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In touch with the self: The role of contingent affectionate maternal touch for infant interoception

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Table of contents

Abstract

Interoception, the ability to perceive and interpret internal bodily signals, has gained increasing attention due to its involvement in cognitive processes and implications for mental health. Theoretical accounts highlight the significance of early tactile interactions in the development of interoceptive sensitivity. Especially maternal affectionate touch, as it is proposed to help infants to connect external sensory inputs with their internal physiological states, thereby building more accurate internal models of their body. An important property of touch might be its contingency, meaning how well the touch is attuned to the infant's internal state. However, the relationship between contingent affectionate maternal touch and infant interoceptive sensitivity is yet to be examined. The present study aimed to investigate the associations between contingent and non-contingent affectionate touch and infant cardiac interoceptive sensitivity at 9 months of age ($N = 49$). Findings revealed no significant associations for either form of affectionate touch with cardiac interoceptive sensitivity. Interestingly however, both associations revealed a positive trend, contrary to the initially hypothesized negative association for non-contingent touch. These findings suggest that the investigated variables (affectionate touch, cardiac interoceptive sensitivity) might represent distinct interoceptive submodalities that are not directly related. This contributes to the growing understanding of interoception as a collection of separate processes. Future research is necessary to better understand the role of affectionate touch in interoception, thus promoting the healthy development of infants.

Keywords: interoception, maternal touch, affectionate touch, contingency, mother-infant-interaction, development

Introduction

Our bodies are continuously engaged in a complex internal dialogue, sending and receiving signals that are fundamental to our survival and well-being. The ability to sense and interpret internal bodily states, encompassing sensations such as heart rate, respiration, and hunger, is referred to as interoception (Craig, 2002). Much of the research on interoception to date focuses on adults. However, little is known about how and when this ability develops, what role it plays in infancy, and especially, what factors contribute to its development. Here, we investigate for the first time the relationship of early maternal tactile interactions and infant interoceptive abilities.

Understanding interoception: definition and function

In the last two decades interoception has gained growing attention in research, emerging as a crucial concept for understanding how bodily signals contribute to various processes, spanning from emotional experiences to self-awareness and well-being, influencing diverse fields from neuroscience to clinical psychology (Khalsa et al., 2018). As that interest has increased, so too has the knowledge and understanding of the meaning of interoception. Early approaches to interoception define it as the perception of visceral signals from within the body (Sherrington, 1948 as cited by Craig, 2002). Building up, more integrative definitions have been proposed, viewing interoception as the ability to perceive and interpret signals that inform the brain about the physiological condition of the entire body (Craig, 2002), including sensations that originate from within the body (e.g. heartbeat, respiration, hunger), as well as outside it (e.g. temperature, pain, affectionate touch) (Craig, 2002; Fotopoulou & Tsakiris, 2017). Interoception plays a vital role in regulating homeostasis by creating and updating predictions about bodily states, thus providing continuous feedback on the body's homeostatic state (Critchley & Harrison, 2013; Fotopoulou & Tsakiris, 2017). It is, therefore, crucial for detecting homeostatic changes in the body, allowing for appropriate responses that help restore homeostatic balance.

In order to fully grasp the function and meaning of interoception, it is essential to consider its neuroanatomical basis. Interoception is formed by a specialized afferent system which relies on small-diameter fibers, primarily C -and Aδ-fibers that terminate in a specific layer of the spinal cord, the lamina I (Craig, 2002). Among these C-fibers, a specific subgroup of C-tactile fibers is particularly significant, playing a crucial role in transmitting signals related to gentle, affective touch (Craig, 2010). From lamina I, information travels along a distinct ascending pathway, the spinothalamocortical pathway of the lamina I to the posterior insular cortex (Craig, 2002, 2009). This pathway reflects the physiological state of the body's tissues, forming a primary representation of the current state of the body. This information is then re-represented in the anterior insular cortex, which is the probable site for awareness of feelings from the body (Craig 2002, 2009), as several kinds of interoceptive signals converge and integrate there (Crucianelli et al., 2022). The described process is largely understood within a predictive processing framework (Feldman et al., 2024). The brain generates predictions about internal states, and discrepancies, so called prediction errors, between these predictions and incoming sensory signals update the brain's internal model of the body, refining its ability to anticipate and regulate physiological needs (Feldman et al., 2024; Fotopoulou & Tsakiris, 2017). Within this predictive framework, affectionate touch from a caregiver, by ideally providing consistent and predictable responses to an infant's internal states, is believed to play a vital role in refining these internal models, thereby fostering the development of accurate interoceptive processing (Filippetti, 2021).

Correlates of interoception

Interestingly, this dynamic processing of interoceptive signals is suggested to not only support homeostatic regulation but also give rise to affective states, as explained in a proposed model by Feldman et al. (2024). According to that model physical events within the body, such as the heartbeat, generate physical energies that are first transduced, meaning translated, into electrical impulses. These signals are then transmitted to the brain, while continuously being compressed, and integrated with data from other sensory streams to produce mental experiences. The model speculates that valence and arousal, the two core dimensions of subjective affective experiences, arise from these complex information flows and predictive mechanisms within the interoceptive system. For example, how these interoceptive signals are translated, transmitted, compressed, and integrated, interacting with the brain's predictions about bodily states, explains why the experience of a racing heart can be perceived as a state of heightened arousal, or as something unpleasant (Feldman et al., 2024).

Evidently, beyond maintaining physiological stability, interoception is also associated with various higher-order functions such as subjective feelings, but also emotion regulation, learning and decision making, and self-awareness (Craig, 2009; Murphy et al., 2017; Khalsa et al., 2018). The ability to accurately perceive interoceptive signals is related to abilities in the emotional domain, encompassing emotion regulation and stability (Murphy et al., 2017).

Consequently, individuals who are more adept at perceiving their internal bodily signals may experience emotions with greater clarity and be better equipped to manage them. Further substantiation for this relationship comes from research on Alexithymia. This refers to difficulties in recognizing and describing felt emotions, which Shah et al. (2016) found to be associated with impaired interoception. The impact of such disturbances in interoception extends to other psychopathologies as well. For instance, Paulus and Stein (2006) suggest that in anxiety disorders, individuals show a heightened awareness of discrepancies between their actual and anticipated bodily states. Ultimately, this prediction of an impending unpleasant internal state leads to typical manifestations and cognitions associated with anxiety (Paulus & Stein, 2006).

Interoceptive modalities and measures

Beyond its fundamental definition, interoception is further characterized by distinct interoceptive features. Interoceptive sensitivity, or accuracy, refers to the objective performance on a task measuring how precisely an individual can detect and discriminate their internal bodily signals (Donaghy et al., 2025; Garfinkel et al., 2015; Murphy et al., 2017). Another dimension is interoceptive sensibility, which pertains to an individual's self-reported beliefs or perceptions regarding their interoceptive abilities (Garfinkel et al., 2015; Murphy et al., 2017), typically assessed using questionnaires or confidence ratings on interoceptive tasks (Garfinkel et al., 2015). Lastly, interoceptive awareness serves as the metacognitive agreement between accuracy and sensibility, thus assessing how well an individual's subjective beliefs align with their objective performance (Garfinkel et al., 2015; Murphy et al., 2017).

The definition of interoception as the ability to perceive the body's internal state may give the impression that it is a single, unitary construct. However, according to some prominent views, interoception comprises not only visceral sensations arising from within the body, but also certain skin-mediated signals which originate outside the body, such as temperature, pain, and importantly, affectionate touch (Craig, 2002; Crucianelli et al., 2022). Nevertheless, the precise classification of these skin-mediated signals remains a subject of ongoing debate. While some views explicitly consider affectionate touch an interoceptive submodality, emphasizing its neuroanatomical pathways to interoceptive brain regions (Crucianelli & Ehrsson, 2023; Crucianelli et al., 2022), others advise for a more nuanced distinction. For instance, Desmedt et al. (2025) propose a definition of interoception that centers on bodily signals "from within itself and below the skin, across conscious and nonconscious levels" (Desmedt et al., 2025, p. 87). The authors suggest that external stimuli like affectionate touch contribute sequentially to interoception. They posit that the initial processing phase is exteroceptive, involving the direct stimulation of the skin's surface. This external sensation then generates internal physiological outcomes or emotional states, the processing of which constitutes interoception. Still, Desmedt et al. (2025) recognize the homeostatic relevance of affectionate touch, as the affective quality of the induced internal states corresponds to the physiological requirements, therefore driving behaviors that uphold homeostatic balance. Thus, for Desmedt et al. (2025), affectionate touch, while homeostatically relevant, is not directly an interoceptive signal, but rather elicits interoceptive experiences as a consequence of external stimulation.

Given that interoception nonetheless spans multiple physiological systems, it seems unlikely that interoception is a unimodal construct. Instead, interoception could arguably rather be viewed as a set of relatively distinct and independent processes (Crucianelli et al., 2022; Khalsa et al., 2018). This perspective is further supported by empirical findings, demonstrating low agreement across various interoceptive modalities (Desmedt et al., 2025). For instance, Crucianelli et al. (2022) found no significant associations between performance across tasks assessing thermosensation, nociception, cardiac interoceptive accuracy, and affectionate touch, which they consider different interoceptive submodalities. Furthermore, a study investigating interoceptive sensitivity across cardiac and respiratory modalities found no significant relationship between the two (Banellis et al., 2025). Moreover, this unrelatedness of cardiac and respiratory interoceptive sensitivity was already observed in young infants (Tünte et al., 2024b), thereby highlighting the inherent variety within interoception itself.

A commonly studied interoceptive modality is cardiac interoceptive accuracy (e.g. Murphy et al., 2017; Crucianelli et al., 2022). It is often measured using the heartbeat counting task (HCT), an objective measure for interoceptive sensitivity, where participants silently count their heartbeats for a set period, without directly feeling it with their hands (Schandry, 1981). Other methods include heartbeat discrimination tasks that involve judging whether external stimuli occur synchronously or delayed in relation to the own heartbeat (Murphy et al., 2017). However, researchers have expressed concerns and limitations regarding the heartbeat counting task and participants' performance therein, primarily because its accuracy can be influenced by several factors such as participants' prior understanding of heart rates, or practice in the task (Crucianelli et al., 2022). Recognizing these inherent limitations in classical measures, many new tasks have been developed to address those shortcomings and provide more valid and reliable assessments of interoceptive accuracy (Desmedt et al., 2023).

Crucially, previous research and methods used to assess interoceptive sensitivity was largely limited to adults and older children, due to methodological constraints. To address this lack of a direct measure for interoceptive sensitivity in very young infants, Maister et al. (2017) developed the Infant Heartbeat Task (iBEAT). It assesses infants' ability to distinguish between visual stimuli presented synchronously or asynchronously to their own heartbeats, based on looking preferences. Initial findings by Maister et al. (2017) with 5-month-old infants showed a clear visual preference for the asynchronous stimulus, interpreted as implicit sensing of interoceptive signals. However, later findings by Tünte et al. (2024b) from more recent and extensive studies using the iBEAT paradigm with 3-, 9-, and 18-month-old infants revealed a different pattern. Here, 9-month-olds showed a significant preference for synchronous stimuli, a finding replicated in 3-month-olds. An additionally conducted mega-analysis across all age groups further supported this synchronous preference (Tünte et al., 2024b). Although these results may initially appear contradictory, they can nonetheless be reconciled. Each preference, either for synchronous or for asynchronous stimuli, could be explained by a preference for either familiar or novel stimuli, respectively. In this regard, both study results support the notion that infants, regardless of their specific direction of preference, are sensitive to their cardiac signals (Tünte et al., 2024b).

To further explore interoceptive sensitivity in infants, beyond the cardiac domain, Tünte et al. (2024b) introduced a novel paradigm, the iBREATH task. This task assesses infants' sensitivity to their own respiratory signals. Similarly to the iBEAT, infants are presented with visual stimuli, animated to expand and shrink in size, either synchronously or asynchronously with the rhythm of their own breathing. Accompanying the visual presentation, a sound's volume adjusts proportionally to the size changes of the image, providing an additional sensory cue (Tünte et al., 2024b). Interestingly, the authors found that 9-month-old infants demonstrated a clear preference for synchronous stimuli, indicating significant sensitivity to their respiratory signals at this age. The other two age groups, the 3-and-18-month-old infants, however, did not show a significant preference for either stimulus (Tünte et al., 2024b). Essentially, while cardiac interoceptive sensitivity appears more consistently present across early infancy, respiratory interoceptive sensitivity, as measured by iBREATH, arguably shows a more nuanced developmental trajectory, with clear evidence at 9 months.

Developing interoception

Recent theories suggest that the capacity to process interoceptive signals is not solely an innate characteristic. Instead, it is dynamically shaped by social interactions, particularly through embodied experiences between infants and their caregivers, usually mothers (Fotopoulou & Tsakiris, 2017). In embodied interactions, affectionate touch, characterized by slow, gentle, caress-like touch (Wigley et al., 2024), plays a prominent role as it has been linked to an array of positive developmental outcomes such as stress regulation and secure attachment (Carozza & Leong, 2021). One of the underlying mechanisms is the activation of afferent C-tactile fibers (CT-fibers; Craig, 2010), a specific group of mechanoreceptors that fire only in response to slow, gentle stroking, with optimal stroking velocities between 1 – 10cm/s (Löken et al., 2009). The activation of CT-fibers conveys a feeling of emotional safety, ultimately supporting homeostatic balance (Craig, 2010). Moreover, the activation of C-tactile fibers through stroking touch has been found to decrease infants' heart rate, when delivered at the optimal velocity and by the caregiver, as opposed to a stranger (Aguirre et al., 2019). Further neuroanatomical support for the connection between affectionate touch and interoception lies in their neural pathway overlap. Both affectionate touch and interoceptive input travel along small-diameter afferents and join in the insular cortex (Zoltowski et al., 2022). This suggests a link between affectionate touch especially, and the development of interoception. Indeed, as noted by Fotopoulou and Tsakiris (2017), affectionate touch integrates information about the external and, at the same time, the internal world (e.g. reduced physiological arousal), promoting an awareness of one's own body being separate from others, and essentially, bodily awareness. Evidence further suggests that this sensitivity to affectionate touch is already observable in early infancy. Fairhurst et al. (2014) found that infants at the age of 9 months already exhibited reduced heart rates in response to slow, caress-like touch that in adults selectively activates C-tactile afferents. Intriguingly, observations of mother-infant tactile interactions across the first year of life revealed that mothers' use of affectionate touch decreased significantly after the first six months (Ferber et al., 2008). This indicates that although the frequency of such maternal tactile behaviors declines, infants remain finely attuned to this kind of affectionate touch at the age of 9 months.

As infants have very limited motor abilities in the early stages of life, they are not able to regulate their physiological states independently. Instead, they rely on the aid of their caregivers to satisfy their needs (Fotopoulou & Tsakiris, 2017). This implies that the infant's predictive models are continually updated based on the caregiver's reactions to the infant's initial signals (Filippetti, 2021; Fotopoulou & Tsakiris, 2017). This process of creating a mental representation of the state of the body, based on tactile interactions between caregiver and infant, is referred to as embodied mentalization (Fotopoulou & Tsakiris, 2017). As a result, one might assume that possibly not only the occurrence of affectionate touch itself, but also the context and timing of such could contribute to the development of infant interoceptive abilities. In line with this, Fotopoulou and Tsakiris (2017) state that “contingent, appropriate” (p.20) caregiver reactions promote the development of more accurate interoceptive models. Furthermore, Filippetti (2021) argues that when a caregiver’s reactions to infant signaling are unpredictable, unsuitable, delayed, or absent, the infant’s ability to process internal bodily signals is disrupted, as it becomes difficult to form consistent expectations about their own needs. Within this intricate dance of mother-infant interactions, embodied reparation is proposed as a vital process (Montirosso & McGlone, 2020). The authors state, that it allows the dyad to move from physiological and emotional misalignment back to a state of attunement, specifically through affectionate touch. This aids the development of an infant’s interoceptive system, as it restores interoceptive balance. The repeated act of moving the infant from internal distress to regulation fosters the infant’s interoceptive refinement and a stable sense of their bodily self (Montirosso & McGlone, 2020).

Research on sensitive maternal caregiving behavior may provide further support for the importance of quality of touch, as it emphasizes the value of contingent caregiver reactions in response to their infants (e.g. Cordes et al., 2017). Maternal sensitivity refers to the mother’s ability to recognize, infer and respond appropriately to the infant’s emotional and mental states (Ainsworth et al., 1974, as cited in Cordes et al., 2017). Conversely, caregiving behavior can also be considered overriding, characterized by a somewhat lack of attunement to the infant’s state, therefore displaying disruptive and restrictive behavior towards the child (Feldman, 1998, as cited in Cordes et al., 2017). As maternal touch is a central form of communication in early infancy (Field, 2014), such responsive or overriding behavior could arguably be evident in maternal tactile behaviors. In fact, one study found evidence for associations between the frequency of different types of maternal touch (e.g. affectionate, static, caregiving, playful, and intrusive touch) and sensitive or overriding caregiving behavior (Cordes et al., 2017). Specifically, they found sensitive behavior to be associated with caregiving touch, also referred to as instrumental touch, due to its functional purposes. Overriding behavior was found to be associated with playful touch, but interestingly not with intrusive touch. The authors speculate that the mothers may have opted for more positive, playful methods to redirect their infants' actions (Cordes et al., 2017). Another study examined a similar construct referred to as maternal mind-mindedness, a mother's ability to comprehend the current mental state of her infant (Crucianelli et al., 2019). Such ability or inability is measured through the mother's use of appropriate, or non-attuned mind-related comments, respectively. In relation to maternal touch, the study distinguished between contingent and non-contingent affectionate touch, finding that non-attuned mind related comments were associated with non-contingent affectionate touch (Crucianelli et al., 2019). As already reflected in these findings, maternal interoceptive sensitivity is increasingly being discussed as an important factor in shaping infants' interoceptive abilities. It is reasonable to assume that a mother's ability to accurately recognize and interpret her own bodily signals is mirrored in her ability to appropriately respond to her infant's signals, ultimately contributing to the development and refinement of the infant's interoceptive processing. In fact, studies suggest that a mother's self-reported ability to accurately sense her own bodily states is positively associated with her infant's respiratory interoceptive sensitivity at 9 months (Tünte et al., 2024a). While this relationship was found for maternal subjective interoceptive abilities, there is also evidence for a relationship with objective interoceptive measures. In the modality of cardiac interoception, a mother's objectively measured accuracy in detecting her own heartbeat showed a positive association with her infant's cardiac interoceptive sensitivity, again at 9 months of age (Tünte et al., 2024a).

In sum, as infant interoceptive development is dependent on the caregiver's reaction, contingent affectionate touch may help infants refine their ability to associate internal physiological states with external regulatory input. Although there is much research on interoception and its relation to affective experience and mental health in adults, we are missing empirical investigation into the development of interoception, and relation to affectionate touch, early in life.

Aim of the study and hypotheses

Recent research highlights the importance of affectionate touch, specifically delivered in tune with an infant's signals, for their physiological regulation and refinement of the predictive models of their own bodies. Yet no research to date has directly investigated whether variations in the contingency of maternal affectionate touch predict infant interoceptive sensitivity. The present study therefore aims to bridge this gap in literature, by examining, in a sample of 9-month-old infants, whether the frequency of contingent versus non-contingent maternal affectionate touch relates to infants' interoceptive sensitivity, as measured through a cardiac interoceptive modality. As for the first hypothesis, it is expected that the frequency of contingent affectionate maternal touch is positively associated with infant cardiac interoceptive sensitivity. Conversely, non-contingent affectionate maternal touch is hypothesized to be negatively associated with infant cardiac interoceptive sensitivity.

Methods

Participants

This study utilized data from participants of a previous study *Mind the Body*, conducted between 2019 and 2022 within the Wiener Kinderstudien. Initially, a total of 90 mother-infant dyads were recruited from the project's database. After excluding cases with missing data, the final sample for the present study consisted of 49 dyads with infants being 9 months old (*M* = 9 months 26 days, *SD* = 10 days).

Study design

The present study employed a correlational, cross-sectional design to investigate the relationship between maternal touch and infant interoceptive sensitivity. The independent variable is defined as the frequency of affectionate touch, categorized as either contingent or non-contingent. The dependent variable being infant interoceptive sensitivity, assessed using the iBEAT task and quantified through individual absolute proportional looking time scores. Given that the sample size was predetermined through a preexisting dataset, a sensitivity analysis was conducted to determine the minimum effect size that could be reliably detected with the available sample. With a targeted statistical power of .80, an α-level of 0.05, and a sample size of 49 dyads, a minimum effect size of $f^2 = 0.27$ could be detected (computed with G*power; Faul et al., 2007), representing a medium to large effect size (Cohen, 1988). The analysis considered four predictors in a multiple regression analysis, thus including other observed forms of maternal touch.

Procedure

The assessment for the *Mind the Body* study took place in a laboratory room at the University of Vienna. Each dyad completed the interaction, and infants additionally the iBEAT task on the same day, respectively. The order of measurements was determined randomly for each dyad. For the assessment of maternal touch behaviors, each dyad was seated facing each other, with the infant placed in a highchair. As part of the original study, both mothers and infants wore fNIRS headcaps to measure neural activity. This data is not analyzed here. However, wearing the caps may have influenced maternal touch behaviors. Mothers were instructed to engage with their infants freely and without toys, aiming to replicate typical interactions as they would occur at home. The session was recorded using three video cameras positioned at different angles within the room.

Measures

Maternal touch

For the present study, maternal touch during the interactions was micro-coded using the video recordings of the sessions. The coding followed the *mother-Infant touch scale* (see Table 1), a novel coding scheme which was developed by Crucianelli et al. (2019) based on previously established coding systems (Polan & Ward, 1994; Reece et al., 2016) to capture both the qualitative aspects and functional roles of maternal touch. To adapt the scheme to the assessment context of the present study, slight modifications were made. A *no touch* category was added to account for moments where either no tactile interaction or infant initiated touch occurred. Also, one of the examples for instrumental touch was adjusted to the specific characteristics of the assessment situation (see Table 1). According to the scheme, an occurring tactile behavior is initially classified as *intentional* or *incidental* (Crucianelli et al., 2019). Intentional maternal touch is then categorized by type, distinguishing between *affectionate*, *instrumental* and *static* touch. The key focus of this coding approach is to further differentiate affectionate touch based on its emotional contingency. Affectionate touch can, therefore, either be *contingent*, meaning it is attuned to the infant's mental and emotional state in that moment, or *non-contingent*, meaning it is not aligned with the infant's needs and state. This includes maternal touch that is restrictive or intrusive, rather than responsive to the infant's actions or emotional expression (Crucianelli et al., 2019).

Table 1

Description and examples of types of maternal touch

Type of maternal touch	Description
Incidental	Touch that occurs by way of actions directed at an object instead of the child
Intentional	Touch directed at the child

Affectionate	Intentional touch that gives a sense of closeness between the child and the mother
a) Contingent	Touch that is contingent with the infant's experience and elicits positive affect in the infant, such as: o Light, gentle, active touch o Firm active (not restrictive) o Kissing or rubbing lips o Tickling o Vestibular stimulation (e.g. lifting) o Proprioceptive stimulations
b) Non-Contingent	Touch that is not contingent with the infant's experience. Intrusive, awkward, overwhelming, rough touch, such as: o Awkward light active affective touch o Restrictive firm active o Rough kissing or rubbing lips; biting o Rough tickling o Vestibular stimulation (e.g. rough or restrictive handling) o Proprioceptive stimulation (awkward holding)
Static	Passive contact such as resting the hand in contact with the infant
Instrumental	Intentional touch that serves the child, such as: o Proprioceptive stimulation (e.g. flexion-extension-flexion of the infant's limb by the mother for the purpose of dressing) o Vestibular stimulation (e.g. adjust the position with change in balance) o Matter-of-touch or functional (e.g. adjusting the clothes; cleaning the child; preventing child from touching headcap)
No touch	No physical contact; infant initiated touch

Note. Coding scheme originally adapted from Crucianelli et al. (2019). Minor modifications for the present study include the addition of a no touch category and a customized example for the matter-of-touch or functional entry within the instrumental touch category.

The coding of maternal touch was done using the Eudico Linguistics Annotator (ELAN; Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands; Sloetjes & Wittenburg, 2008). To ensure the reliability of the coding scheme, inter-observer agreement was calculated using Cohen's kappa (Cohen, 1960). A second coder was trained to code maternal touch. Subsequently, videos of 10 randomly selected mother-infant dyads were coded by each rater. The analysis yielded a kappa value of $\kappa = 0.73$, indicating substantial agreement between raters (Cohen, 1960), which is considered sufficiently reliable. Further, it exceeds the inter-observer agreement ($\kappa = 0.56$) reported in the original study that introduced the coding scheme (Crucianelli et al., 2019). The rest of the videos was then analyzed to code maternal touch. The coding began at the audible start signal and ended at the corresponding audible stop signal of each recording. Videos were micro-coded on a frame-by-frame basis to achieve high temporal precision in capturing maternal touch behaviors. Therefore, any observable incident of maternal touch was coded, regardless of its duration. Intervals of no touch that separated two touch occurrences were only coded if the length of those intervals exceeded 300ms. The total duration of interactions varied between dyads, with a mean duration of 2 minutes and 30 seconds.

Infant interoceptive sensitivity

Infants' cardiac interoceptive sensitivity was assessed using the iBEAT task, a preferential looking paradigm developed by Maister et al. (2017). Infants were presented with animated visual stimuli (e.g., a cloud or a star) on a screen that moved either synchronously or asynchronously with their own heartbeat while their eye movements were recorded trough eye tracking. Infants' cardiac activity was monitored using ECG electrodes attached to their chest to identify their heartbeats, specifically the R-peaks. These were then synchronized to the presented stimuli, either precisely (for synchronous trials), or ±10% slower or faster (for asynchronous trials). As an individual difference score absolute proportional scores were used which indicate the strength of a preference infants show for either stimulus (Tünte et al., 2024b). These scores span from 0 to 1, with higher values demonstrating a greater preference.

Statistical analysis and assumption checks

The collected data was statistically analyzed using R (v4.4.2; R Core Team 2024) with the package glmmTMB (McGillycuddy et al., 2025). To test the two hypotheses regarding the relationship between maternal affectionate touch and infants' interoceptive sensitivity at 9 months of age, a beta regression model was applied, with the iBEAT score as outcome, and affectionate touch as the independent variable (iBEAT ~ Contingent Touch + Non-contingent Touch + Instrumental Touch + Static Touch). This method was chosen because the dependent variable, infant interoceptive sensitivity, was continuous but restricted to the open interval (0, 1).

The first hypothesis investigated the association between the frequency of contingent affectionate touch and infants' interoceptive sensitivity. The second hypothesis focused on the association between non-contingent affectionate touch and interoceptive sensitivity. Both predictors were included simultaneously in the regression model in order to estimate their unique effects, controlling for each other. Additionally, the model included instrumental touch and static touch as covariates to account for other forms of maternal touch. This model allowed for the simultaneous testing of both hypotheses.

The variance inflation factor (VIF) showed high multicollinearity of the variable no touch (VIF > 10) which was subsequently excluded from the model, as it also was not relevant to testing the hypotheses. In the adjusted model, the visual inspection of a posterior predictive check and diagnostic residual plot showed no evidence of violations of the model requirements.

Results

Descriptive statistics

As a preliminary step, a descriptive correlation matrix was computed to explore the bivariate relationships between the interoception score and all categories of maternal touch, including the category no touch (see Table 2). As mentioned above, no touch was not included in the final regression model due to high multicollinearity, but is reported here for descriptive purposes. Means and standard deviations were calculated for all categories of maternal touch (see Table 3).

Table 2

Descriptive correlations for independent and dependent variables

	1	2	3	4	5	6
1. Affectionate contingent touch	–					
2. Affectionate non-contingent touch	–.13	–				

3. Static touch	.1	.13	–			
4. Instrumental touch	.08	–.05	.3	–		
5. No touch	–.75	–.4	–.51	–.37	–	
6. Cardiac interoceptive sensitivity	–.11	.31	.08	–.03	–.08	–

Note. Values represent Pearson correlation coefficients (r).

Table 3

Mean and standard deviation for each maternal touch category

Type of maternal touch	*M* (*SD*)
Affectionate contingent	0.24 (0.18)
Affectionate non-contingent	0.12 (0.11)
Static	0.07 (0.07)
Instrumental	0.05 (0.06)
No touch	0.52 (0.24)

Note. Values are reported as percentages.

Confirmatory analysis

Contingent affectionate maternal touch and infant interoceptive sensitivity

Tests for multicollinearity revealed very low levels of multicollinearity (VIF = 1.03 for affectionate contingent; 1.05 for affectionate non-contingent; 1.11 for instrumental; 1.14 for static touch). The beta-regression analysis showed a slight positive, but not statistically significant association between contingent affectionate touch and cardiac interoceptive sensitivity (b = 0.16, SE = 0.70, z = 0.22, p = .82; see Figure 1). The model explained 2.7% of the variance in cardiac interoceptive sensitivity (Ferrari's R^2= .027).

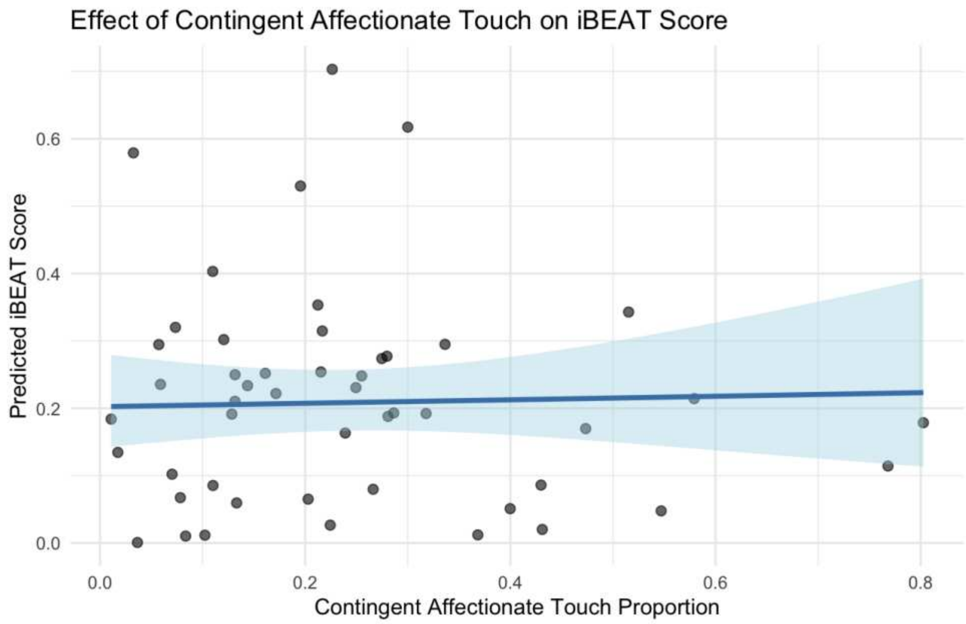

Figure 1. The relationship between contingent affectionate touch and infant interoceptive sensitivity. Predicted interoceptive sensitivity at different levels of contingent affectionate touch. Predicted values (blue line) and 95% confidence interval (shaded area) from the beta-regression model.

Non-contingent affectionate maternal touch and infant interoceptive sensitivity

The beta-regression analysis revealed also a positive, yet statistically non-significant association between non-contingent affectionate touch and cardiac interoceptive sensitivity (b = 1.54, SE = 1.20, z = 1.29, p = .198; see Figure 2). The same model was used to test both hypotheses simultaneously which, therefore, explained 2.7% of the variance (Ferrari's R^2= .027).

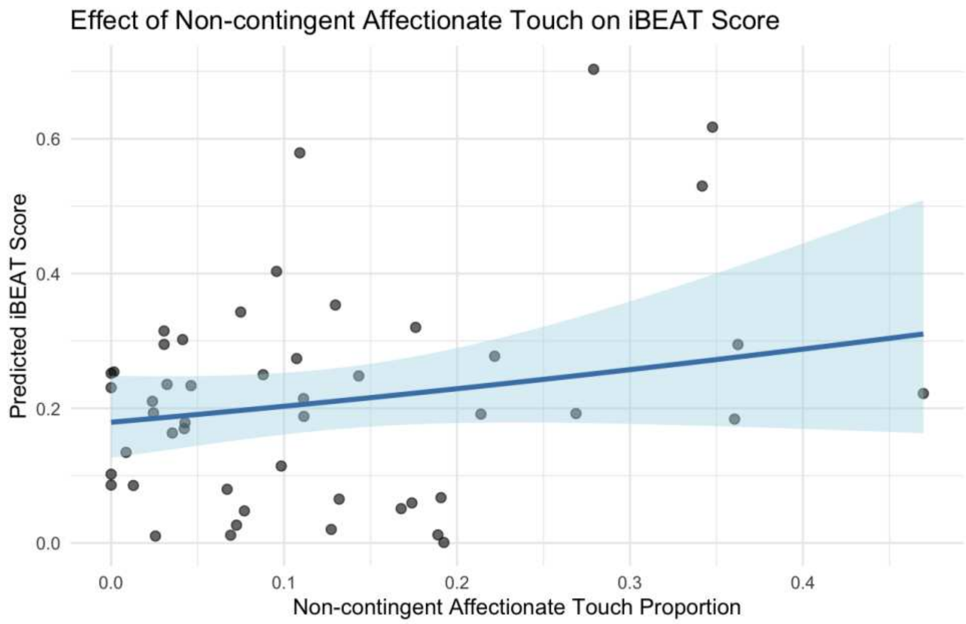

Figure 2. The relationship between non-contingent affectionate touch and infant interoceptive sensitivity. Predicted interoceptive sensitivity at different levels of non-contingent affectionate touch. Predicted values (blue line) and 95% confidence interval (shaded area) from the beta-regression model.

Exploratory analysis of respiratory interoceptive sensitivity

Beyond the primary hypotheses, an exploratory beta regression analysis was conducted to investigate the associations between maternal affectionate touch and respiratory interoceptive sensitivity, as measured with iBREATH, in 9-month-old infants. This analysis included a sample of $N = 36$ mother-infant dyads, reflecting exclusions due to missing data specifically pertaining to the iBREATH paradigm, which differed from the sample size used for the primary analysis. Given that this analysis also utilized a predetermined sample size, a sensitivity analysis was conducted, which indicated that the smallest effect size detectable, with a targeted statistical power of .80, and an α-level of 0.05, was $f^2 = 0.39$ (computed with G*Power; Faul et al., 2007), representing a large effect size (Cohen, 1988). The model included the same four predictors in the multiple regression analysis, as the model of the main analysis.

The exploratory beta regression analysis revealed a positive, yet non-significant association between contingent affectionate touch and respiratory interoceptive sensitivity ($b = 1.78$, $SE = 1.06$, $z = 1.67$, $p = .09$). For non-contingent affectionate touch, the analysis yielded only a slightly positive, albeit not statistically significant, relationship with respiratory interoceptive sensitivity (b = 0.23, SE = 1.49, z = 0.16, p = .88). The model explained 7.3% of the variance in respiratory interoceptive sensitivity (Ferrari's R^2= .073).

Discussion

The present study set out to investigate the relationship between contingent affectionate maternal touch and infant interoceptive sensitivity at 9 months of age. Interoception is increasingly recognized as a fundamental aspect of various developmental functions such as the formation of the bodily self, or emotion regulation (e.g. Montirosso & McGlone, 2020; Murphy et al., 2017). There have been many considerations about how interoceptive abilities develop in the early stages of life, with affectionate touch being widely proposed to play a significant role in that development (e.g. Crucianelli & Filippetti, 2020; Fotopoulou & Tsakiris, 2017). Beyond the mere occurrence of affectionate touch, its contingency has been further suggested as a crucial driver of interoceptive development. From a predictive processing standpoint, infants continuously generate models of their bodily states and update these models in light of their caregivers' responses, primarily touch (Filippetti, 2021; Fotopoulou & Tsakiris, 2017). However, research has not yet directly examined the role of contingency of affectionate touch, that is, whether touch behaviors are attuned to the infant's mental and emotional state at that very moment.

In line with the theoretical accounts emphasizing the importance of contingent affectionate touch in shaping interoceptive ability early in life, it was expected that the frequency of contingent maternal affectionate touch would be positively associated with infants' interoceptive sensitivity at 9 months. However, this assumption was not supported by the results, as the observed association, although trending in the expected positive direction, did not reach statistical significance. A possible explanation for the absence of a significant relationship could lie in the increasingly supported notion that interoception is not a unitary construct. While theoretical accounts posit a positive influence of contingent affectionate touch on interoceptive development, this does not necessarily have to imply a direct association with every interoceptive modality. Research indicates that interoceptive sensitivity across different interoceptive submodalities such as cardiac, respiratory, thermosensory, and affectionate touch, does not correlate, neither in adults (Banellis et al., 2025; Crucianelli et al., 2022), nor in infants (Tünte et al., 2024b) underscoring the variety in facets of the interoceptive system. Considering this, it is plausible that contingent affectionate touch might not specifically relate to the cardiac interoceptive sensitivity assessed in the present study.

The second hypothesis, which posited a negative association between non-contingent affectionate touch and interoceptive sensitivity, was not supported either. Contrary to expectations, the observed relationship was positive, yet not statistically significant. In light of this result, it is possible that even touch that is not contingent, yet affectionate in its nature, still provides somatosensory input that conveys caregiver presence and care. This aligns with the reasoning of Desmedt et al. (2025), who argue that affectionate touch is an exteroceptive signal that induces positive internal physiological outcomes or feelings, which in turn are subject to interoceptive processing. As affectionate touch reduces physiological arousal in infants (Fairhurst et al., 2014; Fotopoulou & Tsakiris, 2017) and conveys a sense of emotional security (Craig, 2010), the mere occurrence of affectionate touch may arguably support homeostatic balance and contribute to developing the interoceptive abilities. However, this consideration should be approached with caution, given the non-significance of the results.

The results of the exploratory analysis further provide a valuable contribution to the conceptualization of interoception. Since affectionate touch was not found to be significantly associated with respiratory interoceptive sensitivity either, this once again underscores the assumed multimodality of interoception. Although non-significant, the strength and direction of associations in the exploratory analysis offer a noteworthy contrast to those from the main analysis. While cardiac interoceptive sensitivity appeared more strongly associated with non-contingent affectionate touch, respiratory interoceptive sensitivity showed a clearer, more positive trend for contingent affectionate touch. When infants experience interoceptive dysregulation and distress, they communicate their current state to their caregivers. At such a young age this primarily happens through cries and respiratory cues, due to their limited motor and verbal abilities. Presumably, maternal affectionate touch, therefore, often happens in response to infant crying or agitated breathing, for instance. Thus, it is possible that the contingency of maternal affectionate touch could be more important for the development of the respiratory interoceptive system specifically. Or at least one could carefully conclude that the potential impact of early touch on interoceptive development may be modality-specific.

Beyond the considerations of interoception encompassing distinct modalities, the age of the infants at the time of assessment could present another crucial factor in interpreting the findings. While theoretical accounts on interoceptive development highlight the critical role of early caregiver interactions and touch, the present study was conducted when infants were 9 months old. However, the frequency of affectionate touch significantly declines after the first six months of life (Ferber et al., 2008). This means that the amount of affectionate touch observed during the assessment at 9 months may not be representative of the affectionate touch frequency the infants typically experienced during earlier, and potentially more critical developmental windows for interoceptive foundation through affectionate touch.

Limitations and implications for future research

The present study is subject to several limitations that should be considered when interpreting the finding, but which simultaneously highlight important avenues for future research. Firstly, the analysis was conducted using a relatively small sample size. The computed sensitivity analysis indicated that only a moderate to large effect size could be detected with the given sample, making it impossible to detect a potentially smaller effect. The same thing goes for the exploratory analysis which was computed with an even smaller sample size. Secondly, the present study utilized a cross-sectional design, with both touch and interoceptive sensitivity data collected on the same day. As previously discussed, it is possible that any potentially existing association between early tactile experiences and infant interoceptive sensitivity would be more readily detectable if affectionate touch were assessed at a younger age, when its frequency is higher than at 9 months. Future research should, therefore, adopt longitudinal designs to unravel the developmental trajectories for early tactile experiences and their relationship with interoceptive development.

The operationalization of affectionate touch in the present study presents a limitation, as it primarily focused on whether the touch was contingent with the infant's emotional and mental state, or not. Therefore, it does not explicitly account for the specific parameters, such as velocity and pressure, known to be optimal for activating C-tactile afferents. CT fibers respond optimally to slow, caressing touch and are central to transmitting the affective aspect of touch, as CT-targeted touch positively modulates the infant's physiological states by decreasing infant heart rate, for instance (Aguirre et al., 2019). Because the affectionate touch coded in the present study probably did not consistently exhibit these optimal CT-activating qualities, its physiological impact might have been less significant, ultimately contributing to the overall lack of significant findings. Furthermore, the coding scheme for maternal touch that was used in the present study has only been employed once before, as it was newly developed by Crucianelli et al. (2019) for the purposes of their study. While it made the important distinction between contingent and non-contingent affectionate touch, it did not include many other forms of touch. Therefore, the category of affectionate touch potentially encompasses touch occurrences that could arguably fit better into other, unmeasured categories. Future investigations could thus employ a coding system that includes and differentiates between more categories of maternal touch, including playful touch, for instance.

Future research would additionally benefit from the use of diverse interoceptive measures, spanning multiple modalities, in further exploring the modular nature of interoception. Finally, another promising avenue for future studies involves exploring potential mediating factors in the relationship between maternal affectionate touch and infant interoceptive development, especially maternal interoceptive sensitivity, given its known association with infant interoceptive sensitivity.

Conclusion

The present study represents the first empirical investigation into the relationship between specific early maternal tactile behaviors and infant interoceptive abilities at 9 months of age. The results did not show any significant associations between maternal contingent or non-contingent affectionate touch and infant cardiac or respiratory interoceptive sensitivity. Nonetheless, the findings offer crucial insights into the complex and multifaceted nature of interoceptive development. The observed trends, particularly the differential patterns across cardiac and respiratory interoceptive modalities, underscore the growing understanding of interoception as a modular construct, where various bodily signals may be processed and influenced distinctly. Interoception is widely recognized as a foundational process underpinning emotional experience and regulation and self-awareness, and disruptions or dysregulations in interoceptive processing are implicated in a wide range of mental health issues. Thus, this study offers an important contribution to the understanding of interoception and its early development. By shedding light on how early experiences, such as maternal touch, contribute to the formation of this fundamental bodily awareness, future research can further identify critical developmental pathways and potential targets for early interventions.

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List of figures

List of tables

List of abbreviations

HCT: Heartbeat counting task

CT-fibers: C-tactile fibers

VIF: Variance inflation factor

Appendix

Abstract

Interoception, the ability to perceive and interpret internal bodily signals, has gained increasing attention due to its involvement in cognitive processes and implications for mental health. Theoretical accounts highlight the significance of early tactile interactions in the development of interoceptive sensitivity. Especially maternal affectionate touch, as it is proposed to help infants to connect external sensory inputs with their internal physiological states, thereby building more accurate internal models of their body. An important property of touch might be its contingency, meaning how well the touch is attuned to the infant's internal state. However, the relationship between contingent affectionate maternal touch and infant interoceptive sensitivity is yet to be examined. The present study aimed to investigate the associations between contingent and non-contingent affectionate touch and infant cardiac interoceptive sensitivity at 9 months of age (N = 49). Findings revealed no significant associations for either form of affectionate touch with cardiac interoceptive sensitivity. Interestingly however, both associations revealed a positive trend, contrary to the initially hypothesized negative association for non-contingent touch. These findings suggest that the investigated variables (affectionate touch, cardiac interoceptive sensitivity) might represent distinct interoceptive submodalities that are not directly related. This contributes to the growing understanding of interoception as a collection of separate processes. Future research is necessary to better understand the role of affectionate touch in interoception, thus promoting the healthy development of infants.

Keywords: interoception, maternal touch, affectionate touch, contingency, mother-infant-interaction, development

Zusammenfassung

Interozeption, die Fähigkeit, interne Körpersignale wahrzunehmen und zu interpretieren, hat aufgrund ihrer Beteiligung an kognitiven Prozessen und ihrer Bedeutung für die psychische Gesundheit zunehmend an Aufmerksamkeit gewonnen. Theoretische Ansätze betonen die Bedeutung früher taktiler Interaktionen für die Entwicklung der interozeptiven Sensitivität. Insbesondere mütterliche affektive Berührung, da sie Säuglingen dabei helfen soll, externe sensorische Inputs mit ihren internen physiologischen Zuständen zu verbinden und dadurch genauere interne Modelle ihres Körpers zu entwickeln. Eine wichtige Eigenschaft der Berührung könnte ihre Kontingenz sein, also wie gut die Berührung auf den inneren Zustand des Babys abgestimmt ist. Der Zusammenhang zwischen kontingenter, affektiver Berührung und der interozeptiven Sensitivität von Säuglingen war bislang jedoch unerforscht. Die vorliegende Studie untersuchte die Zusammenhänge zwischen kontingenter und nicht-kontingenter affektiver Berührung und der kardialen interozeptiven Sensitivität von Säuglingen im Alter von 9 Monaten ($N = 49$). Die Analysen ergaben keine signifikanten Zusammenhänge jeweils zwischen den beiden Formen der affektiven Berührung und der kardialen interozeptiven Sensitivität. Entgegen der ursprünglich angenommenen negativen Assoziation für nicht-kontingente Berührung, zeigten interessanterweise beide Berührungsformen einen positiven Trend in ihrer Beziehung zur interozeptiven Sensitivität. Diese Ergebnisse legen nahe, dass die untersuchten Variablen (affektive Berührung, kardiale interozeptive Sensitivität) möglicherweise distinkte interozeptive Submodalitäten darstellen, die nicht direkt miteinander in Beziehung stehen. Dies unterstützt das wachsende Verständnis der Interozeption als eine Sammlung voneinander unabhängiger Prozesse. Es bedarf zukünftiger Forschung, um die Rolle der affektiven Berührung in der Interozeption besser zu verstehen und so die gesunde Entwicklung von Babys zu fördern.

Schlagwörter: Interozeption, affektive Berührung, Kontingenz, Mutter-Säuglings-Interaktion, Entwicklung

Declaration of independent work

I hereby declare that I have written the present thesis independently and have not used any aids other than those indicated. All passages that are taken either literally or in substance from other works are clearly identified as such, with the source cited and in accordance with the rules of academic referencing. This declaration also applies to any tables and diagrams used in the thesis.

Erklärung zur Verwendung von Künstlicher Intelligenz (KI)

Hiermit erkläre ich, dass ich die folgenden KI-Hilfsmittel zur Erstellung meiner Masterarbeit mit dem Titel *In Touch with the Self: The Role of Contingent Affectionate Maternal Touch in Infant Interoception* verwendet habe. Ich versichere, dass die Kennzeichnung der verwendeten KI-Hilfsmittel vollständig ist, inkl. Verwendungszweck, Produktname, als auch ggfs. Prompts und Outputs des KI-Hilfsmittels. Ich verantworte die Auswahl und die Übernahme sämtlicher Ergebnisse der von mir verwendeten KI-Hilfsmittel vollumfänglich selbst.

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