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Constructing the minimal self: The relationship between maternal touch and interoceptive accuracy

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Introduction

Touch accompanies human existence from the very beginning. Even before babies are born, they experience touch. Foetuses in the third trimester already react to maternal touch and in turn increase their touch of the uterine wall (Marx & Nagy, 2017). Touch is a crucial variable in personal wellbeing (for a review, see Field, 2011), attachment (Beebe et al., 2010), and social orientation (Reece et al., 2016). According to a recently proposed theory, touch may even shape the development of the very basis of the sense of self, the *minimal self* (Fotopoulou & Tsakiris, 2017). However, so far there is only indirect evidence for this theory (Fotopoulou & Tsakiris, 2017; Montirosso & McGlone, 2020). Therefore, this thesis investigates the question: Can variations in maternal touch predict the degree of development of the minimal self in infants?

The Minimal Self

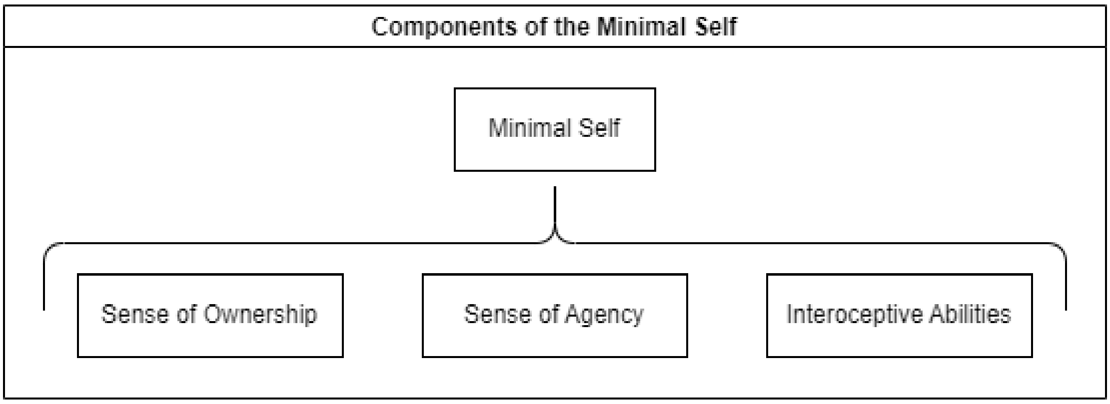
The minimal self (Gallagher, 2000) is defined as a prereflective "feeling of being an embodied, agentive subject" (Fotopoulou & Tsakiris, 2017, p. 6) and is based on an integrative process of interoceptive and exteroceptive bodily signals (Fotopoulou, 2015; Fotopoulou & Tsakiris, 2017). Interoceptive signals such as pain, hunger, pleasant touch, or temperature refer to signals providing information about the state of the body. Exteroceptive signals such as sound or discriminative touch give information about the outside world. Of note, interoceptive signals may emerge not only from the body itself but also from its environment (Craig, 2002). The minimal self does not require awareness of the self or self-referential language such as "I" or "mine" (Georgie et al., 2019; Rochat, 2003). It is in contrast to other aspects of the self, such as the narrative self, which describes a structure of narratives individuals construct about themselves, for example, "a narrative of being a parent" or "what others say about me" (Gallagher, 2000, p. 19).

Components of the Minimal Self

Gallagher (2000) distinguishes two basic components of the minimal self: the *sense of ownership* and the *sense of agency* (see Figure 1). Sense of ownership is defined as the feeling of being the one undergoing an experience, for example, "I feel that my body is moving". The sense of ownership not only includes ownership of physical body parts but also of affective experiences such as emotions. Importantly, the sense of ownership is not object-based (Seth & Tsakiris, 2018). "[…W]e do not experience being a body in terms of the spatial arrangement of our internal organs as objects“ (Seth & Tsakiris, 2018, p. 976). Sense of agency refers to the feeling of being the agent of one's actions, for example, "I am moving my arm" (Gallagher, 2000). Furthermore, Fotopoulou and Tsakiris (2017) argue that *interoceptive ability*, the ability of being aware of one's own interoceptive signals and accurately perceiving them (Garfinkel et al., 2015), over time becomes a component of the minimal self and safeguards against manipulations of the minimal self (see Figure 1). According to Tsakiris (2017), interoceptive abilities may be critical for the stability of the self over time. "…[A]wareness of the interoceptive body may be fundamental to the unity of the self because interoception is required for the experience of a unified, non-hollow self, and to its stability because interoception can counteract the ever-changing influence of exteroceptive signals (Tsakiris, 2017, p. 600)."

Figure 1

Components of the Minimal Self



Note. Components of the minimal self. Sense of ownership refers to the sense of being the one undergoing an experience (Gallagher, 2000). Interoceptive abilities refer to the degree of accuracy and attention in perceiving one's own interoceptive signals (see section below; Garfinkel et al., 2015; Murphy et al., 2019). Sense of agency refers to the sense of being the agent of one's own actions (Gallagher, 2000). Importantly, the minimal self is not static; it is an ongoing probabilistic process of integrating interoceptive and exteroceptive signals (Blanke & Metzinger, 2009; Fotopoulou & Tsakiris, 2017).

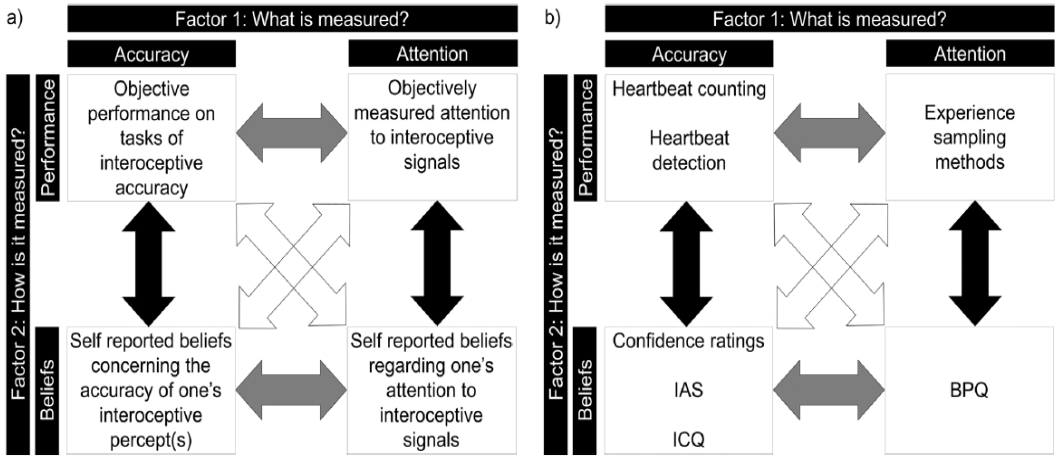
Individual Differences in Interoceptive Abilities

Crucially, the degree to which humans are able to assess the physical state of the body differs (e.g., Garfinkel et al., 2015; Murphy et al., 2020). For instance, one person may be sensitive to minor changes in room temperature, but another may not notice such differences. Similarly, one person may focus on their feelings of hunger and thirst throughout the day, whereas another may forget to eat and to drink. Importantly, these individual differences can be measured. The three-dimensional model by Garfinkel et al. (2015) distinguishes between (a) *interoceptive accuracy* (IAcc; also referred to as *interoceptive sensitivity*), the ability to accurately detect one's physical state, for example, one's heart rate (Schandry, 1981), (b) *interoceptive sensibility*, the subjective reporting of attention to one's own interoceptive signals, that is, the "tendency to be internally self-focused" (Garfinkel et al., 2015, p. 67) and (c) *interoceptive awareness*, the metacognitive awareness of one's accuracy in detecting interoceptive signals, that is, the correspondence between interoceptive awareness and interoceptive sensibility.

Based on the three-dimensional model, Murphy et al. (2019) propose a 2 × 2 factor model (see Figure 2) to increase the precision of categorising individual differences in various forms of interoceptive abilities. The first factor distinguishes whether accuracy (i.e., how precisely an individual can detect their own interoceptive signals) or attention (i.e., how attentive an individual is to their own interoceptive signals) is assessed. The second factor differentiates objective from self-reported measures. Accordingly, the model consists of four types of interoceptive perception: (a) objective IAcc (assessed by objective measures, e.g., a heartbeat counting task), (b) self-reported beliefs regarding one's own IAcc (measured by confidence ratings, e.g., a visual scale from "full perception" to "total guess", or questionnaires such as the *Interoceptive Confusion Questionnaire* [ICQ]; Brewer et al., 2016; or the *Interoceptive Accuracy Scale* [IAS]; Murphy et al., 2020), (c) objective interoceptive attention (measured by objective measures of attention, e.g., experience sampling methods, in which participants are asked repeatedly over a certain period what their object of attention is; Larson & Csikszentmihalyi, 2010), and (d) self-reported interoceptive attention (measured by questionnaires, e.g., the *Body Perception Questionnaire* [BPQ]; Porges, 1993). Interoceptive awareness is then defined as the correspondence between objective and self-reported measures, resulting in two distinct forms of interoceptive awareness: awareness of interoceptive attention and awareness of IAcc (Figure 2, black arrows).

Figure 2

The 2 × 2 Factor Model by Murphy et al. (2019)



Note. The model of interoceptive ability.

a) The 2 × 2 factor model of interoceptive ability. Factor 1 defines the target of measurement: either accuracy or attention. Factor 2 distinguishes between objective performance and self-reported beliefs.

b) Examples of tasks to measure the distinct types of interoceptive abilities. IAS = Interoceptive Accuracy Scale; ICQ = Interoceptive Confusion Questionnaire; BPQ = Body Perception Questionnaire. From "Classifying individual differences in interoception: Implications for the measurement of interoceptive awareness," by J. Murphy, C. Catmur, and G. Bird. (2019). *Psychonomic Bulletin and Review*, *26*(5), p.1469 (https://doi.org/10.3758/s13423-019-01632-7). Copyright 2019 by J. Murphy, C. Catmur, and G. Bird, distributed under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).

Of note, interoceptive abilities are related to other traits and symptoms. For instance, higher objective IAcc as a trait can be linked to higher general anxiety (Schandry, 1981) or increased emotional experience (Wiens et al., 2000). Another study linked objective IAcc to lower anxiety in a public speaking task. The authors explain these results with the assumption that individuals with higher IAcc have more clarity over their own bodily signals, resulting in lower uncertainty over the situation and in turn, lower anxiety during the public speaking task (Werner et al., 2009). Poor sleep quality is linked with both lower objective IAcc and higher self-reported interoceptive attention (Ewing et al., 2017).

The measures to assess interoceptive abilities are typically designed for adults. However, there is little research regarding interoceptive abilities in infants. Only recently, a paradigm that allows for the assessment of interoceptive abilities in infants was developed. In infants, interoceptive abilities can be measured by the use of the *Infant Heartbeat task* (iBEAT; Maister et al., 2017), in which infants sit in front of a screen while their heartbeat is measured via *electrocardiography* (ECG). They watch visual stimuli moving either synchronously or asynchronously with their own heartbeat, while their eye movements are tracked. It was found that 5-month-old infants prefer to look at asynchronous stimuli and vary in their ability to detect differences between the two conditions (Maister et al., 2017).

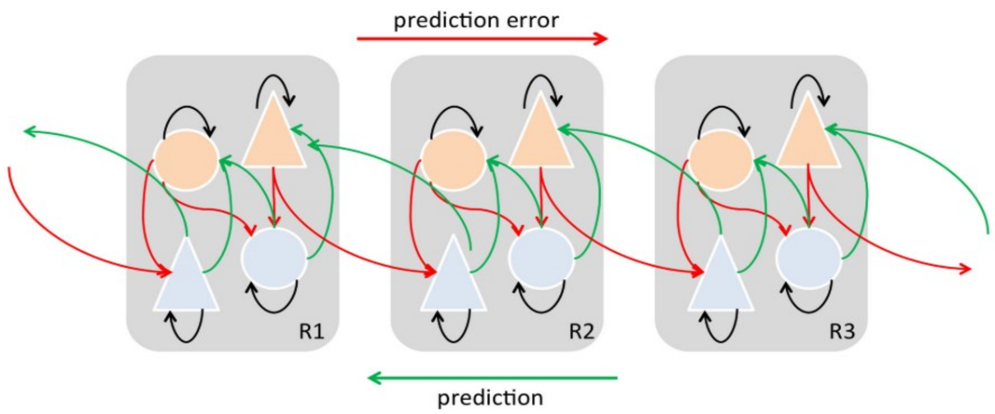
In the 2 × 2 factor model of interoceptive ability, the iBEAT can be classified as a measure of objective IAcc. Infants' abilities are assessed using objective measures (looking times in reaction to stimuli synchronous or asynchronous with their heartbeat). Comparable to the heartbeat detection task for adults, the iBEAT measures how accurately infants can differentiate between stimuli moving synchronously and asynchronously with their heartbeat, that is, how accurately they can detect their heartbeat. Some authors argue that the iBEAT task measures not only IAcc, but also interoceptive attention, as infants' attention to the screen in relation to their heartbeat is measured (Tünte et al., 2025). However, according to the 2 × 2 factor model of interoceptive abilities, interoceptive attention is defined as the attention to interoceptive signals over time and is typically measured through experience sampling methods in adults (Murphy et al., 2019). Seeing stimuli move according to their heartbeat on a screen is an unfamiliar situation for infants and highly differs from their everyday life. Thus, it is unlikely that the attention they display in the iBEAT task can be generalised to infants' attention to their heartbeat throughout the day.

The Predictive Coding Framework

In this view of the self as based on the body and its movements, interoception is vital, as it provides information about the state of the body (Craig, 2002; Seth & Tsakiris, 2018). Recently, multiple authors have conceptualised interoception based on the view of the brain as an *inference engine,* which aims to infer causes of sensory input (Dayan et al., 1995; Friston, 2010; Friston et al., 2006; Seth et al., 2012). For example, the brain may receive input from thermoreceptor cells and then infer that the temperature outside is the cause for this input. The interoceptive predictive coding model by Seth et al. (2012) is based on the *predictive coding framework* (PCF). The PCF describes a hierarchical network consisting of multiple levels. At each level (except the lowest), predictions about the response of the next lower level are passed down via feedback connections. Prediction errors are then returned to the next higher level via feedforward connections (see Figure 3). Based on these errors, predictions are updated by a predictive estimator (Rao & Ballard, 1999). Higher levels may represent more elaborate predictions (Rao & Ballard, 1999; Seth & Tsakiris, 2018). For example, upon exploring the environment, an infant may touch a soft, fluffy object. On the lower level, the brain may encode soft, fluffy texture. On the higher level, the prediction "When I touch a plushie, it feels soft and pleasant on my skin." may be constructed. If the infant then encountered another plushie with a coarse texture, a prediction error would occur on the lower level, which would then be passed on to the higher level to update the prediction.

Figure 3

Schematic display of the predictive coding framework



Note. Schematic of hierarchical predictive coding in the brain. Pyramid cells (triangles) and inhibitory interneurons (circles) are organised in three hierarchical levels (grey areas): from the lowest (R1) to the highest (R3) level. Prediction errors (red arrows) are conveyed from lower to higher levels. Predictions (green arrows) are passed down from higher to lower levels. State units are depicted in orange and error units are depicted in blue. From "An interoceptive predictive coding model of conscious presence", by A. K. Seth, K. Suzuki, and H. D. Critchley, 2012, *Frontiers in Psychology*, 3(1), p. 6. https://doi.org/10.3389/fpsyg.2011.00395, adapted from "The free-energy principle: A unified brain theory?," K. Friston, 2010, *Nature Reviews Neuroscience*, 11, p. 130. https://doi.org/10.1016/j.jphysparis.2006.10.001

According to Seth et al. (2012), the brain uses predictive coding to find the most probable cause of an interoceptive feeling. Responses from the sensory and motor systems are compared with predicted responses, resulting in prediction errors, which then refine prediction generation (Seth et al., 2012). Similarly, prediction errors accompanying motor signals are used to update predictions about the sensory consequences of an action. For example, a person may reach for a ball and then see and feel the ball in their hand – or, alternatively, may not see and feel the ball in their hand, resulting in a prediction error. An individual experiences a sense of agency (see Figure 1) if the generated motor signals lead to the desired change in sensory states (Seth, 2013; Seth et al., 2012). Seth et al. (2012) propose that the *anterior insular cortex* (AIC), a brain region associated with interoceptive awareness (Craig, 2002; Critchley et al., 2004; Critchley & Harrison, 2013), serves as module for comparing prior predictions and afferent states. In sum, Seth et al. (2012) model interoception as an inference based on prior predictions and sensory input, with the aim to best explain the causes of that input.

The Free Energy Principle

Humans use interoceptive signals for *homeostasis,* the process of maintaining a relatively stable internal physical state in an uncertain external environment, using feedback mechanisms (Modell et al., 2015). However, it would be inefficient to rely only on error correction when certain physiological parameters (e.g., blood sugar levels, heart rate, etc.) reach a critical threshold. *Allostasis* refers to a higher-level process of maintaining the internal physical state by anticipating needs before they arise (Sterling, 2012). This means staying within a small range of physical states and limiting the amount of *surprise*. Surprise refers to an outcome with low probability (Friston, 2010). To keep the body in a balanced state, surprise or *entropy* (the long-term average of surprise) need to be minimised. “Here, “a fish out of water” would be in a surprising state (both emotionally and mathematically). A fish that frequently forsook water would have high entropy”(Friston, 2010, p. 127). The upper limit of surprise is called *free energy* (Friston et al., 2006). Free energy can be expressed mathematically as a function of sensory states and the *recognition density* (i.e., a probabilistic representation of the cause of a sensory state; Friston, 2010). Crucially, both parameters can be assessed by humans (or other biological agents; Friston et al., 2006). For example, a person may feel their body temperature rising and assume an increasing environmental temperature as the probable cause. According to the *free energy principle* (FEP), the brain relies on the generation of top-down predictions, so-called *priors*, about bodily states. Deviations from these predictions, evoked by inputs from interoceptive signals, cause prediction errors. Through updating prior predictions or taking actions to change sensory input (the latter referred to as *active inference*), free energy is minimised. More precise prediction errors (i.e., greater inverse variance) have greater influence, as they give more information (Friston, 2010; Friston et al., 2006).

The FEP is consistent with and adds to the predictive coding framework (Friston, 2010; Friston et al., 2006). Predictive coding describes an inference process across multiple hierarchical levels; the minimization of free energy optimises this process (Friston, 2010; Seth, 2013). Autonomic reflexes may be executed by hierarchically lower levels, whereas more elaborate priors about expected physiological outcomes of actions may be encoded in higher levels. These higher-level predictions enable humans to regulate their physiological long-term needs in different environments. Importantly, the aim of these generative models is not to represent reality, but to generate predictions that are instrumental for allostasis (Seth & Tsakiris, 2018).

Active inference is emphasised in the FEP as a way of changing the environment to minimise prediction errors, by selectively sampling expected sensations (Friston, 2010). For example, a person may look out of the window to decide whether to put on a jacket when leaving the house (a prior prediction). Once outside, they may monitor their body’s reaction to the temperature to possibly confirm their previous assumption. Alternatively, they might discover that the temperature is higher than they anticipated (a prediction error) and remove the jacket again (active inference), as well as use their experience for more accurate predictions about the temperature when looking out of the window next time (i.e., update their generative model). The ability to use active inference is already present a few hours after birth: Neonates will move their arm to a beam of light, keeping it visible for exploration (Meer, 1997). In doing so, they are using active inference to see their arm (the expected sensation) instead of darkness (in this case, a prediction error). This enables them to gain information about their body. Ultimately, the aim of these actions is to minimise free energy and maintain allostasis (Friston, 2010; Seth & Tsakiris, 2018).

Free Energy and the Minimal Self

Recently, the FEP has been applied to describe not only interoception but also the minimal self (Apps & Tsakiris, 2013; Fotopoulou & Tsakiris, 2017; Seth & Tsakiris, 2018). Similarly to how humans construct generative models of likely causes of interoceptive sensations, they may construct a generative model that represents the minimal self. Through multisensory inputs occurring at the same time, humans generate predictions about themselves over time. The construction of the minimal self is an ongoing process, which is constantly updated as new inputs emerge, to minimise prediction errors (Fotopoulou & Tsakiris, 2017). For instance, when individuals feel cold, they not only receive input from thermoreceptor cells but may also look at their skin and notice goose bumps on their arm. Binding these inputs together, they can infer that their arm is most likely a part of themselves. Adults may then put on a jacket to feel warm again, thus experiencing themselves as the agent of an embodied action. Infants, however, cannot put on a jacket on their own but need the help of an adult to do so. Indeed, infants rely on others to satisfy their needs and provide interaction (Atzil et al., 2018; Fotopoulou & Tsakiris, 2017). Hence, Fotopoulou and Tsakiris (2017) propose that the development of the minimal self is shaped by embodied interactions with others.

The Development of the Minimal Self

The earliest, rudimentary form of embodied interactions may already take place before birth. Crucially, humans develop within another body (Ciaunica et al., 2021): Basic perception, movement, and even social orientation emerge in utero (Castiello et al., 2010; Lymer, 2011; Marx & Nagy, 2017). The skin is the first sensory organ to develop (Bradley & Mistretta, 1975). The fine hair covering the foetal body (lanugo) may activate the *C-tactile* (CT) fibres during foetal movement, stimulating oxytocin release and regulating foetal growth (Bystrova, 2009). CT-fibres are unmyelinated afferents, which are responsive to slow, gentle touch (Löken et al., 2009). Discriminative properties of touch, such as the ability to locate an object on the skin, seem to develop and gain relevance after birth (Begum Ali et al., 2015), but in utero touch perception may mostly rely on CT-fibres (Bystrova, 2009; Ciaunica & Crucianelli, 2019).

During these developments, foetuses depend on their mothers to maintain homeostasis. However, they are not just passive recipients in this process but active agents in bi-directional maternal-foetal interactions (Quintero & De Jaegher, 2020), specifically participating in the co-regulation of maternal and foetal bodily states, so-called *co-homeostasis* (Ciaunica et al., 2021). For example, the foetuses' kicking may cause their mother to touch her belly, go for a walk, or drink water (Ciaunica et al., 2021). Co-homeostasis is a constant process of adaptation and negotiation between mother and foetus (Ciaunica et al., 2021; Quintero & De Jaegher, 2020). During this process, foetuses may build early predictive models of their self and their environment; they may use active inference to adapt these models (Ciaunica et al., 2021).

For example, by gaining sensory information through startles (e.g., when touching their own body or the uterine wall), foetuses may gradually adjust their movements and actions (Ciaunica et al., 2021). Through contingencies between motor-actions and sensory feedback, self-touch likely contributes to the generation of early sensorimotor models of the infant's body (Georgie et al., 2019; Hoffmann, 2017). There is evidence for early voluntary movement at 14 weeks of gestation (in twin pregnancies), when twin-foetuses touch their co-twin for a longer duration than they touch the uterine wall (Castiello et al., 2010). At 22 weeks of gestation, foetuses reach for their eyes or mouth in a more direct movement pattern than they do at 14 or 18 weeks of gestation, indicating a basic form of action planning (Zoia et al., 2007).

Besides self-touch, foetuses frequently experience touch applied to the maternal abdomen through the uterine wall. In the third trimester, foetuses react to maternal abdominal touch by touching the uterine wall more than when there is no abdominal touch. At this stage, foetuses seem to be able to differentiate maternal touch from touch by other persons: Foetuses show less self-touch during maternal abdominal touch compared to abdominal touch by their father or a stranger (Marx &

Nagy, 2017). Gradually, the developing brain may be able to differentiate between sensory consequences of the foetuses' own movements and sensory consequences of maternal movements. The foetus may be able to predict whether the cause of a sensation is their own motor activity or external. This marks the first differentiation between the self and the environment, and thus, the first construction of a probabilistic model of the self. Of note, awareness or consciousness are not required for this process (Woźniak, 2024). Thus, touch, specifically as mediated by CT-fibres, may shape the minimal self already in the womb (Ciaunica & Crucianelli, 2019).

After birth, an infant's interoceptive and exteroceptive inputs differ from those in utero: Visual input increases and tactile input changes, as infants are no longer surrounded by uterine fluid. Just as in utero, infants must differentiate whether sensory input is caused by themselves or by their environment (Woźniak, 2024). Infants must detect and signal their needs, and caregivers must adequately respond to these signals. Through congruent and incongruent responses and gradual adjustments by both infant and caregiver, infants learn to predict their physiological needs. Again, infants are not passive recipients in this process but must learn to perceive their own bodily states and communicate them to their caregivers (Filippetti, 2021).

If the caregiver correctly responds to the infant's requests, the infant's allostatic balance is maintained, which may serve as a reward. Over time, caregivers and infants gradually attune their signals and responses (Atzil et al., 2018). However, in some cases, the infant's communication of need may be inefficient or unclear, causing the caregiver to react in a way that does not fulfil the infant's needs. Similarly, the caregiver may misinterpret the infant's clear signal and respond inadequately, with a delay, or not at all. These mismatches may prevent the infant from making reliable predictions about their needs. For instance, a caregiver may mistake an infant's feelings of stress for hunger and use feeding to soothe the infant. Consequently, the infant may not be able to make accurate predictions about their own bodily states of hunger or fullness, associating feelings of anxiety or stress with feeding (Filippetti, 2021). Indeed, it has been shown that feeding to soothe an infant is related to a higher BMI in children, and this increase is mediated by emotional eating in childhood (Jansen et al., 2019).

Touch and the Minimal Self

Many of these early interactions are accompanied by touch, possibly contributing to the infant's perception of the skin as a boundary between themselves and their environment. For instance, when a caregiver tickles their infant during play, the infant may feel the sensation of being touched, hear the caregiver's giggling, and see their own limbs. These multisensory inputs are bound together to create representations of both the infants' body and the caregiver's body and behaviour (Fotopoulou & Tsakiris, 2017). Embodied interactions with a *good-enough* (Winnicott, 1972) caregiver include both congruent moments, in which the caregiver responds adequately to the infant's needs, and incongruent moments, in which the caregiver fails to do so. During these congruent moments, infants may experience self-other fusion; incongruent moments may lead to self-other distinction (Fotopoulou & Tsakiris, 2017).

Indirect evidence for the importance of touch for the development of the minimal self is derived from experiments investigating *body ownership*. Body ownership refers to the state of perceiving the body or part of the body as one's own (Fotopoulou & Tsakiris, 2017) and contributes to the sense of ownership, a component of the minimal self (see Figure 1). In the *rubber hand illusion* (RHI) paradigm, participants were seated at a small table with their left arm hidden behind a screen and a life-sized rubber hand placed next to them. Both the rubber hand and their real hand were then stroked at the same time with a soft brush (synchronous condition). Afterwards, participants were asked to fill out a short questionnaire and locate their left hand using their right hand while their eyes were closed. Results showed that participants reported the perceived position of their own hand to be closer to the rubber hand than participants in the control group, who had received touch administered with a delay (asynchronous condition), did. Additionally, participants in the synchronous condition reported feelings of body ownership over the rubber hand (Botvinick & Cohen, 1998). The RHI indicates that body ownership does not simply arise from *having* a body part. Rather, body ownership is a probabilistic model of what is most likely to be part of one's body, based on multi-sensory inputs (Apps & Tsakiris, 2013; Seth & Tsakiris, 2018). Fotopoulou and Tsakiris (2017) explain the RHI as the joint integration of visual and tactile inputs, which occur at the same time, as one experience. Participants see the rubber hand being touched while feeling their own hand being touched. Thus, the rubber hand is inferred to be part of the body.

Infants are already able to detect visual-tactile synchroneity a few hours after birth. In a study investigating newborns 12 to 103 hr of age, infants were touched with a soft brush while watching a video of another infant's face being touched either synchronously or asynchronously with themselves. It was found that infants looked longer at the synchronous stimuli than at the asynchronous stimuli (Filippetti et al., 2013). These results indicate that infants use input from external causes to make inferences about their own body (Fotopoulou & Tsakiris, 2017).

Affectionate Touch

Affectionate touch is defined as a form of touch with positive affect and no clear functional purpose (Feldman & Eidelman, 2007) and includes behaviours such as stroking, massaging and caressing (Feldman & Eidelman, 2007; Ferber et al., 2008; Jean & Stack, 2009; Weisman et al., 2012). The importance of affectionate touch is highlighted by a unique system of CT-fibres found in the hairy parts of the skin (Vallbo et al., 1999). CT-fibres are highly responsive to slow gentle touch with an optimal velocity of 1-10 cm/s (Löken et al., 2009).

At 9 months, infants can already differentiate between various forms and velocities of touch. When mothers touched infant's bellies in an abrupt, negative way, infants were more likely to show negative emotions and were less likely to interact with the objects presented to them than in a control condition where no additional touch occurred, or a condition where mothers relaxed their grip around the infant's belly (Hertenstein & Campos, 2001). Infants prefer CT-fibre optimal touch at around 3 cm/s (Aguirre et al., 2019) and respond with a decreased heart rate, and increased engagement (Fairhurst et al., 2014). Similarly, mothers spontaneously stroke their infants at velocities consistent with or slightly higher than CT-fibre-optimal touch, specifically 7 - 20 cm/s (Bytomski et al., 2020). In mother child interactions, affectionate touch is associated with coregulation in stressful situations (Moreno et al., 2006) and the degree of *reciprocity*, that is, play of give and take (Ferber et al., 2008), when compared to other forms of touch. How is affectionate touch related to the minimal self?

Affectionate Touch and the Minimal Self

First, there seems to be a neural basis for a link between affectionate touch and the minimal self (Fotopoulou & Tsakiris, 2017). In humans, CT-fibres project to the *posterior insular cortex* (PIC; Morrison et al., 2011; Björnsdotter et al., 2009). Interoceptive information is then integrated in a "post-to-mid-to-anterior pattern" (Craig, 2009, p. 59) in the insular cortex, where the level of complexity of representations increases towards the AIC (Craig, 2009). The AIC is associated with interoceptive awareness (Craig, 2002; Critchley et al., 2004; Critchley & Harrison, 2013), one form of interoceptive ability, which is a component of the minimal self (see Figure 1). The convergence of how interoceptive awareness and affectionate touch are represented in the brain suggests a specialised system for processing social, affectionate touch (Fotopoulou & Tsakiris, 2017).

Indeed, previous research has shown that affectionate touch is an important variable in the perception of body ownership (Buckmaster et al., 2020; Crucianelli et al., 2013; Fahey et al., 2019). In an adapted version of the classical RHI, participants saw a rubber hand being touched at the same velocity as their unseen hand: either at a slow (CT-fibre-optimal) or a fast velocity. As expected, participants reported slow touch to be more pleasant than fast touch. Moreover, in the slow touch condition, participants perceived the location of their hand as closer to the rubber hand, compared to the fast touch condition (Crucianelli et al., 2013). This provides evidence for the theory that the multisensory integration process that generates a sense of body ownership is related to affectionate touch (Fotopoulou & Tsakiris, 2017). As affectionate touch and visual input from seeing the rubber hand being touched occurred at the same time, they were "wired" together, that is, "mentalised as one experience" (Fotopoulou & Tsakiris, 2017, p. 16). Consistent with Fotopoulou and Tsakiris (2017), slow stroking acted as a simple embodied interaction, which in case of ambivalent sensory input, caused participants to update their prediction models to include the rubber hand as part of their body.

In addition to that, Fahey et al. (2019) found that stroking, circling, and rubbing as forms of affectionate touch resulted in a higher degree of body ownership of a rubber hand than neutral forms of touch, such as knocking or measuring the rubber hand. Applying the theory of Fotopoulou and Tsakiris (2017), the RHI elicited a prediction error, where participants felt the rubber hand being touched. Rather than relying on top-town predictions of what belongs to their body, they updated their generative models to include the rubber hand. Additionally, the pleasantness of affectionate touch may have served as a reward, enhancing the RHI. Indeed, affectionate touch was perceived as more pleasant by participants in conditions where the rubber hand was embodied (Fahey et al., 2019), indicating that the pleasantness of affectionate touch enhanced the RHI. These results highlight the unique contribution of affectionate touch to the construction of body ownership (Crucianelli et al., 2013).

Affective Touch and Interoception

Affectionate touch and other forms of interoceptive perception frequently occur together. For example, healthy mothers (i.e., mothers without diagnoses such as depression) use touch to calm crying infants (Mercuri et al., 2023) and during playful interactions (Serra et al., 2020). Touch has been shown to lower the infant's cortisol response to stress (Feldman et al., 2010; Hardin et al., 2020) and increase oxytocin levels in mothers and infants (Hardin et al., 2020). Fotopoulou and Tsakiris propose that "[…]given that these interoceptive and exteroceptive data generated by a single tactile stimulus occur by necessity at the same time and place (thus they are characterised by the amodal properties of temporal and spatial congruency that bind modalities together and create predictions and generative models of their causes), they are progressively mentalised as one experience" (Fotopoulou & Tsakiris, 2017, p.16). For example, a mother might stroke her crying infant to calm them. The infant experiences an elevated level of physical arousal (among other signals, a high heart rate), followed by affectionate touch and (in the ideal case) their body returning to a calm state. In terms of the FEP, the infant might update their internal model to associate affectionate touch with calmness and in future situations of high arousal use active inference to selectively sample the expected state (e.g., seek maternal affectionate touch to calm themselves).

In adults, touch has been shown to increase IAcc. Edwards et al. (2018) found that two forms of massaging touch therapy increased objective IAcc (measured by a heartbeat counting task) from pre- to post-intervention. In a control condition in which participants received no touch intervention, no such increase was found. In this context, touch may have caused participants to experience the skin as a boundary between their body and their environment. Furthermore, as touch and other interoceptive properties are represented in overlapping areas in the brain, this input may have caused participants to update not only their internal model of their skin, but also their internal model of the minimal self, resulting in an improved ability to perceive themselves and thus increased IAcc.

Reciprocally, there is some evidence that IAcc could modulate the relationship between touch and body ownership. Individuals with high IAcc were less susceptible to external manipulations of the self in an RHI task (Schauder et al., 2015; Tsakiris et al., 2011) and manipulations of self-other boundaries (Tajadura-Jiménez & Tsakiris, 2014). However, other results indicate that higher IAcc is related to more susceptibility to external manipulations of the self. Individuals with higher IAcc were more likely to accept a virtual image of their own hand that was shown to be pulsating either synchronously or asynchronously with the participant's heartbeat (Suzuki et al., 2013). These differences could be explained by the fact that the latter study used a virtual image of the participant's hand, rather than a rubber hand, and thus the a priori willingness to accept the manipulated image as their own was higher for individuals high in IAcc (Ainley et al., 2016; Suzuki et al., 2013). Additionally, in the latter study, the projection of the heartbeat on the virtual hand may have provided a salient cue for individuals with higher IAcc, causing them to accept the virtual hand as part of their body (Tsakiris, 2017). In sum, individuals with high IAcc of their heartbeat may also be more accurate at perceiving other parts of their body (e.g., their hand) and thus less susceptible to manipulations of the self. However, when their heartbeat is used to enhance these manipulations, they may in turn become more susceptible to them. Overall, individuals with high accuracy in heartbeat perception may rely more on their heartbeat when making inferences about the self (Tsakiris, 2017).

Touch and the Minimal Self in Infants

Thus far, there is little research on the relationship between touch and components of the minimal self in infants. Hence, developmental aspects of the minimal self remain unclear. In one recent study, 5-month-old infants watched prerecorded stimuli of other 5-month-old infants being touched on their forehead. At the same time, the infants themselves were touched on their own foreheads either synchronously with the stimuli on the screen or with a delay between touch and stimuli (asynchronous condition). The velocity of touch was varied: In half of the trials, infants were touched at a slow, CT-fibre-optimal velocity of 3 cm/s; in the other trials they were touched at a faster velocity of 18 cm/s. Infants preferred to look at the synchronous video only when they were touched at a slow velocity. When being touched at a faster velocity, no such effect was found (Della Longa et al., 2020). These findings are consistent with the theory by Fotopoulou and Tsakiris (2017). Infants experienced visual input from the video along with tactile input. In the case of synchronicity, they may have integrated these sensations as one experience, resembling an embodied interaction with a caregiver during congruent moments. The preference for the synchronous target may reflect a rudimentary form of self-other fusion, causing the infants to experience the target face as more similar to themselves.

Infants at 7 months and 10 months preferred to look at videos of doll legs being stroked synchronously with their own legs, compared to doll legs that were stroked asynchronously with their own legs (Zmyj et al., 2011). Here, the synchronous stroking condition may again act as an embodied interaction, binding together the experience of feeling affectionate touch and seeing the doll legs being stroked. Thus, infants may experience the doll legs as part of their own body (Fotopoulou & Tsakiris, 2017; Zmyj et al., 2011).

These studies provide further evidence for the importance of affectionate touch on the minimal self, but they were focused on isolated forms of touch in a controlled environment. Infants were touched at predefined velocities by their caregiver or an experimenter. However, maternal touching behaviour patterns, such as frequency or duration of different types of touch, are known to vary between individuals (Beebe et al., 2010; Fairhurst et al., 2014; Jean & Stack, 2009; Mantis et al., 2019), and are related to social and interpersonal variables of mother and child. For instance, mothers with severe depressive symptoms show a decreased amount of touch (Mantis et al., 2019), whereas more sensitive parenting is linked to increased touching behaviour (Jean & Stack, 2009). Less frequent affectionate touch is linked to feeding disorders (Feldman et al., 2004) and insecure-resistant attachment styles (Beebe et al., 2010). Moreover, mothers with a lower heart rate stroke infants at a slower (CT-fibre optimal) velocity, particularly when the infant is calm (Bytomski et al., 2020). Thus, controlled experiments provide limited insight into how real-life patterns of touch shape the minimal self in infants. Instead, a focus on mother-infant interactions is needed.

Mother-Infant Interactions

Previous research has shown that the interactions of dyads, aside from developmental changes, are consistent across time (Feldman, 2007). Thus, it can be assumed that the way dyads interact in a laboratory setting is representative of the way they interact at home. One method to investigate such mother-infant interactions is *micro coding*, a method of assigning behavioural codes to short segments of time (e.g., 1 second) in recorded mother-infant interactions (Beebe et al., 2010). Micro coding mother-infant interactions provides unique insights when studying mother-infant relations. In fact, the behavioural codes derived from coding only 3 min of mother-infant interaction at 4 months were able to predict attachment styles of infants at 1 year (Beebe et al., 2010).

At 9 months, infants' loco-motoric and cognitive development increases (for a review, see Campos et al., 2000). The emerging autonomy of the infant might contribute to a change in maternal touching behaviour: It was found that 9-month-old infants are touched less frequently than their 3- or 6-month-old peers. Infants become more active participants in their interactions with others, developing a give-and-take pattern (Feldman, 2007). However, as in younger infants, the amount of affectionate touch still uniquely correlates with the degree of give-and-take at 9 months (Ferber et al., 2008). By this stage, mothers and infants mutually influence each other, and both react to the other's emotional state. A pattern in the interaction of mother and child has formed (Feldman, 2007). Thus, at 9 months, an infant should have gained enough experience in the perception of maternal touch through social interactions to shape their infant's minimal self at least to some degree.

Through social interaction, they should have encountered situations in which their caregivers adequately responded to their needs (e.g., by calming the infant down when crying or putting on clothing to regulate body temperature) and situations in which their caregivers failed to do so (e.g., by falsely attributing crying to hunger instead of tiredness). Ideally, caregivers have become increasingly efficient in correctly predicting the infants' needs, and infants have in turn learned to better identify their own needs, that is, upgrade their interoceptive inference models (Atzil et al., 2018). During these encounters, touch and other interoceptive experiences may have often occurred together. For instance, in moments of stress or sadness, infants may have felt their caregivers' affectionate touch on their skin and their own heart rate decrease simultaneously. During these experiences, CT-fibres activated by affectionate touch projected to the posterior insular cortex, along with other interoceptive information (Björnsdotter et al., 2009; Craig, 2009; Morrison et al., 2011). According to Fotopoulou and Tsakiris (2017), these inputs may have been mentalised as one experience. In each of these encounters, the infants' minimal self models may have been updated, leading to more efficient predictions over time. Infants who frequently experienced these embodied interactions accompanied by touch should have more refined minimal self models and should thus be able to make more accurate predictions about components of the minimal self, such as body ownership and interoception (i.e., have higher interoceptive abilities). As affectionate touch and interoceptive inputs are integrated in similar pathways in the brain and frequently occur together, infants who experienced more affectionate touch should have higher interoceptive abilities than infants who experienced less affectionate touch.

No study thus far has investigated how maternal touching behaviour patterns relate to objective IAcc as one component of the minimal self in infants. If the caregiver's affectionate touch shapes components of the minimal self of the infant, differences in maternal touching behaviour patterns should result in differences in objective IAcc in infants. Currently, there is only indirect evidence for the theory that touch shapes the development of the minimal self (Ciaunica & Fotopoulou, 2017; Fotopoulou & Tsakiris, 2017; Montirosso & McGlone, 2020). Studies focusing on the components of the minimal self while assessing touch in naturalistic interactions are missing. Hence, there is no empirical evidence regarding how spontaneous touching patterns of mothers are related to the development of the minimal self in infants. Studying IAcc in relation to embodied mother-infant interactions could further the understanding of the minimal self in infancy and possibly provide evidence for the theory of Fotopoulou and Tsakiris (2017).

The iBEAT task has only been developed recently. In the original study, interindividual differences in the infants' ability to detect objective IAcc were found (Maister et al., 2017). This study aimed to contribute to the validation of the iBEAT task as a measure for assessing infant objective IAcc, as well as to investigate links between objective IAcc and other traits.

Aims of the Current Thesis

The aim of the current thesis was to investigate whether maternal touching patterns contribute to the development of the minimal self in infants, as assessed through detect objective IAcc. To address this question, the interactions of mother-child dyads during a naturalistic free play interaction were recorded and micro coded. Additionally, infants underwent an iBEAT task (Maister et al., 2017) to measure their objective IAcc.

Based on previous literature and the theory of Fotopoulou and Tsakiris (2017), it was hypothesised, that

a) the percentage of time mothers touch their infant in a free play mother-infant interaction predicts objective IAcc in infants; and
b) a higher percentage of affectionate maternal touch over time in a free play mother-infant interaction is related to a higher objective IAcc in infants.

Method

Participants

The current thesis is part of a larger project, involving 90 mother-infant dyads, multiple procedures, and a follow-up 9 months later. For the current thesis, the data of 59 mother-child dyads were considered. Sample size was chosen based on previous literature (Della Longa et al., 2020; Maister et al., 2017). Participants were recruited from a database of mothers who had volunteered to participate in studies at the Wiener Kinderstudien Lab, aiming for a gender-balanced infant sample. Advertisements for the database were posted on social media, via leaflets in local toy and child apparel shops, and via the birth ward of the general hospital in Vienna. Initially, the aim was to test infants from 9.0 to 10.0 months. However, due to Covid-19 restrictions during data collection, this age span was expanded to 9.0 months to 10.15 months, to allow for a higher number of infants to be included in the sample. Testing took place in the Wiener Kinderstudien Lab from September 2020 to June 2021. Dyads were excluded from data analysis if there was less than one good iBEAT trial per trial type (n = 33), less than one minute interaction task video data (n = 3), or if infants sat on the mother's lap during the interaction task (n = 1). The final sample consisted of 22 mother-child dyads. Infants (27 % girls, 5% diverse) were, on average, 9.8 (SD = 0.4) months old at the time of testing. The mean age for mothers was 33.16 years (*SD* = 4.6.). The average birth weight for infants was 3,518g (*SD* = 779.5). 59 % of mothers held a university degree and 73% were employed. One mother (5%) reported birth complications. No diseases, visual, or auditory impairments of the infants were reported. Demographic characteristics for the final sample are provided in Table 1.

Table 1

Sociodemographic Characteristics of Participants

Characteristic	*n*	%
Gender infant		
Female	6	27
Male	15	68
Diverse	1	5
Highest educational level mother		
Apprenticeship	3	14
High school	1	5
Vocational school with higher education entrance qualification	3	14
University degree	13	59
Missing	2	9
Employment mother		
Employed	16	73
Public officiant	2	9
Self-employed	1	5
Missing	2	9
Birth complications [a]	1	5
Single motherhood [a]	2	9

Note. N = 22.

[a] Reflects the number and percentage of participants answering "yes" to this question. Two participants did not answer the question.

Testing Procedure

The current thesis was part of the *Mind the Body* (MiBo) project, a larger longitudinal project investigating the emergence of the minimal self in infants. The overall procedure took up to three hours, including breaks. Following Covid-19 regulations, mothers and experimenters wore masks during the procedure, but mothers removed their masks during experiments. Mothers were instructed to bring familiar toys and snacks for the infant to the lab, to make their infant feel comfortable. All mothers gave their written informed consent at the beginning of the testing session in a separate reception room, followed by a warm-up period in the testing room. During this warm-up period, mothers and infants were offered beverages and given time to play and adjust to the new environment. Infants could choose one toy from a basket filled with a variety of toys of similar size (e.g., balls, squishies, or rattling toys). The tasks were structured into three work packages, which were randomised across mother-child-dyad. After each work package, there were breaks for feeding, changing and/or playing. Additional breaks between tasks were given according to the infant's and mother's needs, if necessary. Experiments were aborted if the infant became too fussy or cried, or if the mother requested to stop the experiment. Upon completing the tasks, mothers were asked to fill out a questionnaire, which they could choose to do either in the reception room or at home. Afterwards, mothers were thanked, debriefed, and received a small gift (mothers had the choice between a book or a 15 € voucher for a drugstore), and compensation for the travel costs. Infants were allowed to keep the toy chosen at the beginning of the procedure. The testing for the current thesis was completed in one session.

Measures

The overall testing procedure of the MiBo project contained various tasks, assessing empathy, introspective measures, language, and facets of mother-child interactions. Other studies and master theses focused on these tasks (Boyadzhieva, 2022; Bullinger, 2021; Jordan, 2022; Lutz, 2023; Maier, 2023; Neumann, 2022; Triebenbacher, 2024; Tünte et al., 2024, 2025; Vanoncini et al., 2024, 2025, 2022; Wittmann, 2022). For this thesis, only the results of the measures relevant to the research question, namely the iBEAT task and the free interaction task, will be reported.

IBEAT Task

IAcc was measured with the iBEAT task, replicating the procedure of Maister et al. (2017). Three ECG electrodes were placed on the infant's chest and stomach in a 3-lead ECG setup. Due to Covid-19 safety regulations, the placement was done by the infants' mothers following an illustrated guide and instructions from the experimenter. Cardiac activity was monitored and recorded via ADInstruments Powerlab and BioAmp equipment (www.adinstruments.com). The hardware-based ADinstruments function "fast response output" allowed for the identification of R-peaks in the ECG trace by sending a signal to the computer via a custom-made Arduino setup when the voltage reached a threshold. Thresholds were predefined individually for each infant.

Infants were seated in a car-seat, at a distance of approximately 60 cm from the screen. Mothers sat behind their infant in a chair. Mothers were instructed not to touch or interact with the infants in any way, but to hold their infant's hand if they start to cry or get fussy. An additional camera monitored maternal and infant behaviour during the experiment to check for possible influences outside the stimuli on the screen (for instance the mother pointing at the screen or talking to the infant). If the infant became fussy upon being placed in the car seat, mothers were instructed to hold the infant on their lap.

Stimulus presentation was implemented via a custom-made Matlab (Version R2018b) algorithm and displayed on a 21.5 inch BenQ GL2250 LED monitor. Infant eye movement was measured via an EyeLink® 1000 plus eye tracking device with a 16 mm lens at 500 Hz. A three-point eye tracking calibration was done at the beginning of the procedure. After successful calibration, the iBEAT task was started.

Before each trial, a fixation stimulus accompanied by a sound was shown at the centre of the screen for 5 s, followed by the presentation of either a synchronous or asynchronous stimulus for 5–20 s, depending on the infant's attention. The trial ended automatically if the infant looked away from the screen for more than 2 s or if the 20 s maximum presentation time was over. The iBEAT task started with a synchronous trial, to calculate the inter-peak interval required for the asynchronous trials. Stimuli moved up and down rhythmically. Synchronous stimuli moved in time with the R-peak detected by the ECG. Asynchronous stimuli moved with a delay of

+10 or -10 % of the mean inter-peak interval of the infant. The up-and-down movement was coupled with a jumping sound, played on two Logitech Z200 speakers

For each infant, synchronous and asynchronous trials were each displayed by a respective visual stimulus — either a yellow cloud or a pink star. The assignment of stimuli to trial type was counterbalanced across infants. Stimuli were presented on either the right or the left side of the screen. Stimulus location and trial type (synchronous or asynchronous) were pseudo-randomised. The iBEAT task ended after a maximum of 80 trials or if the infant looked away from the screen for more than 4 consecutive trials. Moreover, the task was aborted if the infant became too fussy or upon the mother's request.

Mother-Infant Interaction

Maternal touch was assessed during a naturalistic mother-infant interaction. Portable ECG Electrodes (Smarting 24, mBrainTrain) were placed on the (a) right and (b) left shoulder, on the (c) right and (d) left abdomen, and on (e) the chest of both mothers and infants. Again, mothers applied the electrodes following an illustrated guideline and instructions from the experimenter. Moreover, both mothers and infants wore functional near-infrared spectroscopy (fNIRS) caps during the task. These measures were taken to assess physical signals unrelated to the current study, as part of the Mibo project. Infants were placed in a high-chair, mothers were seated in a chair facing the infants. Three cameras recorded the interaction at 25 frames per second: one directed at the mother's upper body; one directed at the child's upper body; and one recording the interaction from the side.

Mothers were instructed to play with their infant as they would at home and to interact as naturally as possible. The interaction consisted of two conditions: The first condition lasted 2.5 min. Mothers were instructed not to use toys during this condition. The second condition lasted 5 min. A break between conditions was given if needed. Mothers were instructed to interact with their infant using the toy the infant had chosen at the beginning of the testing session, but to use other toys in case the infant got bored. This way, maternal touch could be assessed across two naturalistic conditions, resembling situations likely occurring in the infant's everyday life. Previous results have shown that mothers touch less in sessions involving toys (Serra et al., 2020), thus two types of conditions were applied to foster a situation that resembles everyday life more closely. The interaction task ended after the second condition, or if the infant became too fussy or the mother requested to end the task.

Data Preprocessing

Video Coding

Maternal Touch was micro coded with Mangold Interact (Version 16). Coding definitions were based on previous studies (Feldman & Eidelman, 2007; Ferber et al., 2008; Jean & Stack, 2009; Nguyen et al., 2021; Weisman et al., 2012). Affectionate touch was further divided into touch by mouth (i.e., kissing) and touch by hand, as, to the best of my knowledge and upon reviewing relevant literature, no studies regarding touch by mouth in relation to the minimal self exist.

Previous studies on affectionate touch and the minimal self frequently administered affectionate touch using a soft brush, rather than by hand (Aguirre et al., 2019; Della Longa et al., 2020; Fairhurst et al., 2014). However, most studies assessing touch in a free play interaction or during the still face experiment did not include affectionate touch by an object (Carozza & Leong, 2021; Feldman & Eidelman, 2007; Ferber et al., 2008; Jean & Stack, 2009; Weisman et al., 2012). Although there is little difference in brain activation when 4-month-old infants are being stroked by a spoon or a hand (Pirazzoli et al., 2019), Della Longa et al. (2020) found that 5-month-old infants performed better at detecting visual-tactile synchrony when being touched by a brush, rather than a hand. Given these results, it is currently unclear if the mode of touch (hand or object) affects awareness. Thus, for stimulatory and affectionate touch, additional categories were created to code for touch by object. Finally, consistent with a study assessing touch during a free play session with toys (Serra et al., 2020), an additional category was added to code times when mother and infant touched a toy at the same time, for example, by playing together or when the mother handed the infant a toy.

In the first condition, the following forms of touch were coded: (a) affectionate touch by hand (soothing, positive touch, e.g., stroking or massaging), (b) affectionate touch by mouth (i.e., kissing), (c) stimulatory playful touch by hand (often fast, stimulatory touch in playful situations, e.g., tickling), (d) stimulatory functional touch by hand (stimulatory touch with the aim to get the infant’s attention back, e.g., tapping), (e) functional touch (caring for the infant’s need, e.g., correcting clothing or removing the infant's hand from a cable), (f) static touch (hand rests on infant), (g) unintentional touch, (h) no touch, (i) not codable.

For the second condition, additional codes were added: (a) affectionate touch by object (e.g., stroking the infant with a soft toy), (b) stimulatory playful touch by object, (c) stimulatory functional touch by object, (d) shared object touch (mother and infant touch an object at the same time). All videos were coded by one coder. Additionally, 20% were coded by a second coder independently to calculate interrater reliability ($k = 0.86$).

The percentage of time each type of touch occurred was used as a measure. Percentage of time of touch was defined as the overall duration of all touch categories other than "no touch" and "not codable", relative to the duration of the overall condition. Time periods in which the mother took the infant out of the chair were excluded from video coding analysis.

Percentages of overall touch and affectionate touch were log-transformed, as they were not normally distributed. To decrease multicollinearity, looking times and percentages of overall touch and affectionate touch were then z-transformed.

IBEAT

To assess looking times, an area of interest was defined as the maximum area a given stimulus moved on the screen. Looking time was then calculated as the duration of all eye-tracking samples in that area. Trials with 0 looking time were excluded, as it was unclear whether infants did not look at the screen or there was a technical error. All trials were inspected and excluded if technical problems were detected (e.g., a detached electrode or a connection failure between the monitor and presentation computer). The quality of the R-peak detection in the iBEAT task was visually assessed and categorised as either "low", "medium" or "high" quality. Trials with low and medium quality were excluded from analysis. 1,026 trials were excluded from analysis this way. Six further trials were excluded because infants did not complete at least one trial in both synchronous and asynchronous conditions. Finally, 28 trials were removed because infants who completed these trials were excluded for not completing at least 1 minute of the mother-infant interaction task or sitting on the mother's lap during the mother-infant interaction task. As a result, 230 trials remained in the final data sample for further analysis.

While infants in the original iBEAT task preferred asynchronous stimuli (Maister et al., 2017), in studies investigating the detection of synchroneity in other modalities, a preference for synchronous stimuli was found (Della Longa et al., 2020; Filippetti et al., 2013). Thus, no assumption regarding the direction of the difference was made.

Looking times were not normally distributed. In accordance with the recommendations by Cisbra et al. (2016), looking times were log-transformed. No outliers were excluded. A difference score was calculated for transformed looking times. Difference scores were defined as the absolute amount of difference between the mean looking time for synchronous trials and the mean looking time for asynchronous trials, relative to the overall looking time.

Data Analysis

Data analysis was carried out using R version 4.1.0 (R Core Team, 2021) and the R package lme4 (Bates et al., 2015). P-values were estimated with the R package lmerTest (Kuznetsova et al., 2017). Intraclass correlation (ICC) was calculated using the R package irr (Gamer et al., 2019).

Intraclass Correlation

A two-way agreement variance component analysis (ICC, A1) was used to assess if the number of trials infants completed was equally distributed between synchronous and asynchronous trials (Stahl et al., 2010). An ICC of 1 would indicate that the type of stimuli has no effect on the variance of the number of trials (Shrout & Fleiss, 1979).

LMMs

The data set was analysed using weighted *linear mixed models* (LMM). LMMs are an extension of linear models, appropriate for the analysis of repeated measures. In addition to fixed effects, random effects can be included in the model. Fixed effects are associated with continuous covariates or factors; random effects refer to the influence of random variables. LMMs are robust against missing data. While LMMs assume normality of residuals, small violations of this assumption are unlikely to bias the results (Knief & Forstmeier, 2021).

Looking time was defined as the outcome variable, trial type (synchronous or asynchronous) and touch or affectionate touch were the independent variables. Trial index (i.e., the number of sequences of a given trial), trial sum (the overall number of trials an infant completed), and infant seating position were checked for correlations with looking time. Only the trial index correlated with looking time and was included as a covariate. Participant was included as a random effect. In accordance with the recommendation by Barr et al. (2013), the random effect structure was specified as maximum, resulting in the following saturated models:

(a) Log looking time ~ affectionate touch × trial type × trial index + (1+trial type|participant)

(b) Log looking time ~ touch × trial type × trial Index + (1+trial type|participant)

The most appropriate model was chosen using a top-down approach, starting with the most saturated model. In each step, one parameter was excluded. After each step, an analysis of variance (ANOVA) was used to determine if adding more parameters would significantly improve the fit of the model, following the recommendations by West et al. (2015). Only if the model fit improved significantly, the model with more parameters was used for further comparison, otherwise, the reduced model was compared to the further reduced model in the next step. This approach resulted in the following additional models:

Step 1: The first interaction term was removed.

(a) Log looking time ~ affectionate touch + trial type × trial index + (1+trial type|participant)

(b) Log looking time ~ touch + trial type × trial index + (1+trial type|participant)

Step 2: The second interaction term was removed.

(a) Log looking time ~ affectionate touch + trial type + trial index + (1+trial type|participant)

(b) Log looking time ~ touch + trial type + trial index + (1+trial type|participant)

Step 3a: Touch was removed as a predictor.

Log looking time ~ trial type + trial index + (1+trial type|participant)

Step 3b: Trial type was removed as a predictor.

(a) Log looking time ~ affectionate touch + trial index + (1+trial type|participant)

(b) Log looking time ~ touch + trial index + (1+trial type|participant)

Step 4: Both touch and trial type were removed as predictors, resulting in a trial-index-only model.

Log looking time ~ trial index + (1+trial type|participant)

Step 5: Trial Index was removed as a predictor, resulting in a baseline model.

Log looking time ~ (1+trial type|participant)

Weights

The number of trials varied across infants. Since a larger number of trials yields more precise information, it can be assumed that variance differs depending on how many trials an infant completed. To avoid violating the assumption of homoscedasticity, an inverse variance weighted regression approach was applied (Stahl et al., 2010). First, a linear model was fitted, predicting looking times from the number of trials, using maximum likelihood estimation. The residuals predicted by the fitted values of the linear model were then used to define the weights as the inverse of the estimated variance. Thus, trials with lower variance carried more weight in the LMM analysis (Stahl et al., 2010).

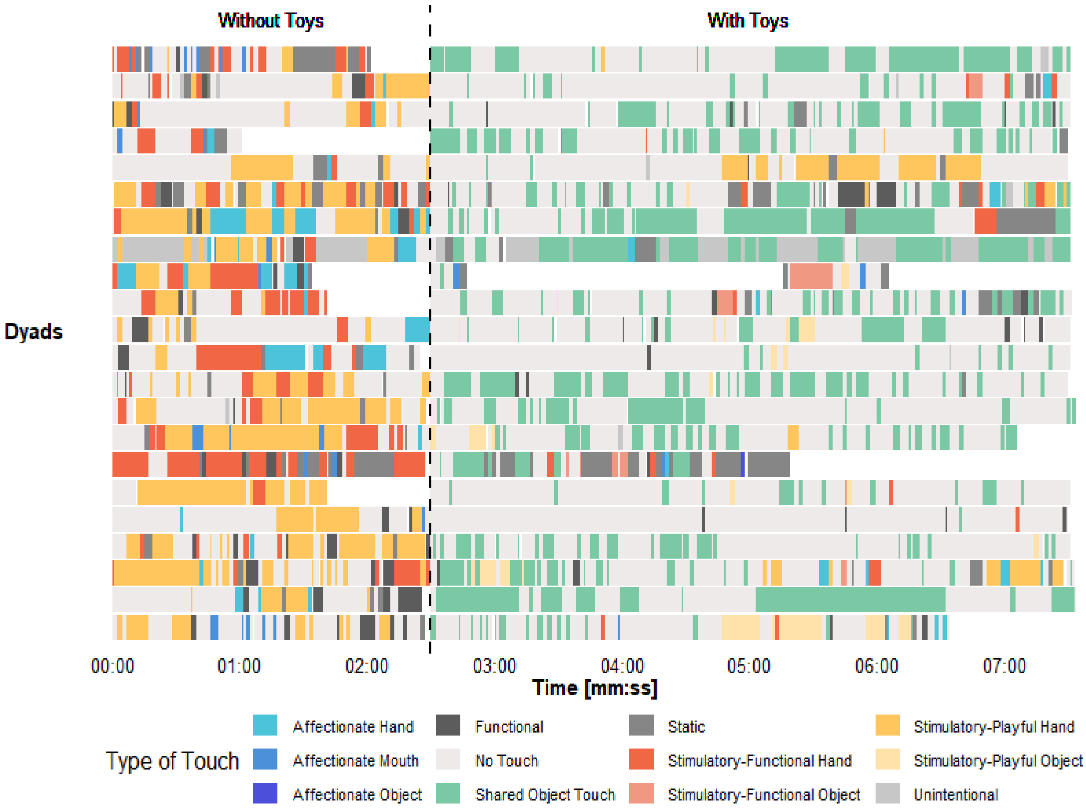
Results

Touch

Overall, mothers touched their infants on average 49.87% (*SD* = 21,56%) of the interaction time. The mean percentage of affectionate touch was 2.94% (*SD* = 4.33%). Figure 4 depicts the occurrence of each type of touch over the course of the interaction time for the final sample. Of note, the percentage of affectionate touch was higher in the condition without toys (*M* = 5.33%, *SD* = 8.87%) than in the condition with toys (*M* = 0.55%, *SD* = 0.99%). Considering all types of touch, mothers touched their infants more in the condition without toys (*M* = 58.73%, *SD* = 22.39%) than in the condition with toys (*M* = 41.01%, *SD* = 24.64%).

Figure 4

Types of Touch over Time



Note. Types of touch by time. Each horizontal line represents a mother-infant dyad. White areas show time segments that were not codable or during which the infant was taken out of the car seat. The dashed line marks the end of the without-toys and beginning of the with-toys condition. Infants were given a break between conditions if needed, these time periods were not coded for touch and are not depicted in the figure.

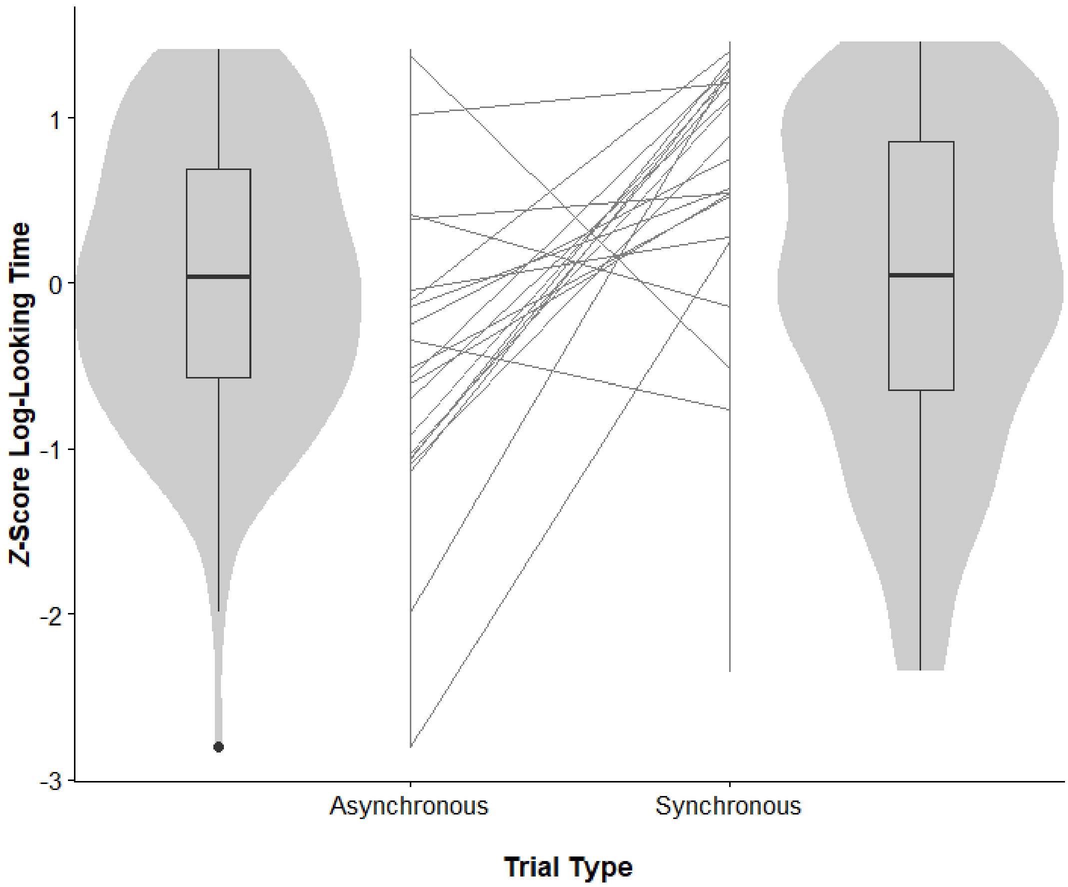
IBEAT Task

On average, infants completed 6.84 trials in the synchronous condition (*SD* = 3.04), and 7.27 trials in the asynchronous condition (*SD* = 3.27). An *ICC* (intraclass correlation) indicates how equally distributed the experimental conditions (synchronous or asynchronous) were on the completed trials. It can take a value from 0 to 1. Here, the ICC was 0.62 (F = 4.54, $p < .01$). Overall, infants completed between 2 and 24 trials ($M = 13.89$, $SD = 6.28$). There was no significant correlation between looking time and the sum of trials infants completed ($r_S = -0.12$, $p = .06$). On average, infants looked at the screen for 6,228.9 ms ($SD = 4,864.58$) per trial. The mean raw looking time for synchronous trials was 6,397.58 ms (*SD* = 5,073.28), whereas the mean raw looking time for asynchronous trials was 6,071.56 ms (*SD* = 4,677.57). *Z*-scores of looking times by trial type are shown in Figure 5.

Trial index ranged from trial number 0 to 35 (*M* = 10.58, *SD* = 7.21). There was a significant correlation between trial index and looking time ($r_S = -0.55$, $p < .01$), thus trial index was included as a covariate.

Figure 5

Log- and Z-Transformed Looking Times by Trial Type



Note. Violin plots for log- and *z*-transformed looking times, for asynchronous and synchronous trials. Grey lines depict individual infants' difference in mean log- and *z*-transformed looking times between asynchronous and synchronous trials. Grey areas show the probability distribution of log- and *z*-transformed looking times for asynchronous and synchronous trials. *N* = 22. Observations = 230.

Infant Seating Position

One infant sat in the car seat, rather than the highchair during the interaction task. Three infants sat on their mother's lap during the iBEAT task. There was no significant correlation between infant seating position and looking times ($r_S = -0.06$, $p = 0.36$), thus no further data were excluded from analysis and seating position was not included as a control variable.

Difference Scores

Difference scores ranged from 0.01 ms to 0.22 ms ($M = 0.05$ ms, $SD = 0.05$ ms). Difference scores did not significantly correlate with affectionate touch ($r_S = -0.35$, $p = .11$) or overall touch ($r_S = -0.15$, $p = .50$).

LMMs

Affectionate Touch

In step 1, the AIC for the full model was 503.54, compared to 505.67 of the reduced model and the full model had a significantly improved fit over the reduced model ($\chi 2 = 8.13$, $df = 3$, $p = .43$). In step 2, the reduced model had an AIC of 503.78, but the full model did not significantly improve fit over a reduced model ($\chi 2 = 8.23$, $df = 4$, $p = .08$). Removing affectionate touch or trial type as predictor in steps 3a and 3b yielded an AIC of 502.17 and 502.58, respectively. The reduced model from step 2 did not significantly improve model fit over either model ($\chi 2 = 0.39$, $df = 1$, $p = .53$; $\chi 2 = 0.80$, $df = 1$, $p = .37$). The model with trial type as the only predictor (3a) was chosen for further comparison, because of the lower AIC. In step 4, the AIC value of the trial-index-only model was 500.98 and the model fit of the reduced model from step 3a was not significantly improved over the trial-index-only model ($\chi 2 = 0.40$, $df = 1$, $p = .53$). Consequently, the most appropriate model for affectionate touch was a trial-index-only model, which showed a significantly improved model fit over a baseline model ($\chi 2 = 101.52$, $df = 1$, $p < 0.001$). The model is shown in Table 2.

Touch

In step 1, the AIC of the full model was 507.34, compared to an AIC of 506.57 for the reduced model, and there was no significant improvement in model fit ($\chi 2 = 5.23$, $df = 3$, $p = .16$). In step 2, the further reduced model without interaction term had an AIC of 504.58, there was no significant improvement in model fit ($\chi 2 = 0.02$, $df = 1$, $p = .90$). In step 3a, removing touch as a predictor resulted in an AIC of

502.98, model fit was not improved ($\chi2$ = 0.40, *df* = 1, *p* = .53). In step 3b, removing trial type as a predictor resulted in an AIC of 502.58 and model fit did not significantly improve ($\chi2$ = 0.01, *df* = 1, *p* = .99). Model 3b was chosen for further comparison due to its lower AIC. In step 4, the trial-index-only model yielded an AIC of 500.98, model fit did not improve ($\chi2$ = 0.39, *df* = 1, *p* = .53). Finally, in step 5, the AIC of the baseline model was 600.50. The trial-index-only model was the most appropriate model, significantly improving model fit over the baseline model ($\chi2$ = 101.52, *df* = 1, *p* < .001). The model is summarised in Table 2.

Table 2

Trial-Index-Only Model

Effect	Estimate	95% *CI*	*P*
Fixed effects			
Intercept	9.17	[8.95, 9.39]	<.001***
Trial index	−0.08	[−0.09, −0.06]	<.001***
Random effects			
σ^2		0.81	
$\tau_{00\ \text{participant}}$		0.13	
$\tau_{11\ \text{participant} \times \text{trialtype}}$		0.01	
$\rho_{01\ \text{participant}}$		0.02	
ICC		0.14	

Note. N = 22, Observations = 230. CI = confidence interval

***p <.001.

Explorative Analysis

Outlier Analysis

The analysis was repeated with the exclusion of outliers above or below 2 SDs from the mean log- and *z*-transformed looking time. The outlier analysis is detailed in Appendix A. For affectionate touch, the fully saturated model was the most appropriate model, while the trial-index-only model was the most appropriate model for touch. The model is summarised in Table A1 of Appendix A. Similarly, the analysis was repeated with the exclusion of outliers above or below 3 SDs from the mean log- and *z*-transformed looking time. The model is shown in Table A2 in Appendix A.

Toys Condition

As the percentage of touch and affectionate touch differed across toys condition, separate analyses were conducted for each toys condition. These analyses are detailed in Appendix B. For the without-toys condition and affectionate touch, the most appropriate model was a trial-index-only model. However, the comparison between the trial-index-only model and the full model yielded a *p*-value close to 0.05 ($\chi 2 = 11.67$, $df = 6$, $p = .07$). For the with-toys condition and touch, as well as both conditions and touch, the trial-index-only model was the most appropriate model. Of note, the interaction between iBEAT trial type and affectionate touch in the without-toys condition was significant both when excluding outliers below and above 2 *SD* and 3 *SD* from the mean log- and *z*-transformed looking time. These models are summarised in Table B1 and B2 in Appendix B.

Discussion

The aim of the present thesis was to investigate whether maternal touch is related to IAcc as one facet of the minimal self in infants. Specifically, the hypotheses were: (a) The percentage of time mothers overall touch their infants predicts IAcc in infants and (b) A higher percentage of affectionate maternal touch is related to a higher IAcc in infants. Mothers and infants were recorded during a naturalistic playful interaction. To measure IAcc, infants watched symbols on a screen moving either synchronously or asynchronously with their own heartbeat, while their looking times were tracked. The effects of maternal touch on the relationship between trial type (synchronous or asynchronous) and looking times were estimated. The results did not support either of the hypotheses. Neither overall touch nor affectionate touch was related to IAcc in infants. However, exploratory analyses revealed a potential link between affectionate maternal touch during the without-toys condition and IAcc. These results will be discussed below.

In the current thesis, IAcc was measured as one component of the minimal self. Contrary to prior hypotheses, neither overall, nor affectionate touch was associated with IAcc in infants. A major distinction of the current research is that it aimed to investigate the effects of natural variations of maternal touch on the development of the minimal self. In previous research, touch has been delivered in a controlled and standardised way (Botvinick & Cohen, 1998; Crucianelli et al., 2013; Della Longa et al., 2020; Edwards et al., 2018; Filippetti et al., 2013, 2016; Tajadura-Jiménez et al., 2013; Zmyj et al., 2011). For instance, in multiple experiments, infants watched displays of faces being touched, while their own face was touched either synchronously or asynchronously with the faces in the videos. Infants looked longer at the synchronous videos (Della Longa et al., 2020; Filippetti et al., 2013, 2016) and they showed this preference as early as a few hours after birth (Filippetti et al., 2013). Similarly, infants looked longer at videos of doll legs that were stroked synchronously, rather than asynchronously with their own legs (Zmyj et al., 2011). For adults, it was found that touch applied to one's own face synchronously to seeing another face being touched leads to changes in self-recognition (Tajadura-Jiménez et al., 2013). Finally, the *rubber hand illusion* (RHI) demonstrated that adults perceive a rubber hand that is stroked synchronous to their own hand as part of their body (Botvinick & Cohen, 1998), particularly when touch is delivered at a C-fibre-optimal velocity (Crucianelli et al., 2013).

All these studies found a link between the minimal self and touch. No such link was found in the current thesis. Here, touch was not manipulated experimentally but rather assessed in a naturalistic mother-child interaction, with the aim of observing mothers touching their infants like they would in their everyday life. It is possible that the effect of touch on the minimal self is only temporary, that is, individuals may have a higher IAcc (Edwards et al., 2018) or be more likely to accept the rubber hand as part of their body after experiencing affectionate touch (e.g., Crucianelli et al., 2013). However, these effects may not lead to a long-lasting change in the minimal self, particularly not to a higher IAcc. In other words, mothers frequently touching their infants in everyday life may result in a temporary increase in the infant's interoceptive abilities but may not be related to a general increase in the infant's interoceptive abilities.

Another possible explanation is that different components of the minimal self may develop independently of each other. Rather than one generalised model of the minimal self, infants may develop multiple self models, one for each modality or component of the self (Woźniak, 2024). That is, the ability to detect one's skin being touched might not transfer to the ability to detect one's heartbeat or other bodily functions. In the studies discussed above, the effect of touch on the perception of various body parts (faces, arms, legs) was investigated (Botvinick & Cohen, 1998; Crucianelli et al., 2013; Della Longa et al., 2020; Filippetti et al., 2013, 2016; Tajadura-Jiménez et al., 2013; Zmyj et al., 2011). These are external body parts that can be touched directly through the skin. The same is not true for internal organs such as the heart. It is plausible that touch only relates to minimal self models of body parts that can be touched in everyday life. Maternal touch could enhance the infant's experience of the skin as a boundary of their body (Ciaunica & Fotopoulou, 2017; Fotopoulou & Tsakiris, 2017), but not relate to the infant's detection of their own heartbeat. Indeed, it was found that objective IAcc, measured by a heartbeat counting task, was not associated with the degree of embodiment in the RHI for adults (Crucianelli et al., 2018).

Nevertheless, there are contradictory findings. For example, there is evidence that adults with higher IAcc exhibit stronger self-other boundaries (Tajadura-Jiménez & Tsakiris, 2014) and are less likely to perceive the rubber hand as their own (Tsakiris et al., 2011). However, another study found greater susceptibility to manipulations of the self for adults with higher IAcc (Suzuki et al., 2013), compared to adults with lower IAcc. Notably, it has been shown that two forms of therapeutic affectionate touch increase the IAcc of adults immediately post intervention (Edwards et al., 2018). At the present, much about the relationship between different components of the minimal self remains unclear and needs to be explored further in future research.

Age could be a crucial variable in the relationship between affectionate touch and the minimal self. At 9 months, motor skills are more developed and infants explore the world more than their younger peers (Adolph & Hoch, 2019; Campos et al., 2000). In doing so, they might rely less on their mothers to regulate their body. For example, when an infant crawls through a room, they might reach the walls or touch various objects such as chairs or toys. Thus, they would experience the skin as a boundary of their body without the need for others to touch them. Indeed, mothers touch 9-month-old less than they touch 3-month-old infants (Ferber et al., 2008). It is possible that there is a link between maternal touch and IAcc at an earlier age, but that maternal touch is less relevant at 9 months of age.

The applied method for measuring IAcc could be another reason why no link between maternal touch and IAcc was found. Of note, synchronous and asynchronous trials did not differ significantly in looking time. In fact, infants looked longer at synchronous trials than at asynchronous trials, although this preference did not reach statistical significance. In contrast, Maister et. al (2017) found significantly longer looking times for asynchronous trials. There are multiple possible explanations for this discrepancy.

First, it is unclear whether the findings by Maister et. al (2017) can be generalised to other populations. The original results show a link between the amplitude of the *heartbeat evoked potential* (HEP), an event-related potential associated with adults' abilities in the heartbeat counting task (Pollatos & Schandry, 2004), and infants' performance in the iBEAT task (Maister et al., 2017). For instance, the infants in the current research differed from the infants tested by Maister et. al in age. In a recent study, infants aged between 5 and 7 months took part in a visual cardiac task similar to the iBEAT: Stimuli blinked on the screen either synchronously or asynchronously with the infant's heartbeat. In one condition, the blinking of the stimuli was accompanied by a beeping sound. No preference for synchronous or asynchronous stimuli was found; furthermore, HEP did not correlate with individual differences in looking time (Weijs et al., 2023). More research is needed to validate the iBEAT task and its application in different populations of infants.

Second, data preprocessing and analysis differed. Maister et. al (2017) excluded outliers two standard deviations above or below the mean, while no outliers were excluded in the current thesis. Indeed, when excluding outliers 2 or even 3 SDs above or below the mean, in exploratory analysis, the results changed. Trial type then had a significant effect on looking time, that is, infants looked longer at synchronous trials. However, excluding outliers based on the mean and standard deviation can be problematic, as these statistical parameters are affected by outliers themselves, especially in data sets with smaller sample sizes (Leys et al., 2019). At least for some statistical methods, it has been shown that excluding outliers 2 SDs below or above the mean increases type I error rates (Bakker & Wicherts, 2014). In the current thesis, outliers were kept in the data and analyses were repeated excluding outliers, following one of the recommendations by Aguinis et al. (2013). It was revealed that one influential outlier had changed the results. Thus, the current data do not strongly support the null hypothesis.

However, exploratory analyses revealed a potential link between affectionate maternal touch during the without-toys condition and IAcc. Infants who received less affectionate touch looked longer at asynchronous trials, whereas infants who received more affectionate touch looked longer at synchronous trials. These results need to be confirmed in future studies; nevertheless, they indicate a possible shift in synchrony preference based on touch. There are two possible explanations for this shift.

On the one hand, the preference for synchrony could be linked to an advancement in social orientation. In a previous study, it was found that infants who preferred to look at synchronous videos of their own legs moving, rather than asynchronous (delayed) videos, were more likely to imitate a mouse puppet. The imitation of the mouse puppet indicates a more advanced social development, or at least a higher social interest (Klein-Radukic & Zmyj, 2016). It is plausible that a higher amount of affectionate touch is related to more social interest in infants and that this effect is associated with a higher synchrony preference.

On the other hand, a preference for either synchronous or asynchronous trials could be interpreted as an increase in IAcc. It has been shown that infants who receive less affectionate touch from their mothers exhibit higher amounts of self-touching behaviour (Herrera et al., 2004). When touching themselves, infants explore their skin as a boundary of their body. In comparison, infants who received a moderate amount of affectionate touch would get neither of the benefits associated with maternal or self-touch. Thus, self-touching could compensate for the lack of affectionate touch in developing the minimal self. Indeed, active self-touch was found to increase body ownership in an RHI experiment (Hara et al., 2015). In the current thesis, infant self-touch was not measured. The relationship between infant self-touch, maternal touch and the IAcc should be explored in future research.

Notably, these effects only occurred in the without-toys condition, and they were specific to affectionate touch, rather than overall touch. In accordance with previous findings (Serra et al., 2020), mothers touched their infants more often in an affectionate way when playing without toys, showing a higher amount of direct touch, rather than touching through toys. Skin-to-skin touch has been shown to facilitate positive developmental outcomes, such as lower stress reactivity and enhanced brain maturation (Hardin et al., 2020; Scher et al., 2009; Schneider et al., 2012). The exploratory results point to a possibly unique role of skin-to-skin touch in the development of the minimal self.

Limitations and Future Directions

There are some limitations to the present research. First, the final sample only consisted of 22 infants and 230 observations. The overall study took up to three hours. Some infants napped between experiments, whereas others were tired or fussy, resulting in a large amount of data that had to be excluded from analysis (e.g., because infants only participated in one of the tasks or sat on their mother's lap during the free play interaction). While small sample sizes are common for infant studies (in fact, few studies include data from more than 24 infants per cell), they may lead to a reduced power and possible false positive or false negative outcomes (Oakes, 2017). Although the sample size of the current thesis is comparable to other infant studies, a larger sample or more observations per infant would have improved the power of the analysis. Future research should attempt to recruit more mother-infant dyads and minimise the duration of experiments, to ensure infants do not get tired during the testing.

Second, the demographic sample differed from the general Austrian population (Statistik Austria, 2022). Mothers' education level was above average. It is plausible that the mothers who participated in the current research had more knowledge about infant care, thus leading to less variation in affectionate touch. Similarly, the sample consisted of a low-risk group of infants without variables such as low birth weight. Thus, the current findings should only be generalised to low-risk infants. The effects of maternal touch on the development of IAcc in at-risk samples, such as preterm infants or infants with depressed mothers could be an endeavour for future research.

Third, mothers displayed little affectionate touch overall during the free play interaction task (see Figure 4). The overall lack of affectionate touch could partly explain the null results for hypothesis 2, that is, not finding a significant link between affectionate maternal touch and IAcc. In the present research, mothers showed more affectionate touch during the without-toys condition than during the with-toys condition. Thus, the present results confirm the findings of Serra et. al (2020), indicating that maternal touch varies depending on situational context. Future research should examine maternal touch patterns in a greater variety of naturalistic interactions, for example, caregiving situations such as diaper changes.

While touch and affectionate touch were measured by filming and video coding a free play interaction, other approaches to measuring touch exist. For example, Bytomski et. al (2020) measured touch by applying a calibration tape to the chair, and then measured the speed of stroking via automatic video coding. This approach might be a more precise method to assess affectionate touch. Different paradigms of measuring touch and how they relate to each other and to everyday situations are an important topic for future research.

Despite results on the relationship between IAcc and aspects of psychological wellbeing, such as emotional experience (Wiens et al., 2000) or decreased anxiety in a public speaking task (Werner et al., 2009), there is little research on how to facilitate increases in IAcc. In adults, massaging touch has been found to enhance IAcc immediately (Edwards et al., 2018). However, to the best of my knowledge, it is currently unknown if and how it is possible to enhance IAcc in infants. As research on interoception grows rapidly and more knowledge about the benefits and downsides of higher IAcc emerges (Quigley et al., 2021), it is crucial to identify parenting behaviours that help infants develop IAcc. Such parenting behaviours could then be communicated to parents and other caregivers to help promote favourable parenting styles.

Overall, the present thesis highlights the importance of investigating maternal touch in naturalistic situations, such as free play interactions and caregiving actions. Although previous studies found links between touch and other facets of the minimal self in controlled experiments (Botvinick & Cohen, 1998; Crucianelli et al., 2013; Della Longa et al., 2020; Edwards et al., 2018; Filippetti et al., 2013, 2016; Tajadura-Jiménez et al., 2013; Zmyj et al., 2011), maternal touch was not related to the infants' minimal self when assessed during a free play interaction in the current research. Both controlled and naturalistic research approaches are needed to gain a complete understanding of the development of the minimal self.

Conclusion

In sum, the present thesis does not confirm the theory that patterns of maternal touch are related to IAcc as one component of the minimal self. Neither overall touch nor affectionate touch was linked to infants' IAcc. However, exploratory analyses revealed a potential connection between affectionate touch in the without-toys condition and IAcc. Although the results of the exploratory analyses need confirmation, they point to a potentially vital role of affectionate skin-to-skin touch in the development of the minimal self. No such results were found for overall maternal touch, providing further evidence for the unique role of affectionate touch.

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Tables

Figures

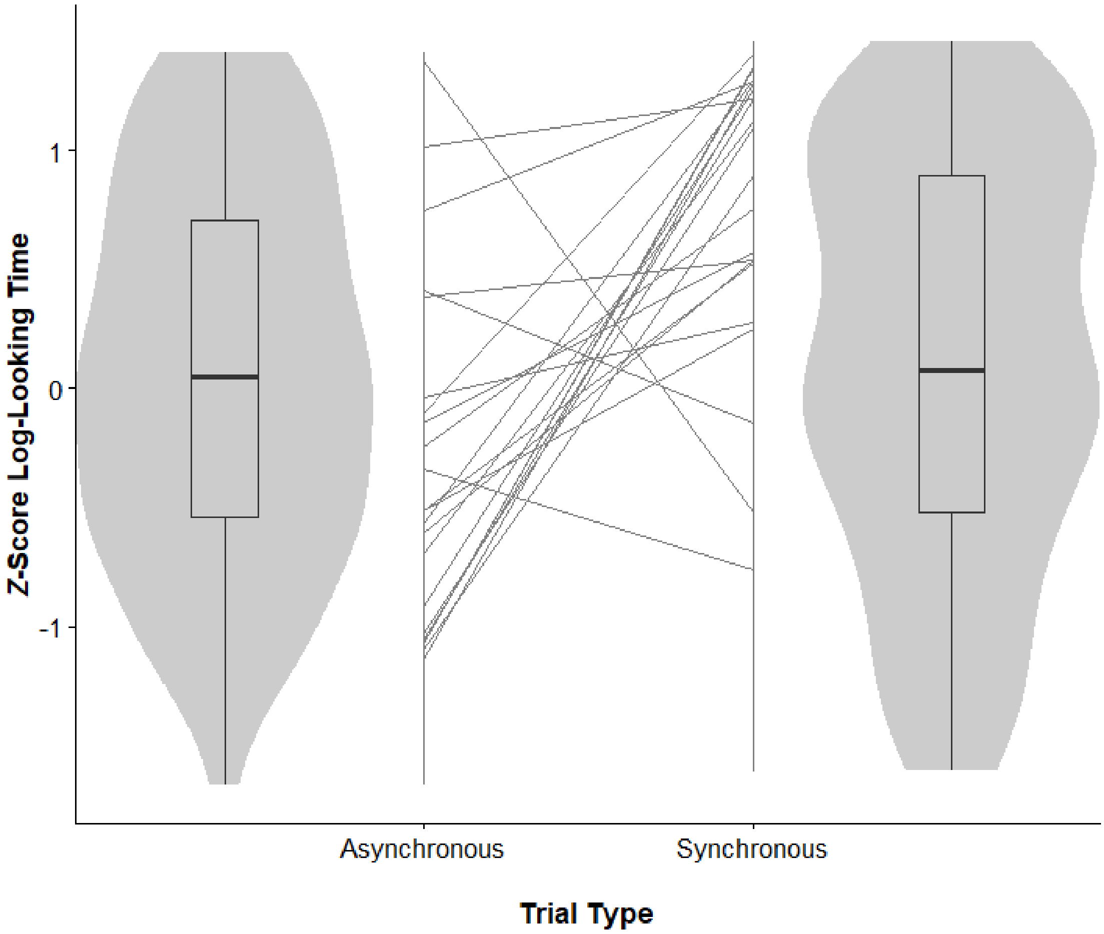
Appendix A

Removing Outliers +/− 2 *SD*

The analysis was repeated excluding outliers below and above 2 *SD* from the mean log- and *z*-transformed looking time. As a result, 8 trials were excluded. The distribution of log- and *z*-transformed looking times after exclusion can be seen in Figure A1.

Figure A 1

Log- and Z-Transformed Looking Times by Trial Type Excluding +/− 2 SD



Note. Violin plots for log- and *z*- transformed looking times, for asynchronous and synchronous trials. Grey lines depict individual infants' differences in mean log- and *z*-transformed looking times between asynchronous and synchronous trials. Grey areas show the probability distributions of log- and *z*-transformed looking times for asynchronous and synchronous trials. Outliers more than 2 SDs below or above the mean have been excluded from the data. *N* = 22

Affectionate Touch

In step 1, the full model yielded an AIC of 459.14, while the reduced model yielded an AIC of 454.67. The full model significantly improved model fit over the reduced model (χ^2 = 10.46, *df* = 3, *p* = .02). In step 2, the AIC of the reduced model was 457.21, the model fit of the full model was significantly better (χ^2 = 10.53, *df* = 4, *p* = .03). In step 3, removing touch as a predictor (3a) resulted in an AIC of 456.52 and removing trial type (3b) resulted in an AIC of 456.26. The full model had a significantly improved fit over the models in 3a and 3b (χ^2 = 11.84, *df* = 5, *p* = .04; χ^2 = 11.59, *df* = 5, *p* = .04). In step 4, the trial-index-only model yielded an AIC of 455.58, and the full model had a significantly better model fit (χ^2 = 12.90, *df* = 6, *p* = .04). Finally, in step 5, the AIC of the baseline model was 534.37. The most appropriate model was a full model, significantly improving model fit over the baseline model (χ^2 = 93.70, *df* = 7, *p* < .001). The model is shown in Table A1. There was a significant main effect for trial index (*b** = −0.06, *p* < .01) and IBEAT trial type (*b** = 0.30, *p* = .05), as well as a significant interaction between trial index and affectionate touch (*b** = −0.04, *p* = .01).

Table A1

Affectionate Touch Model Excluding Outliers +/− 2 SD

Effect	Estimate	95% *CI*	*P*
Fixed effects			
Intercept	0.58	[0.31, 0.85]	<.001***
Affectionate touch	0.21	[−0.13, 0.55]	.23
Trial type (synchronous)	0.30	[0.00, 0.60]	.047*
Trial index	−0.06	[−0.08, 0.04]	<.001***
Affectionate touch × trial type	−0.30	[−0.68, 0.08]	.122
Affectionate touch × trial index	−0.04	[−0.06, −0.01]	.011*
Trial type:trial index	−0.02	[−0.05, 0.00]	.107
Affectionate touch × trial type × trial index	0.03	[−0.00, 0.07]	.078
Random effects			
σ^2		0.81	

τ_{00} participant	0.12
τ_{11} participant × trial type	0.00
ρ_{01} participant	−0.56
σ^2	0.81

Note. Total *N* = 22, Observations = 222. CI = confidence interval
$^{*}p < .05$. $^{***}p < .001$.

Touch

For overall touch, a bobyqa optimiser was used, to help with model convergence. In step 1, the reduced model had an AIC of 460.51, the full model had an AIC of 460.52. There was no significant improvement in model fit ($\chi^2 = 5.98$, $df = 3$, $p = .11$). In step 2, the AIC of the reduced model was 458.51, the model fit was not improved by additional parameters ($\chi^2 = 0.01$, $df = 1$, $p = .95$). In step 3a and 3b, the models yielded an AIC of 456.52 and 457.57, the model fit of the more elaborate model was not significantly better ($\chi^2 = 1.06$, $df = 1$, $p = .30$; $\chi^2 = 0.01$, $df = 1$, $p = .95$). The model removing touch as a predictor (3a) was chosen for further comparison because of the lower AIC. In step 4, the trial-index-only model yielded an AIC of 455.58, there was no improvement in model fit ($\chi^2 = 1.06$, $df = 1$, $p = .30$). In step 5, the AIC of the baseline model was 534.37. The most appropriate model was a trial-index-only model, significantly improving fit over the baseline model ($\chi^2 = 80.80$, $df = 1$, $p < .001$). The model is summarised in Table A2.

Table A2

Trial-Index-Only Model Excluding Outliers +/− 2 SD

Effect	Estimate	95% *CI*	*P*
Fixed effects			
Intercept	9.11	[8.91, 9.32]	<.001***
Trial index	−0.07	[−0.08, −0.05]	<.001***
Random effects			
σ^2	0.84		
τ_{00} participant	0.13		

τ_{11} participant × trial type	0.01
ρ_{01} participant	−0.55

Note. Total $N = 22$, Observations = 222. CI = confidence interval

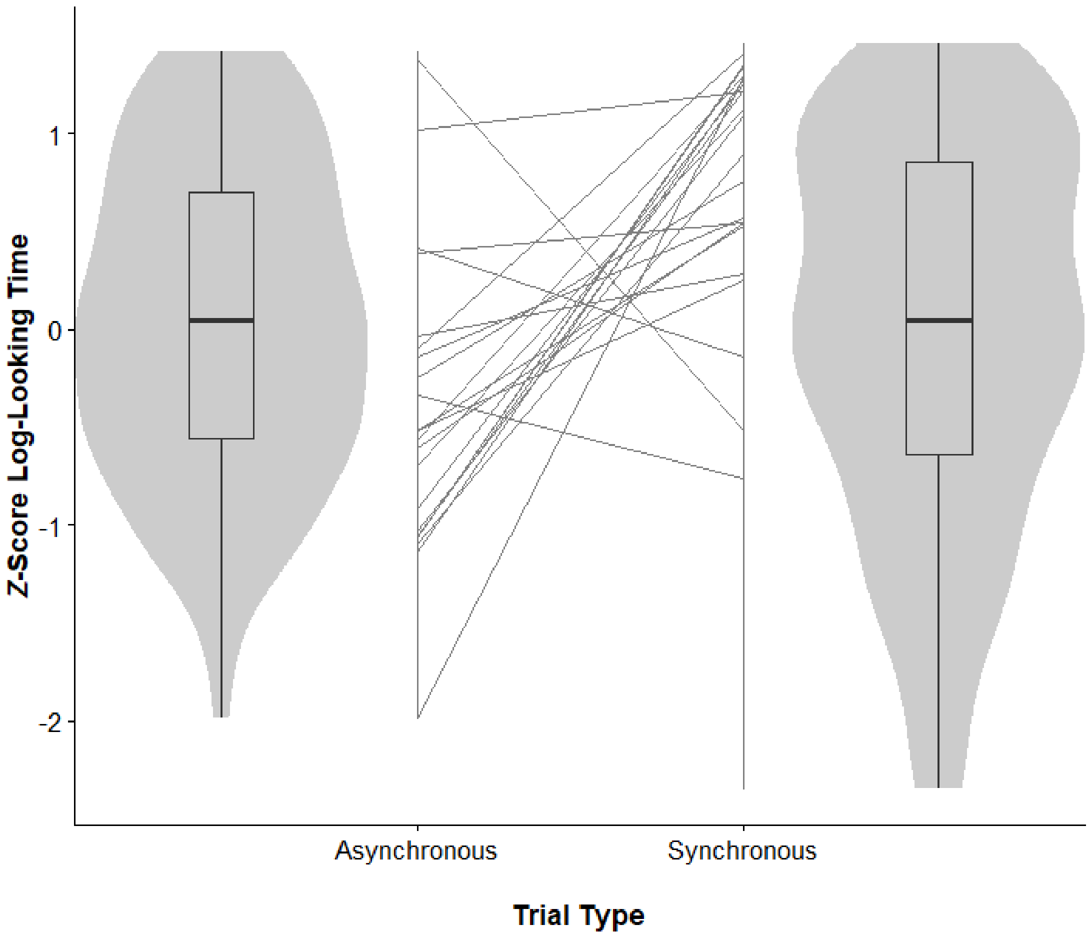
$^{***}p < .001$.

Removing Outliers +/− 3 *SD*

The analysis was repeated, excluding outliers in log- and *z*-transformed looking time below and above 3 *SD*. Consequently, 1 trial was excluded. The distribution of log- and *z*-transformed looking times can be seen in Figure A2.

Figure A 2

Log- and Z-Transformed Looking Times by Trial Type Excluding +/− 3 SD



Note. Violin plots for log- and *z*- transformed looking times, for asynchronous and synchronous trials. Grey lines depict individual infants' differences in mean log- and *z*-transformed looking times between asynchronous and synchronous trials. Grey areas show the probability distributions of log- and *z*-transformed looking times for asynchronous and synchronous trials. Outliers +/− 3 *SD* above or below the mean were excluded.

Affectionate touch

The full model yielded an AIC of 491, the reduced model yielded an AIC of 496.23 and the improvement in model fit was significant ($\chi^2 = 11.23$, $df = 3$, $p = .01$). In step 2, the full model again improved model fit over a reduced model (AIC = 494.49; $\chi^2 = 11.48$, $df = 3$, $p = .02$). In step 3a, the AIC was 493.42 and the full model had a significantly better model fit ($\chi^2 = 12.416$, $df = 5$, $p = .03$). In step 3b, the AIC was 492.6 and the full model again had a significantly better model fit ($\chi^2 = 11.61$, $df = 5$, $p = .04$). The AIC of the trial-index-only model was 491.56. The model fit of the full model was significantly better ($\chi^2 = 12.55$, $df = 6$, $p = .49$). For affectionate touch, the most appropriate model was a saturated model, significantly improving fit over the baseline model (AIC = 589.03; $\chi^2 = 112.02$, $df = 7$, $p < .001$). The model is summarised in Table A4.

Table A3

Affectionate Touch Model Excluding Outliers +/− 3 SDs

Effect	Estimate	*95% CI*	*p*
Fixed effects			
Intercept	0.61	[0.34, 0.88]	<.001***
Affectionate touch	0.19	[−0.16, 0.54]	.285
Trial type (synchronous)	0.33	[0.02, 0.64]	.04*
Trial index	−0.06	[−0.08, −0.04]	<.001***
Affectionate touch × trial type	−0.31	[−0.70, 0.09]	.125
Affectionate touch × trial index	−0.03	[−0.06, −0.00]	.024*
Trial type × trial index	−0.03	[−0.05, −0.00]	.039*
Affectionate touch × trial type × trial index	0.03	[−0.00, 0.07]	.065

Random Effects

σ2	0.78
$\tau 00_{\text{participant}}$	0.12

Note. Total *N* = 22, Observations = 229. CI = confidence interval
$^{*}p < .05$. $^{***}p < .01$. $^{***}p < .001$.

Touch

In step 1, the model fit of the full model (AIC = 496.39) was not significantly better than the model fit of the reduced model (AIC = 497.42; $\chi^2 = 7.03$, $df = 3$, $p = .07$). In step 2, the model from step 1 was again not better fitting than the reduced model (AIC = 495.42; $\chi^2 = 0.03$, $df = 1$, $p = .95$). Step 3 yielded an AIC of 493.42 when removing touch as a predictor (3a), and an AIC of 493.56 when removing trial type as a predictor (3b). There was no significant improvement of model fit for either parameter ($\chi^2 = 0.01$, $df = 1$, $p = .97$; $\chi^2 = 0.13$, $df = 1$, $p = .71$) and the model from step 3a was chosen for further comparison because of the lower AIC. The trial-index-only model yielded an AIC of 491.56 and there was no significant improvement in model fit ($\chi^2 = 0.13$, $df = 1$, $p = .71$). The most appropriate model for overall touch was a trial-index-only model, improving fit over the baseline model (AIC = 589.03; $\chi^2 = 99.47$, $df = 1$, $p < .001$). The model is summarised in Table A4. There was a significant main effect for trial index ($b^* = -0.08$, $p < .01$).

Trial-Index-Only Model Excluding Outliers +/− 3 SD

Table A4

Effect	Estimate	95% *CI*	*P*
Fixed effects			
Intercept	9.11	[8.94, 9.38]	$<.01^{***}$
Trial index	−0.08	[−0.09, −0.06]	$<.01^{***}$
Random effects			
σ^2		0.81	
$\tau_{00\ \text{participant}}$		0.12	
$\tau_{11\ \text{participant} \times \text{trial type}}$		0.00	

ρ_{01} participant	0.89

Note. Total N = 22, Observations = 229. CI = confidence interval.

$^{***}p$ <.001.

Appendix B

Explorative Analysis

In an explorative analysis, only affectionate touch and overall touch occurring during the without-toys condition was considered for analysis. Next, a separate analysis was done, only considering affectionate touch and overall touch during the with-toys condition.

Without-Toys Condition

Affectionate Touch. In step 1, the full model (AIC = 501.30) was chosen over the reduced model (AIC = 506.28), as the model fit was significantly better ($\chi 2$ = 10.98, *df* = 3, *p* = .01). In step 2, the reduced model had an AIC of 504.28 and the full model was the more appropriate model ($\chi 2$ = 10.98, *df* = 4, *p* = .03). In step 3a, removing affectionate touch yielded an AIC of 502.58 and the full model had a significantly better model fit ($\chi 2$ = 11.28, *df* = 5, *p* = .046). In step 3b, removing trial type resulted in an AIC of 502.68 and the full model was the more appropriate model ($\chi 2$ = 11.38, *df* = 5, *p* = .04). In step 5, the trial-index-only model was chosen for further comparison (AIC = 500.98; $\chi 2$ = 11.67, *df* = 6, *p* = 0.069). The baseline model yielded an AIC of 600.50, the trial-index-only model was the most appropriate model ($\chi 2$ = 101.52, *df* = 1, *p* < .001). The model is shown in Table 2.

Touch. In step 1, the full model (AIC = 508.17) did not significantly improve model fit over a reduced model (AIC = 506.24; $\chi 2$ = 4.07, *df* = 3, *p* = .25). In step 2, the reduced model (AIC = 504.28) was chosen for further comparison ($\chi 2$ = 0.04, *df* = 1, *p* = .84). In step 3a, the reduced model was the more appropriate model (AIC = 502.58; $\chi 2$ = 0.29, *df* = 1, *p* = .59). In step 3b, the additional parameter did not improve model fit (AIC = 502.68; $\chi 2$ = 0.4, *df* = 1, *p* = .53). Model 3a was chosen for further comparison due to the lower AIC. The trial-index-only model was chosen for further comparison in step 4 (AIC = 500.98; $\chi 2$ = 0.39, *df* = 1, *p* = .53). Finally, in step 5, the baseline model yielded an AIC of 600.5. The trial-index-only model was the most appropriate model ($\chi 2$ = 101.52, *df* = 1, *p* < .001). The model is summarised in Table 2.

With-Toys Condition

Affectionate Touch. The full model yielded an AIC of 503.43, while the reduced model yielded an AIC of 505.33. The full model significantly improved model fit in step 1 ($\chi 2$ = 7.90, *df* = 3, *p* = .048). In step 2, the reduced model (AIC =

503.85) was chosen for further comparison 1 ($\chi2$ = 8.42, *df* = 4, *p* = .08). In step 3, removing touch resulted in an AIC of 502.58 and removing trial type resulted in an AIC of 502.24. The model from step 2 did not significantly improve model fit over either of these models ($\chi2$ = 8.81, *df* = 5, *p* = .12; $\chi2$ = 9.15, *df* = 5, *p* = .10) and model 3b was chosen for further comparison because of the lower AIC. In step 4, the trial-index-only model was the more appropriate model (AIC = 500.98; $\chi2$ = 0.74, *df* = 1, *p* = .38). The baseline model yielded an AIC of 600.50 and the trial-index-only model had significantly better model fit AIC = 500.98; $\chi2$ = 101.52, *df* = 1, *p* < .001). The model is summarised in Table 2.

Touch. In step 1, the full model (AIC = 505.30) did not significantly improve model fit over the reduced model (AIC = 506.38; $\chi2$ = 7.08, *df* = 3, *p* = .07). In step 2, the reduced model yielded an AIC of 504.41 and was chosen for further comparison ($\chi2$ = 0.02, *df* = 1, *p* = .88). In step 3a, the reduced model was the more appropriate model (AIC = 502.58; $\chi2$ = 0.08, *df* = 1, *p* = .67). In step 3b the reduced model yielded an AIC of 502.78 and was the more appropriate model ($\chi2$ = 0.38, *df* = 1, *p* = .54). Model 3a was chosen for further comparison. In step 4, the trial-index-only model yielded an AIC of 500.98 and model 3a did not have a significantly improved model fit ($\chi2$ = 0.40, *df* = 1, *p* = .53). Finally, the AIC of the baseline model was 600.50 and the trial-index-only model was the most appropriate model ($\chi2$ = 101.52, *df* = 1, *p* < .001). The model is shown in Table 2.

Explorative Analysis removing outliers +/− 2 SD

The explorative analysis was repeated, excluding outliers 2 *SD* below or above the mean log- and *z*-transformed looking time. Separate LMMs were constructed for affectionate touch and touch in the without-toys and the with-toys condition.

Without-toys Condition

Affectionate Touch. In step 1, the full model (AIC = 452.80) had a significantly improved model fit over the reduced model (AIC = 459.93; $\chi2$ = 13.12, *df* = 3, *p* = .004). In step 2, the reduced model yielded an AIC of 457.94, there was a significantly improved model fit for the full model ($\chi2$ = 13.14, *df* = 4, *p* = .01). In step 3, the full model had an improved model fit over the models without affectionate touch (3a; AIC = 456.52) and trial type (3b; AIC = 457) as a predictor ($\chi2$ = 13.711, *df* = 5, *p* = .02; $\chi2$ = 14.20, *df* = 5, *p* = .01). The trial-index-only model in step 4 yielded an AIC of 455.58, there was a significantly improved fit for the full model ($\chi2$ = 14.77, *df* = 6, *p* = .02).

The most appropriate model was a full model, improving fit over the baseline model (AIC = 534.37; $\chi 2 = 95.57$, $df = 7$, $p < .001$). The model is summarised in Table B1. Of note, there is a significant interaction between iBEAT trial type and affectionate touch ($b* = -0.3$, $p = .046$). The model is shown in Table B1.

Table B1

Affectionate Touch Model Without toys (ATWT) Excluding Outliers +/−2SD

Effect	Estimate	*95% CI*	*p*
Fixed effects			
Intercept	0.56	[0.29, 0.84]	<.001***
ATWT	0.26	[−0.01, 0.53]	.061
Trial type (synchronous)	0.31	[0.02, 0.61]	.039*
Trial index	−0.06	[−0.07, −0.04]	<.001***
ATWT × trial type	−0.30	[−0.60, −0.00]	.046*
ATWT × trial index	−0.03	[−0.06, −0.01]	.003**
Trial type × trial index	−0.02	[−0.05, 0.00]	.086
ATWT × trial type × trial index	0.03	[0.00, 0.06]	.04*
Random effects			
σ^2		0.80	
$\tau_{00 \text{ participant}}$		0.14	
$\tau_{11 \text{ participant × trial type}}$		0.01	
$\rho_{01 \text{ participant}}$		−0.56	

Note. Total $N = 22$, Observations = 229. CI = confidence interval

$^{*}p <.05$. $^{**}p <.01$. $^{***}p <.001$.

Touch. In step 1, the full model yielded an AIC of 462.26 and the reduced model yielded an AIC of 460.35. There was no significant improvement in model fit ($\chi 2 = 4.09$, $df = 3$, $p = .25$). In step 2, the AIC of the reduced model was 458.39 and there was no significant improvement in model fit for the more elaborate model ($\chi 2 = 0.03$, $df = 1$, $p = .85$). In step 3a and 3b, the AIC was 456.52 and 457.46 respectively, model fit was not significantly improved ($\chi2 = 0.13$, *df* = 1, *p* = .72; $\chi2 = 1.07$, *df* = 1, *p* = .30). Model 3a was chosen for further comparison because of the lower AIC. The trial-index-only model yielded an AIC of 455.58 in step 4. There was no improvement in model fit ($\chi2 = 1.06$, df = 1, p = .30). Finally, in step 5, the AIC of the baseline model was 534.37. The trial-index-only model was the most appropriate model, with a significantly improved model fit ($\chi^2 = 80.80$, *df* = 1, $p < .001$). The model is shown in Table A2.

With-Toys Condition

Affectionate Touch. In step 1, the full model had an AIC of 457.65, the AIC of the reduced model was 458.63, but there was no significant improvement in model fit for the full model ($\chi^2 = 6.98$, *df* = 3, *p* = .07). The AIC of the reduced model in step 2 was 457.74 and there was no improvement in model fit ($\chi^2 = 1.11$, *df* = 1, *p* = .29). Step 3a and 3b yielded an AIC of 456.52 and 456.77 respectively. There was no improvement in model fit ($\chi2 = 0.78$, df = 1, *p* = .38; $\chi2 = 1.03$, df = 1, *p* = .31). For further comparison, model 3a was chosen. The trial-index-only model yielded an AIC of 455.58 in step 4. There was no improvement in model fit ($\chi2 = 1.06$, df = 1, *p* = .30). Finally, in step 5, the most appropriate model was a trial-index-only model, model fit was significantly improved compared to the baseline model (AIC = 534.37; $\chi^2 = 80.80$, *df* = 1, $p < .001$). The model is shown in Table A2.

Touch. In step 1, the full model (AIC = 458.01) had a significantly improved model fit over the reduced model (AIC = 460.26; $\chi2 = 8.25$, df = 3, *p* = .04). In step 2, the reduced model yielded an AIC of 458.30, but there was no significant improvement in model fit ($\chi2 = 8.30$, df = 4, *p* = .08). In Step 3a and 3b the AIC was 456.52, respectively 457.33. There was no improvement in model fit 457.33) and model 3a was chosen for further comparison. In step 4, the trial-index-only model yielded an AIC of 455.58. The trial-index-only model was the more appropriate model ($\chi2 = 1.06$, df = 1, *p* = .30). In step 5, the AIC of the baseline model was 534.37. Consequently, the most appropriate model was the trial-index-only model, with a significantly better model fit than the baseline model ($\chi^2 = 80.80$, *df* = 1, $p < .001$). The model is summarised in Table A2.

Explorative Analysis Removing Outliers +/− 3 SD

Outliers 3 SD below or above the mean log- and *z*-transformed looking time were excluded, and explorative analysis was repeated. Separate LLMs were created for affectionate touch and touch in the without-toys and the with-toys condition.

Without-toys Condition

Affectionate Touch. When excluding outliers 3SD below or above the mean, the full model (AIC = 489.12) had a significantly improved fit over a reduced model (AIC = 497.07; $\chi^2 = 13.95$, $df = 3$, $p = .003$). In step 2, the reduced model yielded an AIC of 495.09 and the full model had a significantly better model fit ($\chi^2 = 13.97$, $df = 4$, $p = .007$). In step 3, removing affectionate touch without toys as a predictor yielded an AIC of 493.42 and removing trial type as a predictor yielded an AIC of 493.22. The model fit of the full model was significantly improved over either of the reduced models ($\chi^2 = 14.30$, $df = 5$, $p = .14$; $\chi^2 = 14.10$, $df = 5$, $p = .14$). In step 5, the model fit of the full model was significantly better than the model fit of a trial-index-only model (AIC = 491.56; $\chi^2 = 14.44$, $df = 6$, $p = .03$). When excluding outliers 3 *SD* below or above the mean, for affectionate touch without toys, a full model was the most appropriate model, improving fit over the baseline model AIC = 589.03; $\chi2 = 113.91$, $df = 7$, $p < .001$). The model is shown in Table B2.

Affectionate Touch Without toys (ATWT) Model Excluding Outliers +/− 3 SDs

Table B2

Effect	Estimate	95% *CI*	*p*
Fixed effects			
Intercept	0.60	[0.31, 0.87]	<.001***
ATWT	0.24	[−0.03, 0.52]	.082
Trial type (synchronous)	0.34	[0.03, 0.64]	.03*
Trial index	−0.06	[−0.08, −0.04]	<.001***
ATWT × trial type	−0.32	[−0.63, −0.01]	.042*
ATWT × trial index	−0.03	[−0.05, −0.01]	.006**
Trial type × trial index	−0.03	[−0.05, −0.00]	.025*
ATWT × trial type × trial index	0.03	[0.00, 0.06]	.026*

Random effects	
σ^2	0.77
$\tau_{00\ participant}$	0.13

Note. Total *N* = 22, Observations = 229. CI = confidence interval

* *p* <.05. ****p* <.01. ****p* <.001.

Touch. The full model yielded an AIC of 496.98, the reduced model yielded an AIC of 497.1. There was no improvement in model fit (χ2 = 6.21, *df* = 3, *p* = .10). In step 2, the reduced model (AIC = 495.19) was the more appropriate model (χ2 = 0.001, *df* = 1, *p* = .96). In step 3, removing touch (AIC = 493.34) or trial type (AIC = 493.42) yielded more appropriate models (χ^2 = 0.22, *df* = 1, *p* = .63; χ^2 = 0.12, *df* = 1, *p* = .72) and the model removing touch as a predictor was chosen for further comparison, because of the lower AIC. In step 4, the more saturated model did not improve model fit over the trial-index-only model (AIC = 491.56; χ2 = 0.14, *df* = 1, *p* = .71). The trial-index-only model was the most appropriate model, yielding significantly better model fit than the baseline model (AIC = 589.03; χ^2 = 99.47, *df* = 1, *p* < .001). The model is summarised in Table A4.

With-Toys Condition

Affectionate Touch. In step 1, the full model (AIC = 492.51) had a significantly improved fit over a reduced model (AIC = 495.69; χ2 = 9.18, *df* = 3, *p* = .03). In step 2, the full model again was the more appropriate model, compared to the reduced model (AIC = 494.53, χ2 = 10.02, *df* = 4, *p* = .04). In step 3a, the full model did not significantly improve fit over the reduced model (AIC = 493.42; χ2 = 10.91, *df* = 5, *p* = .053). Similarly, in step 3b, the reduced model was the more appropriate model (AIC = 492.66; χ2 = 10.15, *df* = 5, *p* = .07). For further comparison, the model from step 3b was chosen. In step 4, the 3b model did not improve model fit over the trial-index-only model (AIC = 491.56; χ2 = 0.89, *df* = 1, *p* = .34). The trial-index-only model was the most appropriate model, the model fit was significantly improved over a baseline model (AIC = 589.03; χ^2 = 99.47, *df* = 1, *p* < .001). The model is shown in Table A4.

Touch. When considering only the with-toys condition and percentage of overall touch, in step 1, the full model (AIC =496.98) did not improve model fit over a reduced model (AIC = 497.19; χ2 = 6.21, *df* = 3, *p* = .11). In step 2, the reduced model

(AIC = 495.19) was the more appropriate model ($\chi 2 = 0.001$, *df* = 1, *p* = .96). In step 3a, the reduced model yielded an AIC of 493.42 and the more saturated model did not significantly improve model fit ($\chi 2 = 0.23$, *df* = 1, *p* = .63). In step 3b, removing trial type as a predictor yielded an AIC of 493.34 and the more saturated model did not improve model fit ($\chi 2 = 0.14$, *df* = 1, *p* = .71). The model from step 3a was chosen for further comparison. In step 4, the trial-index-only model was the more appropriate model (AIC = 491.56; $\chi 2 = 0.14$, *df* = 1, *p* = .71). In step 5, the trial-index-only model was chosen, significantly improving model fit over a baseline model (AIC = 589.03; $\chi^2 = 99.47$, *df* = 1, $p < .001$). The model is summarised in Table A4.

Appendix C

Abstract

The minimal self, the feeling of being an embodied subject, might be shaped by mother-child interactions. Maternal touch, particularly affectionate touch, is related to many intrapersonal variables in mother and child, but patterns of maternal touch vary between individuals. The aim of this thesis was to investigate the relationship between maternal touch behaviours in a naturalistic setting and interoceptive accuracy, one component of the minimal self, in 9-month-old infants. Maternal touch was assessed by video coding a free mother-infant play interaction. Interoceptive accuracy was measured using the iBEAT task, where infants watched stimuli moving synchronously or asynchronously with their heartbeat, while looking times were recorded. Linear mixed model analysis revealed that neither overall maternal touch nor affectionate maternal touch was related to interoceptive accuracy in infants. However, exploratory results indicate a potential link between affectionate touch and interoceptive accuracy in the context of a playful interaction without toys. The results add to the knowledge about interoceptive accuracy and maternal touch.

Zusammenfassung

Das minimale Selbst, das Gefühl, den eigenen Körper und die eigenen Handlungen als zu einem selbst gehörend wahrzunehmen, könnte durch Mutter-Kind-Interaktionen geformt werden. Mütterliche Berührungen, vor allem liebevolle Berührungen, stehen in Verbindung mit einer Vielzahl von intrapersonalen Faktoren von Mutter und Kind, aber die Muster dieser Berührungen unterscheiden sich zwischen Individuen. Das Ziel dieser Arbeit war es, den Zusammenhang zwischen mütterlichem Berührungsverhalten und interozeptiver Akkuranz, als einer Komponente des minimalen Selbst, bei 9 Monate alten Säuglingen zu untersuchen. Mütterliche Berührungen wurden während einer freien, spielerischen Mutter-Kind Interaktion beobachtet. Interozeptive Akkuranz wurde mittels der iBEAT Aufgabe gemessen, bei welcher Säuglinge Stimuli beobachteten, die sich entweder mit oder gegen den Rhythmus ihres Herzschlages bewegten, während ihr Blickverhalten gemessen wurde. Die Analysen mittels linearer gemischter Modelle ergaben keinen Zusammenhang zwischen mütterlichen Berührungen und interozeptiver Akkuranz. In explorativen Analysen konnte ein möglicher Zusammenhang zwischen liebevollen mütterlichen

Berührungen und interozeptiver Akkuranz im Kontext einer spielerischen Interaktion ohne Spielsachen gefunden werden. Die Arbeit trägt zum Wissen über interozeptive Akkuranz und mütterlichen Berührungen bei.