correlation between cardiac accuracy and skin-mediated interoception is in line with other papers that found no link between these two sensory modalities, such as that of Crucianelli et al. (2018) and Agostinho et al. (2019). However, this finding opposes our hypothesis that there would be a link between the thermal matching task and heartbeat counting task, as suggested by Crucianelli et al., (in preparation). The present data supports the idea that the interoceptive abilities cannot be assessed using only one measurement, a viewpoint with accumulating evidence (Crucianelli et al., in preparation; Ferentzi et al., 2018a). As discussed before, interception as a concept is not unitarily perceived, and the measurements used to study it should reflect this diversity (Ferentzi et al., 2018a).

4.4. Limitations of the Present Study

The heartbeat counting task has shown to be heavily reliant on cognitive factors such as beliefs, strategies, estimates and personal decision thresholds (Brener & Ring, 2016; Desmedt, Luminet, & Corneille, 2018; Ring & Brener, 2018; Ring, Brener, Knapp, & Mailloux, 2015). While controlling for attention is difficult in the present experimental setting, the present data showed no support that cardiac scores were lower in the longer time intervals. It is therefore likely that attention did not affect scores for the longer intervals. These issues are not directly translatable to the thermal matching task, as prior knowledge or beliefs of temperatures were negligible or non-existent. During the experiment, the participants were instructed that temperatures were within the non-painful range of neutral temperatures, but the actual values were not presented. As such, the participants were not presented with any prior knowledge of the temperatures. Nevertheless, certain strategies could have influenced task performance, such as always selecting the fourth stimulus as a matching temperature. This would grant the participant a unproportionally high thermal accuracy. Similarly, participant individual decision threshold could also affect their selected temperature. To limit guessing by participants could answer retrospectively, meaning they could state an earlier stimulus as matching the reference temperature. While individual threshold still affects decision making, this method ensured participants were more confident in their decision making and limit second-guessing.

The experimental procedures were kept in a constant order, as this study was done as part of a larger investigation. As such, randomizing the order of the tasks was not possible. The lack of randomization together with the higher scores in the thermal matching task relative to the heartbeat counting task could indicate a learning effect. I would expect a learning effect, if present, to remain between the sessions due to their proximity in time. However, the lack of main effect of session in either of the task deems a learning effect unlikely. The differences in score means for the tasks can be attributed to a potential ceiling effect of the thermal matching task. I would argue the higher scores in the thermal matching task is a consequence of the fewer amount of possible errors, as participants could at maximum have four “error-steps” per trial.

4.5. Future Directions

These results indicate that the thermal matching task could serve as a new measurement of skin-mediated interoception. However, there seems to be a difference between genders, alternatively a related confounding variable. Future studies should aim to investigate this in order to validate the test. In addition to this, there also seems to be a potential ceiling effect, and future studies should expand one of the components discussed in order to counteract this.

The present study further supports the lack of unitary perception in interoception, and I argue that an inclusive interoceptive battery, such as that proposed by Crucianelli et al., (in preparation) should be used to assess the interoceptive abilities of a person.

As previously shown by Zamariola et al., (2018) the heartbeat counting task is heavily dependent on sustained attention, as cardiac accuracy scores have been found to significantly differ between time intervals. Murphy et al., (2018) argue that a time estimation task can be used to control for external factors such as fatigue and motivation affecting attention (and by extend performance). Attention plays an important role in the thermal matching task. However, similar to the heartbeat counting task there was no order effect, in this task regarding starting body site. There is no task equivalent to the time estimation task for the thermal matching task which controls for attention relative to the task. Future studies could therefore set out to determine a potential control task for this factor. Other cognitive factors could also affect the task, such as sensory memory and working memory, although this study did not investigate such features. As mentioned earlier, other modalities of interoception (such as cardiac and gastric) have shown correlations within modalities across tasks (Ferentzi et al., 2018a; Garfinkel et al., 2015). Future studies could investigate whether a similar trend exists within thermal perception. This could be done with method-of-limits (as it is well defined). Comparing the present data from the thermal matching task with previous studies using method-of-limit studies indicates that these tasks are not equivalent. I therefore suspect these tasks to not correlate. Whether these differences are due to different sensory mechanism or cognitive processes remains unclear. Future studies could therefore explore the extent to which thermal perception is dependent on cognitive demands and methodology, and to which extent it is independent of these. Lastly, the present data indicated a potential ceiling effect. To explore whether this is the case, future studies could use more trials per reference temperature. This could be done either by repeating the task identically, or by increasing the thermal range, or more preferentially decrease the amount of change and add more stimulus to distinguish between for each trial.

5. Conclusion

In the present study it was shown that the thermal matching task could serve as a new measurement of skin-mediated interoception when conducted on dorsal forearm, as is a reliable method. However, a difference in temporal accuracy was found between genders, for the test to be standardized this difference needs to be addressed and further investigated. The present study argues that interoception is not unitarily perceived across modalities and the measurements should reflect this diversity. As such, there is potential to include the thermal matching task in an interoceptive battery. Furthermore, this study provides more reference data for future usage of the task. Significant differences between both performance and reliability for the task across was found between body sites. Participants performed significantly better on the dorsal forearm compared to both dorsal hand and palm but no difference between the latter. This indicates a role of body part in the task. Furthermore, the dorsal forearm showed a significant temporal stability, as measured by cross-session correlations, although this was also affected by gender. The dorsal hand and palm were not correlated across sessions, however showed strong correlations within sessions. No link between cardiac accuracy, measured by a well-established heartbeat counting task, and the new thermal matching task could be supported. In line with recent findings I argue that interoception is not unitarily perceived across modalities, and the measurements used to assess interoception should reflect this diversity. I suggest the thermal matching task is a potential measurement which can be included in an interoceptive battery for a comprehensive assessment of a individuals interoceptive ability, although more research needs to address underlying processes and its relationship to other methodologies of temperature perception.

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Appendix

Cross-task correlations split between genders.

		Females		Males	
		Cardiac accuracy S1	Cardiac Accuracy S2	Cardiac accuracy S1	Cardiac Accuracy S2
Cardiac accuracy session 1	Pearson Correlation	1	,451	1	,704**
	Sig. (2-tailed)		,069		,007
	N	18	17	15	13
Cardiac accuracy session 2	Pearson Correlation	,451	1	,704**	1
	Sig. (2-tailed)	,069		,007	
	N	17	17	13	13
Thermal accuracy Forearm Session 1	Pearson Correlation	,042	-,181	-,020	-,052
	Sig. (2-tailed)	,868	,486	,943	,866
	N	18	17	15	13
Thermal accuracy Forearm Session 2	Pearson Correlation	-,272	,009	-,004	,420
	Sig. (2-tailed)	,292	,972	,990	,153
	N	17	17	13	13
Thermal accuracy Dorsal hand Session 1	Pearson Correlation	-,434	-,571*	-,238	-,389
	Sig. (2-tailed)	,072	,017	,394	,189
	N	18	17	15	13
Thermal accuracy Dorsal hand Session 2	Pearson Correlation	-,031	,154	,031	,010
	Sig. (2-tailed)	,906	,555	,919	,974
	N	17	17	13	13
Thermal accuracy Palm Session 1	Pearson Correlation	-,170	-,356	-,127	-,414
	Sig. (2-tailed)	,513	,176	,652	,160
	N	17	16	15	13
Thermal accuracy Palm Session 2	Pearson Correlation	-,432	-,281	,026	-,123
	Sig. (2-tailed)	,083	,275	,932	,690
	N	17	17	13	13