Mother Knows Best? Maternal Interoception Aids Interpretation of Children's Heart Rate

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ABSTRACT

Interoception, at the conscious level, involves the perception of shifts in the body's internal signals in response to fluctuations in the internal and external environments. Being interoceptive, termed interoceptive ability, allows one to interpret their physiology and subsequently make changes to regulate bodily responses. Most research, however, examines how interoceptive ability aids the interpretation of one's *own* needs rather than the needs of *others.* The present study uniquely examines how the ability to interpret one's own physiology relates to the ability to interpret physiology in another individual. In this case, we examine how a mother's ability to perceive changes in her physiology relates to, predicts, and potentially aids perception of her preschool child's heart rate.

Current measures of interoception are flawed, and there is a need to develop improved interoception methodologies. The present study introduces a novel method, which involves use of a wearable device that provides real-time heart rate data from the child, thereby allowing insight into the accuracy of their mother's perceptions. Here, we coin the term *mother's objective maternal interoceptive accuracy* (MOMIA) to describe the mother's objective ability to accurately interpret her child's HR. While the device records the child's HR, the mother holds a smartphone with an application developed for Bluetooth communication with the device. The child engages in several tasks while their mother reports her perceptions of her child's HR, as well as her confidence.

Results found that a mother's certainty in her child's *mental states* significantly relates to her ability to accurately interpret her child's *HR*; however, a mother's confidence in her perceptions of her child's HR is unrelated to the accuracy of her perceptions. Further, results indicated that a mother's certainty in her child's mental states is a significant predictor of her ability to accurately interpret her child's HR, as well as her child's emotion-behavioral development. Follow-up analyses additionally found that a mother's tendency to notice her physiology and perceived closeness to her child does significantly predict her ability to accurately interpret her child's HR in contexts of low physiological arousal. However, a mother's ability to accurately interpret her child's physiology in contexts of high arousal is uniquely predictive of her child's emotion-behavioral development.

Overall, this study incorporates two important features: maternal interoception and the use of a novel monitoring device. Our results provide novel direction for not only dyadic interoception, but also the importance of mentalizing others' mental states in order to understand their physiology and support their needs. Future research should consider developing interventions that aim to improve maternal interoception and educate parents on the significance of both healthy body awareness and mindfulness of children's mental states to support emotion-behavioral development.

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1.1 Preface

The conjunction of variables considered in the present work is novel, and the introduction extends across several literatures. First, the concept of interoception and the distinct definitions associated with it are introduced. Next, measures used to quantify interoception are considered. Although limited, the research examining interoception in mothers or caregivers and their children is then reviewed. The introduction further branches towards a consideration of mind-mindedness and parental reflective functioning, which have not been extensively examined in relation to interoception because of their roots in developmental and clinical domains. Lastly, perceived closeness and anxiety are discussed as additional variables of interest before a final presentation of the present study's hypotheses and aims.

1.2 What is Interoception

At the conscious level, interoception is the perception of the body's internal signals in response to various internal and external stimuli. These signals range anywhere from communicating temperature and sensual touch to muscular and visceral sensations, and they provide insight into the "material me" or how one feels (Craig, 2002). It is this conscious perception of the body that has been argued as the basis for human emotion (James, 1890). Outside consciousness, interoception involves the brain's automatic formation of probabilities for sensations within the body, given past experiences (Clark, 2013; Friston, 2010).

As interoception research grows, new definitions arise to consider the multidimensionality of interoceptive abilities, from perceiving hunger and respiration to heart rate (HR) and metabolism (Khalsa & Lapidus, 2016). While Vaitl (1996) describes interoception as generally relating to proprioception and visceroception, Paulus (2013) alternately defines interoception as the integration of information in the body with the central nervous system. Craig (2002) differentially defines interoception as the result of a homeostatic afferent pathway that allows for insight into the physiological condition of the entire body and not just the viscera (i.e., soft internal organs of the body, such as the lungs). Barrett & Quigley (2021), however, simply define interoception as the construction of all inner sensations. Evidently, no single agreed upon definition exists, given that interoception can be examined from a plethora of differing scientific and philosophical perspectives. There is also no consensus as to the total facets of interoception, such as if it should be measured in terms of the tendency to attend to internal signals (attention or awareness), more specifically in terms of perceived intensity of internal signals (magnitude), how well an individual interprets these signals (accuracy), or even how well an individual believes they can interpret physiological sensations (sensibility; Forkmann et al., 2016; Khalsa et al., 2015; Schandry et al., 1993; Simmons et al., 2013). The most recent literature proposes an entirely new facet of interoception, interoceptive beliefs, to examine individuals' personal views on if sensing their body's signals is either helpful or harmful (MacCormack et al., 2024). Regardless, differences in how interoception is defined causes difficulties in how best to measure its different domains (Khalsa et al., 2018).

One approach utilized to explain interoception is allostasis, which describes the brain as responsible for correcting changes in our homeostatic baseline, yet also a predictive organ that anticipates the body's needs given various internal and external stimuli (Barrett & Simmons, 2015). Predictions based on probabilities from past experiences serve as hypotheses that the brain constantly tests and refines as new sensory input is received. Therefore, incorrect predictions are just as informative as correct ones; though to reduce future error, there are several ways that the brain attempts to refine its probability model of future sensory experiences. In other words, the brain does not merely react, but anticipates information from the world and within the body, allowing for refined energy allocation for maintaining allostasis. Prediction errors allow for the refinement of active inference, resulting in the future production of more accurate visceromotor predictions. The brain constantly runs a "metabolic budget" to ensure that every other brain within the body (i.e., every organ, tissue, cell, etc.) receives its necessary resources to support overall functioning (Barrett & Quigley, 2021). The body's present visceral experience is a combination of what is remembered of past sensory experiences yet also what is expected of future sensory experiences—interoception is the nervous system's self-fulfilling prophecy (Barrett & Simmons, 2015).

Changes in the body and brain influence our emotions, yet we are not always perceptive of these physiological signals. Anger being a result of hunger, for example, is not always recognized by the “hangry” individual, and perceptions of emotions may not be correctly attributed to changes in the body, but other noise or simultaneous stimuli (MacCormack & Lindquist, 2019; MacCormack & Lindquist, 2016). One individual may be sensitive to the somatic markers that assist emotion perception; however, another individual may experience elevated HR and sweaty palms, yet fail to turn their awareness to these biomarkers (Bechara & Damasio, 2005). The Iowa Gambling Task, for example, illustrates how somatic markers create unconscious change in physiology that influence our emotions and consequent decisions, reflective of interoceptive processes that are not perceived, despite the body’s attempt to tell us (Bechara et al., 2005). Successful attention to these internal signals, however, is associated with more intense emotional experiences that influence other cognitive processes for better or worse, whether that be biases, judgements, or behaviors (Damasio et al., 1991; Garfinkel & Critchley, 2013).

Some individuals are not acute interoceptors and obscurely attribute their decisions to “a gut feeling,” whereas others can accurately flag changes in their physiology as related to their change in attitudes (Holzer, 2022; MacCormack & Lindquist, 2016). Being consciously interoceptive, termed as having interoceptive ability, means an individual is able to interpret their physiology; if able to do so accurately, having interoceptive ability can lead to the adoption of behaviors that reduce hindrances to optimal functioning. Colloquially described, interoceptive ability is a “sixth sense,” and current research argues that a third of individuals are conscious of their interoceptive processes (Khalsa & Lapidus, 2016; Ponzo et al., 2021). Whether one is or is not aware of how their body is physiologically changing, the brain predicts internal signals to orchestrate a silent symphony of appropriate changes; however, being consciously aware of how the body reacts in anticipation of external or internal stimuli is when benefits can arise. Being accurately aware of one's physiology holds relevance to various physiological and psychological experiences, such as how we understand hunger and eating disorders, stress, discomfort, and cravings (Khalsa et al., 2022; MacCormack & Lindquist, 2019). Increasing links to mental and physical health illustrate the benefits of possessing conscious interoceptive insight (Adams et al., 2022; Khalsa et al., 2018; Murphy et al., 2019). For example, poor interoception, related to poor emotion regulation, can contribute to the development of mental disorders, such as depression and anxiety (Kever et al., 2015; Martin et al., 2019; Paulus & Stein, 2010; Quadt et al., 2018). Although results are inconsistent, previous literature heavily focuses on the relationship between interoception and BMI. A recent meta-analysis conducted by Robinson et al. (2021b) supports previously found relationships where individuals with higher body mass index (BMI) score lower on a variety of interoceptive measures, both subjective and objective (Mata et al., 2015; Todd et al., 2019; Young et al., 2017). Individuals with a higher BMI self-report being less reliant on internal signals to determine their eating behaviors, and they score lower on measures of interoceptive accuracy, such as the Heartbeat Counting Task (HCT) and Heartbeat Detection Task (HDT), which are reviewed in the following section (Herbert et al., 2013; Herbert & Pollatos, 2014; Mata et al., 2015; Robinson et al., 2021a).

1.3 Measuring Interoception

Interoception research has grown due to increasing links to health (Khalsa et al., 2018), and about a third of individuals are cardiac interoceptive, perpetuating the need for methods that accurately measure individuals' abilities to detect their HR (Khalsa & Lapidus, 2016). Various methods attempt to measure cardiac interoception, with the HCT and HDT being the most utilized methods thus far. The HCT developed by Schandry (1981) requires participants to count the number of their heartbeats in timed intervals, while the Whitehead et al. (1977) HDT asks participants to synchronize a tone to their HR. Self-reported ratings are then compared to an objective measure of HR to determine accuracy (Desmedt et al., 2022; Leganes-Fonteneau et al., 2021; Legrand et al., 2022). However, these tasks are flawed and likely invalid as there is substantial room for error (Zamariola et al., 2018). Current methods additionally often fail to methodologically discriminate between interoceptive awareness and interoceptive accuracy. Murphy et al. (2019) describe interoceptive awareness as the tendency to pay attention to the body's signals, while interoceptive accuracy as the ability to interpret these signals correctly. Given this distinction, a person may notice that their heartbeat has changed yet fail to interpret these afferent signals accurately. Second, these tasks are problematic because of vulnerability to personal bias, such as prior knowledge of resting heart rate (RHR). In tasks where participants count the number of their heartbeats in timed intervals, there is potential to alternatively count the passing of time due to prior knowledge of the association between beats per minute (BPM) and RHR (ex., a RHR of 60

BPM matches a 1-minute interval of time; Brener & Ring, 2016; Windmann et al., 1999). Further, less research examines interoception in environments where movement is required, given most behavioral measures of cardiac interoception occur during rest. Understanding interoception in contexts where rest is not possible or discomfort is experienced (e.x., anxiety, hunger, dietary fasting, exertion) is significant in order to understand the relationship between interoception and health (Khalsa et al., 2018; Rominger et al., 2021). As a result, interoception research is beginning to consider different types of interoception measurement other than cardiac to understand previously neglected internal perceptions. Skin-mediated interoception, for example, investigates how thermosensation may be measured in a matching task where participants pair a reference temperature to presentation of warmer, cooler, and neutral thermodes (Crucianelli & Ehrsson, 2023; Crucianelli et al., 2022). As another example, gastrointestinal interoception can be measured with the Water Load Test, which asks participants to ingest water until perceived 1) satiation and 2) maximum fullness. The volume of water ingested to reach satiation is divided by the total volume of water consumed to quantify an individual's gastric interoception (Dyck et al., 2016). While it is important to examine previously neglected domains of interoception, investigation of cardiac interoception should not be punished due to weaknesses in current measures.

One of the most prominent limitations of measuring interoception is distinguishing between subjective and objective measurement. A surplus of current measures fail to discriminate between different facets of interoception yet also fail to specify their objectivity. Murphy et al. (2019) present a 2x2 factorial model of interoceptive abilities that can be used by researchers to clarify if a measure of interoception is a) objective or b) subjective, as well as if it measures c) accuracy or d) attention (awareness). Most subjective measures of interoception, such as questionnaires (ex., Body Perception Questionnaire, Interoceptive Accuracy Scale, Multidimensional Assessment of Interoceptive Awareness), specify which facet of interoception they measure (i.e., awareness, accuracy). However, many measures of interoception that attempt to provide objective measurement are equally flawed, as they do not discriminate which facet they aim to measure, introducing questionable validity. Future interoception research should emphasize use of the model proposed by Murphy et al. (2019) to improve development of new measures.

1.4 Why Interoception in Mothers?

Most research examines how an individual's interoceptive ability aids interpretation of their *own* needs rather than the needs of *others*. Montirosso et al. (2022) uses the term maternal interoception to specifically describe the interoceptive processes experienced during motherhood as unique and evolutionarily adaptive for recognizing the needs of one's children. In the current study, we've coined the term *mother's objective maternal interoceptive accuracy* (MOMIA) to describe a mother's objective ability to interpret her child's physiology. Although little research examines parents' perceptions of their children's physiology, parents' interoceptive abilities positively relate to their children's mentalization development, such that children of interoceptive parents are better able to comprehend the mental states of others (Abraham et al., 2019). Those parents that are not only perceptive to their own physiology, but also able to understand the physiological state of their children, are more likely to engage in appropriate behaviors that aid their children's development of social cognitive skills (Imafuku et al., 2023). Parents even simply possessing knowledge of what interoception is (i.e., interoceptive knowledge) positively relates to their children's socialization and understanding of emotions (MacCormack et al., 2020). Abraham et al. (2019) similarly finds that greater parental interoceptive sensibility (i.e., confidence in one's interoceptive ability) during infancy predicts the child's somatic symptoms at age six. Thus, when we improve the parent's confidence in their ability to perceive their child's physiology, the child's care may improve as well. Attentiveness to the body shapes how mothers regulate their own emotions, but also how they interact with their child, revealing clinical implications for improving mothers' body-emotion awareness (Engelhard et al., 2021). Current research reveals that interoception is a skill that can be improved and, when encouraged in the caregiver, supports reflective parenting to enhance the child-caregiver relationship—such is not surprising, given individuals' interoceptive awareness predict their recognition of positive and negative emotions in others (Hübner et al., 2021). Interventions led by Jones (2021) highlight the importance of educating caregivers of children on how to improve their interoceptive ability to improve understanding of their children's needs. Most recently, a recent 9-session prenatal mindfulness relationship-based group treatment program implemented pre-birth successfully revealed improvements in mothers' self-reports of mindfulness, interoception, relationships with their children, and reduced depressive symptoms postpartum (Sansone et al., 2024).

Improving interoception in mothers suffering from depression and/or anxiety is especially relevant as symptoms related to these disorders can hinder mothers' abilities to interpret their children's needs. An estimated 14% of women develop postpartum depression (Getahun et al., 2023), while an estimated 30.8% of mothers report symptoms of anxiety as prolonged as 24 months postpartum (Cena et al., 2021). Given the extensive range of bodily changes experienced during pregnancy and motherhood, often for the first time in a woman's life, it is not uncommon for feelings of anxiety and depression to erupt in association with perceptions of bodily changes (Noda et al., 2022). That being said, it is important to consider improving mothers' internal perceptions, as well as their beliefs as to how their perceptions are helpful, to reduce body-related anxieties. Interoception changes during motherhood, and maternal interoception may serve as a unique tool for mothers to support the social-emotional development of their children, but also themselves. Improving maternal interoception and body trust, for example, is suspected to improve body satisfaction in the mother post-pregnancy (Crossland et al., 2022). If confidence in interoceptive ability relates to body satisfaction, there is reason to improve mothers' interoceptive knowledge, as well as confidence in their perceptions to improve their experiences of motherhood.

Research measuring interoception in children is even more scarce, yet more work is beginning to develop measures of interoception in children as young as infancy, such as the Infant Heartbeat Task (iBEATS), to understand how and when interoception first develops. For example, to examine interoceptive ability in 5-month old infants, figures were presented simultaneously with images that moved either synchronously or asynchronously to their HR. Results revealed that infants spent more time looking at asynchronous images, due to daily familiarity with HR sensations and interest in novel stimuli, suggestive of possessing awareness of cardio-visual synchrony (Maister et al., 2017). Using an adapted method of iBEATS, it was found that infants' interoceptive ability relates positively to their social behaviors during mother-child interactions, such as synchronous eye contact and smiling. Therefore, the infants' interoception potentially heightens the positivity of experiences with their mother, encouraging greater contact and social interaction (Imafuku et al., 2023). As suggested by current research, the separate interoceptive abilities belonging to the parent and child may equally contribute to the development of the shared parent-child relationship. It may be that the mother's interoception is not only essential in aiding her understanding of her child's needs, but also influential in the development of her child's own interoceptive ability. It may also be that the child's interoceptive ability is essential for engaging in affirming interactions with their mother, fostering a caregiver who is attentive to the child's physiology. Future work is required to unfold these questions, yet all the more reason remains to examine how maternal interoception may aid interpretation of children's needs.

1.5 Mind-Mindedness and Reflective Functioning

Mind-mindedness describes how parents view their children as independent agents capable of their own feelings, thoughts, and desires (Hughes et al., 2017; Meins, 1997; Meins et al., 2003). In other words, the mind-minded parent views their child as a being with their own mind rather than simply an entity with needs to be met (Meins et al., 2003). Parental reflective functioning (RF) has been described similarly as the parent's tendency to mentalize about the mental states of their children (Allen & Fonagy, 2006). Mind-mindedness can be measured by solely recording the frequency of the parent's mind-related comments about their child or by additionally considering the appropriateness of these comments, given the child's age. Therefore, not all mind-related comments are advantageous since non-attuned comments do not accurately represent or validate a child's internal state (Meins et al., 2012; Meins & Fernyhough, 2010). An anxious parent, for example, may project perceptions of their own feelings onto their child and interpret crying as fear, when in actuality their child is simply hungry. How well the parent recognizes their child's emotions consequently predicts the child's ability to recognize their own affective state. For example, if a child becomes frustrated by a difficult task, a mind-minded parent will recognize this emotional arousal and alter their behavioral engagement to assist with their child's recovery, allowing their child to gradually learn how to properly self-regulate (Meins et al., 2012; Zeegers et al., 2018). In other words, parents better able to recognize their children's emotions may engage in emotion socialization by coaching appropriate emotional responses (Spinard et al., 2004). The majority of mind-mindedness research occurs during infancy, yet parental mentalizing predicts children’s self-regulation in toddlers and preschoolers as well (Nikolić et al., 2022).

The mind-minded parent focuses on their child’s mental state attributes rather than physical appearances, which predicts essential developmental outcomes, such as the child’s theory of mind at 45 to 48 months and stream of consciousness at 55 months when mind-mindedness is measured at as early as 6 months (Meins et al., 2003). Similarly, when measured at one year of age, mind-mindedness predicts children’s theory of mind at ages as late as 5 to 6 years (Kirk et al., 2015). Ultimately, parental mind-mindedness significantly contributes to children’s mentalization development and later social understanding (Aldrich et al., 2021; Meins et al., 1998). Therefore, sensitivity to children’s physical needs differs from sensitivity to their psychological needs, and parents’ tendencies to appropriately comment on their children’s mental states at 6 months further predicts their attachment security and emotion regulation at as early as 12 months (Meins et al., 2001; Zeegers et al., 2018). Maternal mind-oriented language, both appropriate and non-attuned, has been found to be a stronger predictor of attachment security than maternal sensitivity (i.e., attunement with children’s needs), supporting mind-mindedness as a useful predictor of positive developmental outcomes (Ainsworth et al., 1971; Meins et al., 2001; Meins et al., 2012; Meins, 2013).

Most research examines mind-mindedness in mothers specifically due to their heightened parental involvement during infancy, which is shown to more strongly predict children’s heart rate variability (HRV) in comparison to mind-

mindedness in fathers. Appropriate mind-related comments from mothers at as early as 4 months predicts HRV in their children, while mind-mindedness in fathers does not begin to predict HRV until 12 months (Zeegers et al., 2018). Mothers, irrespective of fathers, impact their children’s emotion regulation, suggesting that mothers possess a unique ability to understand their children’s internal experiences and physiology. Mothers’ mind-mindedness at as early as 9 months, for example, consistently predicts and ties to children’s executive functioning and inhibitory control at as far as 2–3 years of age (Cheng et al., 2018; Gagné et al., 2018; Senehi et al., 2018). Most recent literature finds that this relationship extends to older ages as well, where maternal mind-mindedness at 3 years additionally predicts children’s self-regulation and HRV at 4.5 years (Nikolić et al., 2022). Being able to understand a child’s non-verbal cues as a mother is especially important during these early ages when the child is unable to directly communicate their needs themselves (Hughes et al., 2017). Further, maternal mind-mindedness measured at 8 months negatively relates to disruptive behaviors reported at 44 and 61 months in children from lower socioeconomic status (SES) families (Meins et al., 2013). Given that mind-mindedness may serve as a protective factor for at-risk families, there is additional reason to examine how mind-mindedness relates to maternal interoception to encourage healthful child development.

Why mind-mindedness differs among mothers is partially explained by the stability of the mother’s cognitive-behavioral traits as well as by the specific caregiver-child relationship, yet surprisingly not the child’s temperament (Meins et al., 2011). Maternal mind-mindedness can consequently be described as more so a reflection of the parent's representation of their child rather than the child's behavior itself (Meins et al., 2011). However, a mother's mind-mindedness can be predicted as early as during pregnancy with her descriptions of how her baby will be like in the future (Arnott & Meins, 2008). Similarly, maternal mind-mindedness is positively predicted by if the mother planned her pregnancy, evaluated it as enjoyable, and contentedly recounts the first contact with her baby. Contrastingly, mother-centered factors, such as SES, education level, and psychological well-being are mostly independent from a mother's MM, regardless of psychopathology severity (i.e., schizophrenia, concurrent maternal depression, perceived social support; Meins et al., 2011; Pawlby et al., 2010).

To what extent the construct of mind-mindedness is a fixed trait or capable of improvement remains questioned. Investigation of mentalization-based interventions to improve caregivers' mind-mindedness is growing, yet not quite fully understood (Smith-Nielsen et al., 2022). Infant mental health-based interventions in low-income populations, such as Early Head Start (EHS), have been shown to increase appropriate mental-based comments, when moderated by parenting stress (Brophy-Herb et al., 2022). Relatedly, mothers exhibiting medium-high mind-mindedness benefit more from parent-child interaction therapy (PCIT) in comparison to mothers possessing medium-low levels of MM, suggesting that prior use of mind-mindedness interventions might multiply the benefits of other interventions (Meynen et al., 2022). These promising results encourage investigation of how mind-mindedness may be changed to enhance the child-caregiver relationship or improve the effectiveness of other interventions, such as those targeting maternal interoception. If able to improve parental MM, a parent's ability to recognize the physiological changes in their child, or parental interoception, might consequently be improved as well. A mother that recognizes frustration in her child during a difficult task, for example, may similarly recognize the physiological changes that coincide with disrupted emotions, such as elevations in HR. Therefore, examination of maternal mind-mindedness in relation to maternal interoception remains necessary, given MM's relationship to various positive child outcomes. Further, while mind-mindedness positively relates to parental sensitivity, no research examines how mind-mindedness relates to objective interoceptive ability, despite evident commonalities.

1.6 Perceived Closeness and Anxiety

The ability to differentiate one's mental state from another person's may be relevant to the ability to differentiate one's body from another person's. Therefore, mothers' perceived closeness to their children is relevant to the discussion of understanding maternal interoception. Mothers who perceive themselves as exceptionally close to their children, for example, may be less able to differentiate their mental states from their children's, resulting in reduced ability to accurately perceive their children's physiology. Or, as found previously, mothers who view their children as far extensions from themselves are less in tune to their children's signals and needs (Planalp et al., 2019). In young adults, attachment style is also related to interoception, where avoidant individuals self-report lower interoception and anxious individuals report heightened interoception. In a separate study, parenting style, as reported by the mother, related to children's abilities to match their emotions with their physiological arousal. More specifically, mothers' rejection of their children's negative emotions is related to less accuracy in children's self-reports of their perceptions of physiological arousal (Oldroyd et al., 2019). It may be that these mothers are less mind-minded or perceptive of the negative affect experienced by their children, in turn less involved in their children's socialization of emotion that consequently weakens the children's abilities to understand the relationships between their emotion and physiology. How mothers interact with their children, and the closeness they share in the parent-child relationship, may significantly relate to their children's interoception and ability to attribute emotion to bodily changes.

The accuracy of mothers' interpretations of their children's physiology may also be influenced by heightened anxiety. The presence of anxiety can interfere with the quality of mother-child interactions by, for example, reducing maternal behaviors essential for the child's social development (Rocha et al., 2022). While low levels of anxiety may be beneficial, as they may cause the mother to remain alert of her child's needs, excessive anxiety becomes maladaptive by reducing interoceptive ability. The mother must be able to find a balance between *perceiving* and *differentiating between* her own body's signals and those of her child (Abraham et al., 2019), which may become particularly difficult when experiencing anxiety. Cortisol, for example, has been identified as a primary contributor to dysregulated interoception, responsible for fueling various body-related mental disorders and weakening the ability to accurately perceive changes in physiology (Schulz et al., 2015; Schulz & Vögele, 2015). Further, neural models of intersubjectivity suggest a link between ability to perceive one's bodily signals and ability to empathize with the physiology and emotions of others, which aids facilitation of “postnatal reciprocal affective communications” between mothers and their children (Ammaniti & Gallese, 2014). If a mother’s ability to perceive her child’s HR is linked to or limited by her ability to perceive her own HR, and she is experiencing severe anxiety that limits self-perceptions, her ability to interpret her child’s physiology may also be constrained. Or, a mother experiencing heightened anxiety may be less able to form a secure attachment to her child, reducing closeness or the tendency to mentalize about her child’s mental states, therefore weakening her ability to understand her child’s needs.

Previous research finds that mothers’ fears of anxiety symptoms stemming from bodily sensations significantly predict infant attachment, and mothers suffering from a postpartum anxiety disorder are significantly more likely to possess an insecure or disorganized attachment with their infant (Klauser et al., 2023). Anxiety during motherhood is also not uncommon, with 20% of mothers experiencing symptoms during the perinatal period (Furtado et al., 2019) and 10-15% suffering from a postpartum anxiety disorder, highlighting the need to consider how anxiety not only influences attachment, but perceptions of physiology (Dennis et al. 2017; Liu et al., 2020; Reck et al., 2018). Mothers’ attentiveness to their body relates to their mental health postpartum (Engelhard et al., 2021), and so it may be that mothers with heightened anxiety are less aware of bodily signals. Although not yet experimentally explored, postpartum depression may be uniquely linked to dysregulated interoception in the mother (Montirosso et al., 2022). There is a need for body-focused interventions that reduce anxiety surrounding physiology and postpartum anxiety disorders that strain the child-caregiver relationship. Indeed, it is important to consider the mother's mental health for not only herself, but also her child and their shared bond.

1.7 Purpose of the Present Study

The little research examining maternal interoception solely examines how a mother's interoceptive knowledge or confidence, rather than her objective interoceptive ability, relate to her child's emotion-behavioral development. As previously stated, confidence relates to the ability to perceive the affective state of others and regulate one's own emotions (Fukushima et al., 2011; Gao et al., 2019; Schmitz et al., 2021; Schuette et al., 2021; Terasawa et al., 2014). However, previous research simply assumes a mother's confidence equates to her ability; as a result, there is a need to measure MOMIA during direct observation of her child (Suga et al., 2022). Previous research examining non-familial dyads has found, for example, that individuals who overestimate their own interoceptive processes perform significantly worse at inferring others' cardiac states (Arslanova et al., 2022). Interoceptive accuracy additionally mediates the strength and direction of the relationship between mothers' perceptions of their children's physiological arousal and mothers' perceptions of their children’s emotions, again suggesting that improving caregiver interoceptive ability is a promising avenue for interpreting children’s needs (Barrett, 2017).

The current study will utilize a novel and unique method adapted from the Cardiac Elevation Detection (CARED) Task by Ponzo et al. (2021) and Stephenson et al. (2024) to examine how a mother’s perceptions of her own body predict and may aid interpretation of her child’s HR. Little research examines interoception in environments where movement is required, and understanding interoception in contexts where discomfort is experienced (e.g., anxiety or exertion) is essential in order to understand the relationship between interoception and health (Khalsa et al., 2018; Rominger et al., 2021). As a result, the current study examines a mother’s ability to interpret her child’s HR during tasks that represent various cardiac states experienced in children. Second, the present study aims to identify potential reasons for differences in maternal interoceptive ability (i.e., mentalization of others’ mental states and perceived closeness), to understand why mothers vary in their ability to accurately interpret their children’s cardiac states. As seen in the interoception literature, discrepancies often erupt between subjective and objective measures, highlighting the need to reduce reliance on self-reports. As a result, the current study utilizes two different measures of mothers’ tendencies to reflect on their children’s mental states. The Five Minute Speech Sample will provide a more objective measure of mothers’ tendencies to describe their children’s mental and non-mental attributes, while the Parental Reflective Functioning Questionnaire will serve as a self-report measure. These separate measures may relate differently to mothers' interoception and their children's development. Lastly, the current study aims to examine maternal interoception among children ages three to five years, which is an under-investigated age group in interoception research.

We hypothesize that a mother's subjective interoceptive awareness and subjective interoceptive accuracy (i.e., self-perceptions of physiology) will positively relate to MOMIA. Further, we hypothesize that maternal interoceptive sensibility (i.e., a mother's confidence in her perceptions of her child's HR) will positively predict MOMIA. We additionally expect MOMIA to relate positively to her mind-mindedness, parental reflective functioning, and perceived closeness to her child. More specifically, we hypothesize that mind-mindedness and perceived closeness will positively predict MOMIA. We will examine mothers' self-reports of anxiety, as we anticipate that a mother's anxiety will relate negatively to MOMIA. Most focal, we hypothesize that a child's emotion-behavioral development will be positively predicted by MOMIA.

Method

2.1 Participants

Mother-child dyads were recruited both online and in-person via advertising in Facebook groups for parents, attending local family-friendly events, and distributing flyers at community centers, stores, daycares, and schools. The majority of participants were recruited from advertising at in-person community events (e.g., pop-up markets), as well as contacting mothers from a previous study at the university for children ages 1–2 years (that provided consent to be later contacted). In sum, the present study recruited 51 mothers (50 female, age range: 24–45 years, *M*=35.00, *SD*=4.21) and their children (27 female, age range: 29.27–71.92 months, *M*=48.80, *SD*=10.41). Annual household income averaged $125,448 (median = $100,000, *SD* = $76,525) and ranged from $18,00–$400,000. Demographic characteristics of participants are presented in Table 1, and this sample size is based on previous literature (Abraham et al., 2019). Mothers were compensated with a $25.00 gift card, and their children also received a small toy. The current study is approved by the university's Institutional Review Board, and treatment of participants met all APA guidelines. All data was de-identified, labeled with unique identification numbers, and secured on a server only accessible to approved research staff. Data collection occurred between August 2023 and May 2024.

2.2 Measures

2.2.1 Child's Heart Rate, MOMIA, & Maternal Interoceptive Sensibility

Measurement of children's HRs, MOMIA, and maternal sensibility is adapted from the CARed Task by Ponzo et al. (2021) and Stephenson et al. (2024). A wearable device (Shimmer) records the child's HR and attaches to their non-dominant wrist with an elastic strap. An optical pulse sensing probe is secured onto their index finger using a strip of Velcro. The Shimmer was selected due to its non-restrictive design (weighing 1.3 lbs.) and prior validation of wearable sensors in biomedical research (Keogh et al., 2021; Singstad et al., 2021; Vijayan et al., 2021; Watson et al., 2021). While the Shimmer records the child's HR, their mother holds a smartphone with an app developed in JavaScript for Bluetooth communication with the Shimmer. The User Interface of the app on the smartphone prompts the mother via vibration to answer two questions on slider scales: "Has your child's heart beat changed?" and "How confident are you in your previous answer?" (see Figure 1). Though not visible to the mother, each slider scale ranged from -100 to 100, where "No change" is 0. During the first three tasks, the mother is promoted three times. In the fourth task, the mother is prompted twice. All prompts are presented every 80 seconds. When the mother initially responds to the first question, *subjective* maternal interoception is measured; however, responses become a measurement of MOMIA once compared to their child's HR to confirm accuracy. The second question measures confidence, or maternal interoceptive sensibility, to later analyze how mothers' confidence predicts their objective ability.

2.2.2 Mother's Anxiety

Generalized anxiety in the mother is assessed with the Generalized Anxiety Disorder Scale-7 (GAD-7; Spitzer et al., 2006). The GAD-7 comprises seven items on a scale of Not At All (0) to Nearly Everyday (3), with scores ranging from minimal anxiety (0–4) to severe anxiety (greater than 15). Mothers report on the severity of their anxiety symptoms over the past two weeks.

2.2.3 Child's Emotion-Behavioral Development

Emotional and behavioral problems in the child are assessed with the Preschool Pediatric Symptom Checklist (PPSC), which is completed by the mother (Sheldrick et al., 2012). The PPSC comprises 18 items on a scale of Not At All (0) to Very Much (2), with scores ranging 0–36 and higher scores indicating poorer development.

2.2.4 Mother's Mind-Mindedness

Maternal mind-mindedness is assessed with the Five-Minute Speech Sample (FMSS), where the mother speaks about her thoughts, feeling, and relationship with her child for five uninterrupted minutes (Gottschalk & Gleser, 1969). The FMSS is a commonly used clinical method in the child development literature that allows the mother to provide an open-ended description of her child, therefore maximizing variability (Sher-Censor, 2015). The researcher first verbalized the following standardized instructions: *"I'd like to hear your thoughts and feelings about [child's name] in your own words and without my interrupting with any questions or comments. When I ask you to begin, I'd like you to speak for five minutes, telling me what kind of a person [child's name] is and how the two of you get along together. After you begin, I prefer not to answer any* *questions until after the five minutes are over. Do you have any questions before we begin?"* (Meins & Fernyhough, 2015). Interviews were recorded, transcribed using Descript, and coded by 1) one of the two primary investigators and 2) one research assistant on the number of mental (i.e., references to the child's desires and preferences, cognitions, emotions, and epistemic states) versus non-mental comments (i.e., references to the child's behaviors, physical appearance, or general comments). The other primary investigator served as a third coder and made final decisions on any discrepancies between the two original coders. The researchers utilized a self-adapted manual based on the original coding scheme created by Meins & Fernyhough (2015) to code the speeches. Speaking about one's child ranges in difficulty for mother participants, so to control for speech fluency, we counted the number of non-mental comments in addition to the number of mental comments. The ratio between the number of mental comments to the number of total comments (i.e., mental / mental + non-mental) quantified a mother's score for mind-mindedness (Hughes et al., 2017). Higher levels of mind-mindedness are associated with higher tendencies to consider the child's mental states and therefore responsive parenting. As instructed by Koo & Li (2016), interrater reliability was determined by calculating the intraclass correlation coefficient (ICC). The ICC and its 95% confidence interval were calculated using IBM SPSS Statistics for Mac, Version 29.0.0.0 based on a mean-rating (k = 2), absolute agreement, one-way random effects model. The average measure ICC was .776, indicative of good reliability between raters, with a 95% confidence interval between .604 and .873 (F(48, 49) = 4.459, p < .001).

2.2.5 Mother's Subjective Interoceptive Awareness

Subjective interoceptive awareness is assessed with the Body Perception Questionnaire-Short Form (BPQ-SF) and Multidimensional Assessment of Interoceptive Awareness-Version 2 (MAIA-2; Porges, 1993; Mehling et al., 2018). In the BPQ-SF, mothers report attention to their body's signals. The BPQ-SF comprises 46 items on a scale of Always (5) to Never (1), with scores ranging 46–230. In the MAIA-2, mothers report self-perceived interoceptive ability for various bodily processes. The MAIA-V2 comprises 37 items using the same scale, with scores ranging 0–185. The MAIA-V2 is arguably a more wholesome measure of body awareness as it is able to differentiate between body awareness due to anxiety and body awareness due to mindfulness (Mehling et al., 2012).

2.2.6 Mother's Subjective Interoceptive Accuracy

Subjective interoceptive accuracy is assessed using the Interoceptive Accuracy Scale (IAS; Murphy et al., 2019). Mothers report how well they perceive bodily sensations. The IAS comprises 21 items on a scale of Strongly Agree (5) to Strongly Disagree (1), with scores ranging 21–105.

2.2.7 Mother's Perceived Closeness

Mothers' perceived closeness to their children is assessed with the Inclusion of Others in Self Scale (IOS; Aron et al., 1992). This measure of closeness has been used to measure many different types of interpersonal relationships and is not limited to parents and their children, yet is nonetheless valid and reliable for mother-child dyads (Gächter et al., 2015). The IOS Scale includes seven images, each image being two circles ranging from completely overlapping (7) to completely separate (1). The mother selects the pair of circles she perceives to be most reflective of her connectedness to her child.

2.2.8 Parental Reflective Functioning

Mothers' reflective functioning is assessed with the Parental Reflective Functioning Questionnaire (PRFQ; Luyten et al., 2017). Mothers report their tendencies to think and understand their children's perspectives, goals, and emotions in the context of their relationship to examine mentalization. The PRFQ comprises 18 items on a scale of Strongly Disagree (1) to Strongly Agree (7), scores ranging from 18–126. A higher level of mentalization suggests a greater ability in the mother to respond appropriately to her child's needs.

2.3 Design and Procedure

Once the researchers received written consent, the study began. The Shimmer was first attached to the child's non-dominant wrist to allow the child to engage in all tasks without physical restriction. Two inches of medical tape were used to secure on top of the hand any excess lead that was between the PPG sensor on the index finger and Shimmer on the wrist. The researcher then provided the mother with further instructions as to the study's procedure. She was instructed to avoid engaging with her child during all tasks, such as during instances where her child asks her for help. However, the mother was allowed to redirect her child's attention to the task. The mother was additionally instructed to observe her child at all times and answer the questions prompted by the smartphone. After providing any clarifications, the researcher left the room while the mother and child watched a five-minute video from *Daniel Tiger's Neighborhood* to establish the child's RHR. The mother and child both remained seated while watching the video. Once the video concluded, the researcher returned to the room, and the 20-minute trial began.

During the tasks, the researcher minimally engaged with the child to avoid influencing their behavior. Only when the child began to wander from the table or attempt to engage in unrelated conversation with the researcher or mother did the researcher attempt to redirect the child to the task. In task one, the child was presented with a box of colored crayons and a selection of three coloring books. The child chose one coloring book and was instructed to draw while seated and to use only the hand without the "bracelet" (i.e., Shimmer). Second, the child was presented with the mildly frustrating task of solving a wooden puzzle designed for children 8+ years. Prior to beginning the puzzle, the researcher told the child that the puzzle is easily solved by other children their age, so they will only be given a few minutes to solve it. The child was given a verbal countdown during the task, and the researcher vocalized the remaining time every one minute (i.e., "You only have 3 minutes left," "You only have 2 minutes left," etc.). At the end of the task, the researcher reassured the child that they did very well, and that the puzzle is designed for "big kids." Third, the child played a bean bag tossing game with the researcher where the child was given several bean bags to throw onto a board. Fourth, the child was presented with a box of toys and told to choose one toy to play with. The researcher allowed the child to play with the toy freely for one minute before placing the toy in a transparent lock box. This task was intended to be frustrating, and so the child was given a set of faulty keys before being asked to retrieve the toy. The child was instructed to retrieve the toy from the box in any way that they can. If the child asked either the researcher or mother for help, the child was given standardized responses from the researcher, such as “You need to figure this out on your own,” “Mom is busy right now,” or “This is easy. You don’t need our help.” At the end of the task, the researcher informed the child that they were accidentally given the wrong keys, and the researcher helped retrieve the toy. The two frustration tasks are age-appropriate and were selected from previous literature (Snyder, 2010; Chaplin et al., 2017). After completion of the tasks, the mother completed the FMSS with the researcher and questionnaires in a separate room.

2.4 Data Analysis

To clean and analyze all data, researchers used IBM SPSS Statistics for Mac, Version 29.0.0.0. Prior to running analyses, PPG data initially captured by the Shimmer was converted to BPM using the window approach in the HeartPy framework, which runs peak detection over slices of time one minute in length; this method is recommended for noisy data collected in ecological conditions (van Gent et al., 2019a; van Gent et al., 2019b). The HR data was next processed by band-passing with a Butterworth filter to remove low/high-frequency noise, ultimately excluding biologically implausible values (i.e., > 130 or < 50 BPM). Children’s HR values were therefore calculated by averaging the 60-second window prior to the submission of each parental report.

To quantify MOMIA, we utilized a statistical method originating in the emotion literature measuring empathic accuracy, where a “perceiver” provides ratings of how they believe a “target” feels (Kral et al., 2017). Traditionally, an accuracy score is created by correlating the perceiver’s ratings with the target’s self-reported ratings of their own affect. This is a commonly used method to determine the objective accuracy of an individual’s ability to perceive the state of another person (Ickes, 2001; Klabunde et al., 2021; Zaki et al., 2009). This statistical method is also seen in the literature examining affect and stress contagion, as well as physiological synchrony in mother-infant dyads. Physiological synchrony is synonymously described as physiological covariation, where the physiology of two individuals is simultaneously measured. Positive covariation hence refers to the slopes of responses showing the same direction of change (e.g., if the child’s HR increases, the mother’s HR increases as well; Waters et al., 2014). Accordingly, we calculated a Pearson correlation for each dyad using the mother’s ratings of perceived changes in her child’s HRs and her child’s actual HRs. The resulting *r*-values served as the measure of MOMIA.

In addition to first identifying statistically significant bivariate relationships with Pearson correlations, we elected to create stepwise regression models. We determined stepwise regression to be an appropriate statistical analysis as it allows us to evaluate a large number of candidate predictors across different models. Given that no other research simultaneously examines our variables of interest, there is no prior indication as to which variables may or may not be most significantly relevant to our dependent variables, as well as how the relevance of each predictor might change as variables are included or removed. From this perspective, the current study is exploratory in that it attempts to identify which novel variables might be significantly relevant to the topic of maternal interoception. Therefore, the models produced with stepwise regression may consequently be used to develop future theory or other models. Arguably, stepwise regression is less favorable if attempting to identify the proportions of variance that are uniquely explained by each predictor when considering all independent variables at once; in this case, multiple regression would be the most appropriate. However, the current study attempts to determine the overall predictability of our dependent variables. The unique predictability of each independent variable is not of primary interest. Rather, the current study aims to identify which variables can explain the most variance in our dependent variables, as well as how the hierarchy of significance for predictors changes as other variables are considered. Indeed, the generalizability of stepwise models has been criticized as restrictive, and this should be considered when interpreting results (Menton, 2020; Smith, 2018).

Results

Results for the current study are presented in two parts. As outlined on page 21, a priori analyses are first presented, which were determined before data collection. Secondly, a posteriori analyses are presented as a follow-up to initial analyses. Despite not being pre-planned, a posteriori analyses were deemed equally important and necessary for improving understanding of the data and transparency.

3.1 A Priori Analyses

Of the 51 dyads, HR data was successfully collected from 48 children participants. Failure to collect HR data from 3 child participants was due to either operation error by the researcher or lack of cooperation from the child. Due to extreme noise, HR data for 5 of the 48 participants was unrecoverable, resulting in a final sample size of 43 for analyses involving HR. Correlations and descriptive statistics for all variables are shown in Table 2 for a priori analyses.

3.1.1 Focal Correlation Analyses

Contradictory to what we hypothesized, MOMIA did not significantly relate to any of the three subjective measures of interoception, those being the IAS ($r(41) = .188$, $p = .226$) for subjective interoceptive accuracy and the MAIA-V2 ($r(41) = .039$, $p = .803$) and BPQ-SF ($r(41) = .201$, $p = .195$) for subjective interoceptive awareness. Unlike what we expected, maternal interoceptive sensibility did not significantly relate to MOMIA ($r(41) = -.024$, $p = .878$); therefore, a subsequent simple linear regression was not performed between these two variables. Further, MOMIA unexpectedly did not significantly relate to mind-mindedness when measured by the FMSS (*r*(41) = -.138, *p* = .376); however, MOMIA did significantly relate positively to the Certainty about Mental States subscale of the PRFQ (*r*(41) = .383, *p* = .011). Perceived closeness, however, did not significantly relate to MOMIA (*r*(41) = .096, *p* = .541); due to the lack of a significant bivariate relationship, perceived closeness was excluded from subsequent regression analyses predicting MOMIA. In contrast to our hypothesis, self-reports of anxiety did not significantly relate to MOMIA (*r*(41) = -.040, *p* = .801). Additionally, children's emotional-behavioral development did not significantly relate to MOMIA (*r*(41) = -.014, *p* = .929).

3.1.2 Secondary Correlation Analyses

Although not initially hypothesized, mind-mindedness significantly related negatively to subjective interoceptive accuracy (*r*(48) = -.442, *p* = .001). Subjective interoceptive accuracy did, however, significantly relate positively to subjective interoceptive awareness as measured by the BPQ-SF (*r*(49) = .340, *p* = .015) and more specifically the Body Awareness subscale (*r*(49) = .322, *p* = .021). Further, the number of children's emotional-behavioral problems significantly related negatively to the Trusting subscale of the MAIA-V2 (*r*(49) = -.303, *p* = .031), positively to the Autonomic Reactivity subscale of the BPQ-SF (*r*(49) = .512, *p* < .000), positively to the Pre-Mentalizing Modes subscale of the PRFQ (*r*(49) = .505, *p* < .000), yet negatively to the Certainty about Mental States subscale of the PRFQ (*r*(49) = -.309, *p* = .027). Perceived closeness did significantly relate positively to the Noticing subscale (*r*(49) = .305, *p* = .030), as well as negatively to the Not-Distracting subscale (*r*(49) = -.361, *p* = .009) of the

MAIA-V2. Further, perceived closeness significantly related positively to the Certainty about Mental States subscale of the PRFQ ($r(49) = .277$, $p = .049$). Interestingly, maternal sensibility only significantly related positively to the Not-Distracting subscale of the MAIA-V2 ($r(48) = .342$, $p = .015$). Regarding the GAD-7, self-reports of mothers' anxiety significantly related negatively to the MAIA-V2 ($r(49) = -.361$, $p = .009$) and, more specifically, negatively to the Not-Worrying ($r(49) = -.590$, $p < .000$), Self-Regulation $r(49) = -.281$, $p = .046$), and Trusting ($r(49) = -.387$, $p = .005$) subscales of the MAIA-V2. Similarly, mothers' anxiety did significantly relate positively to the Autonomic Reactivity subscale of the BPQ-SF ($r(49) = .404$, $p = .003$).

The Certainty about Mental States subscale of the PRFQ did significantly relate positively to the MAIA-V2 ($r(49) = .298$, $p = .034$) and, more specifically, the Attention Regulation subscale ($r(49) = .399$, $p = .004$). Not surprisingly, the Autonomic Reactivity subscale of the BPQ-SF significantly related negatively to the Trusting subscale of the MAIA-V2 ($r(49) = -.290$, $p = .039$). Similarly, the Noticing subscale of the MAIA-V2 significantly related positively to the BPQ-SF ($r(49) = .375$, $p = .007$) and, more specifically, the Body Awareness subscale ($r(49) = .354$, $p = .011$). It was also found that mothers' number of children significantly related positively to subjective interoceptive accuracy ($r(49) = .362$, $p = .009$) and mothers' age ($r(49) = .498$, $p < .000$). Household income significantly related negatively to both the Not-Worrying subscale of the MAIA-V2 ($r(47) = -.358$, $p = .012$) and subjective interoceptive accuracy ($r(47) = -.310$, $p = .030$). For mothers' age, there was a significant negative relationship to the Interest and

Curiosity in Mental States subscale of the PRFQ ($r(49) = -.287$, $p = .041$). For children's age, there was a significant positive relationship to the BPQ-SF ($r(49) = .279$, $p = .048$), more specifically the Body Awareness subscale ($r(49) = .333$, $p = .017$).

3.1.3 Regression Analyses

For regression analyses, data was first visualized to confirm the presence of linear relationships between the variables within each model. To determine the predictability of MOMIA, we examined the link between the Certainty about Mental States subscale of the PRFQ and MOMIA[1]. The simple linear regression revealed that the Certainty about Mental States subscale of the PRFQ explained 14.7% of the variance in MOMIA ($F(1, 41) = 7.065$, $p = .011$). These findings are presented in Table 3.

Next, the most influential predictors of children's emotion-behavioral development were examined using a stepwise multiple linear regression analysis. The criteria for variable entry and removal were set at a probability of F-to-enter ≤ .050 and a probability of F-to-remove ≥ .100. In the first step, the Autonomic Reactivity subscale of the BPQ-SF was entered into the model. The Autonomic Reactivity subscale explained 26.2% of the variance in children's emotion-behavioral development, resulting in significant prediction ($F(1, 49) = 17.366$, $p < .001$). In the second step, the Pre-Mentalizing Modes subscale from the PRFQ was entered into the model. The Pre-Mentalizing subscale explained an additional 14.4% of the variance in children's emotion-behavioral

[1] The PRFQ was excluded from this model to avoid multicollinearity.

development, resulting in further significant prediction ($F(2, 48) = 16.409$, $p < .001$). In the third step, the Certainty about Mental States subscale from the PRFQ was entered into the model. The Certainty about Mental States subscale explained an additional 8.5% of the variance in children's emotion-behavioral development, resulting in further significant prediction ($F(3, 47) = 15.109$, $p < .001$).[2] The final model, which includes all three predictors, explained 49.1% of the variance in children's emotion-behavioral development. These findings are presented in Table 4.

3.2 A Posteriori Analyses

3.2.1 Task-Separated Correlation Analyses

As a follow-up to quantifying a mother's ability to accurately perceive her child's HR as a single Pearson correlation coefficient, Pearson correlation coefficients were created for each of the first three tasks. Pearson correlation coefficients were not calculated for quantifying MOMIA in the fourth and final task, however; mothers only provided two responses in the fourth task, in comparison to three responses in each of the three prior tasks, resulting in a statistical impossibility to calculate Pearson correlation coefficients for the fourth task. Table 5 presents the correlations for a posteriori analyses, which includes the task-separated Pearson correlation coefficients for the first three tasks, as well as the mothers' maternal sensibility during all four tasks (in comparison to

[2] The Trusting subscale of the MAIA-V2 was excluded from this model to avoid multicollinearity with the Autonomic Reactivity subscale of the BPQ-SF, and it was prioritized for inclusion because of its stronger correlation to the PPSC. Both the Pre-Mentalizing Modes and Certainty about Mental States subscales of the PRFQ were significantly correlated to the PPSC, yet not to one another; therefore, they were both included in this model.

the study's other variables). Descriptive statistics for the task-separated MOMIA and maternal sensibility variables are presented in Table 6.

In line with our original hypotheses, MOMIA in the first task (i.e., drawing task) significantly related positively to the Noticing subscale of the MAIA-V2 ($r(34) = .501$, $p = .002$), BPQ-SF ($r(34) = .382$, $p = .021$), more specifically the Body Awareness subscale ($r(34) = .399$, $p = .016$), and the IOS Scale ($r(34) = .503$, $p = .002$). Further, MOMIA in the third task (i.e., bean bag tossing game) significantly related positively to the number of children's emotion-behavioral problems ($r(24) = .444$, $p = .023$). Regarding confidence, maternal sensibility in the second task (i.e., puzzle task) significantly related positively to the IOS Scale ($r(48) = .318$, $p = .024$). Additionally, maternal sensibility during the fourth task (i.e., lock box task) significantly related positively to both the Noticing ($r(48) = .468$, $p < .000$) and Emotional Awareness ($r(48) = .286$, $p = .044$) subscales of the MAIA-V2.

3.2.2 Task-Separated Regression Analyses

The link between children's emotion-behavioral development and task-three MOMIA was examined. The simple linear regression revealed that task-three MOMIA explained 19.7% of the variance in children's emotion-behavioral development ($F(1, 24) = 5.895$, $p = .023$). These findings are presented in Table 7.

Next, the most influential predictors of MOMIA during the first task were examined using a stepwise multiple linear regression analysis. The criteria for variable entry and removal were set at a probability of F-to-enter ≤ .050 and a probability of F-to-remove ≥ .100.[3] In the first step, the IOS Scale was entered into the model, which explained 25.3% of the variance in task-one MOMIA, resulting in significant prediction ($F(1, 34) = 11.523$, $p = .002$). In the second step, the Noticing subscale was entered into the model, which explained an additional 11.8% of the variance in task-one MOMIA, resulting in further significant prediction ($F(2, 33) = 9.742$, $p < .001$). The final model, which includes both predictors, explained 37.1% of the variance in task-one MOMIA. These findings are presented in Table 8.

[3] The BPQ-SF and its Body Awareness subscale were excluded from this model to avoid multicollinearity with the Noticing subscale of the MAIA-V2, which was prioritized for inclusion because of its stronger correlation to MOMIA. Although the Noticing subscale was significantly correlated to the IOS Scale, we chose to include both predictors in this model, given that they are equally correlated to the dependent variable in terms of coefficient size and level of significance. Further, it is not entirely recommended to remove independent variables on the premise of near-collinearity (Gregorich et al., 2021). As instructed by Gregorich et al. (2021), we examined the variance inflation factor (VIF) between the two predictors to estimate how much variance of the regression coefficient is inflated due to multicollinearity. The VIF between the Noticing subscale and IOS Scale was 1.147, which suggests that the sufficient (though, not necessary) conditions had been met for collinearity. Dohoo et al. (1997) argues that if two independent variables possess a VIF larger than 1, collinearity is almost certain, yet not guaranteed. Multicollinearity is more likely to be present when the VIF is between 5 and 10, however (Kim, 2019). Given the VIF was > 1, we reverted to examining the tolerance value. The tolerance value, which was .872, exceeded .1, and a tolerance value lower than .1 suggests multicollinearity. As a result, we decided to retain both predictors in the model.

Discussion

The current study sought to examine how a mother's interoceptive ability, or ability to perceive *her own* physiology, relates to her ability to perceive *her child's* physiology, specifically HR. To examine this unexplored question, we utilized a novel method to capture mothers' perceptions objectively and in the moment. Various other methods attempt to measure cardiac interoception, such as the Heartbeat Counting and Detection Tasks. However, these tasks are flawed and likely invalid, presenting a need to develop measures of objective interoception (Zamariola et al., 2018; Brener & Ring, 2016; Windmann et al., 1999). Here, we introduced the term *mother's objective maternal interoceptive accuracy*, or MOMIA, to describe a mother's ability to accurately interpret changes in her child's HR, which we found was predicted by her subjective interoceptive awareness and perceived closeness to her child in contexts of low physiological arousal. Not only did the current study identify *what* predicts a mother's ability to accurately interpret her child's HR, but also *when* it is important for a mother to do so to support her child's emotion-behavioral development, such as in contexts of high physiological arousal. Although not all hypotheses were supported, the current study additionally sheds light on the interconnectedness between mothers' perceptions of their children's minds and their physiology, where a mother's certainty in her child's mental states significantly predicts MOMIA and child's emotion-behavioral development. However, it is important that maternal sensibility, or the mother's confidence in her perceptions of her child's HR, is not used to infer objective ability, as we found that the two are not significantly related.

4.1 Interpretation of A Priori Analyses

4.1.1 Correlation Analyses

The results first support our hypothesis that there is a significant and positive relationship between mothers' abilities to accurately interpret their children's cardiac states and their parental reflective functioning. Given the theoretical similarities between mind-mindedness and parental reflective functioning, we additionally hypothesized that there would be a similar relationship between MOMIA and mind-mindedness; however, this was surprisingly not found. In other words, although mind-mindedness and reflective functioning supposedly aim to measure the same construct, which is the parent's tendency to mentalize about their child's mental states, the FMSS and PRFQ's separate relationships to MOMIA were statistically and significantly different. Regardless, the lack of statistical significance between mind-mindedness and MOMIA, highlights the need to avoid reliance on self-report parent measures. We additionally expected that intraindividual scores on the FMSS and PRFQ would be consistent and significantly relate to one another positively. Ideally, the PRFQ could then be used in substitution of a more robust measure, such as the FMSS, to capture mothers' tendencies to mentalize about their children's mental states. Albeit the convenience of the PRFQ, it does not offer the same objectivity as the FMSS, which captures mothers' reflections of their children's desires and preferences, cognitions, emotions, and epistemic states in the moment. That being said, although parental reflective functioning significantly related positively to MOMIA, supporting one of our hypotheses, we encourage caution when interpreting this result, given that the PRFQ is a self-report parent measure in comparison to the FMSS.

Nevertheless, the significant relationship between MOMIA and parental reflective functioning can be further specified to the PRFQ's Certainty about Mental States subscale, which was found to be significantly related. This result supports our argument posited in the introduction, which was that mothers able to accurately interpret their children's physiology may be equally able to understand their children's emotions and vice versa. As previously described, a mother that is able to recognize her child's frustration, for example, may also understand that her child is experiencing physiological arousal and therefore needs her assistance to navigate self-regulation. The Certainty about Mental States subscale is described as specifically measuring the parent's certainty in their ability to understand their child's different mental states (e.g., "I always know what my child wants"), certainty in how accessible their child's mental states are (e.g., "I can completely read my child's mind"), as well as understanding of how they cannot possibly always understand their child's mental states (e.g., "I can sometimes misunderstand the reactions of my child). Interestingly, although mothers' certainty in their ability to interpret their children's minds was significantly related to their ability to accurately perceive their children's cardiac states, their certainty about their children's minds was not related to their confidence in interpreting their children's cardiac states. Further, a mother's confidence in interpreting her child's cardiac states, or maternal sensibility, was not significantly related to MOMIA. In other words, mothers' confidence in their abilities to understand their children's minds is distinctly different from their confidence in their abilities to understand their children's physiology. Even though mothers that are highly confident in perceiving their children's minds are significantly able to accurately interpret their children's HRs, their confidence in their abilities to perceive their children's HRs does not similarly relate significantly to their abilities to do so. This result may be due to the fact that mothers are arguably more socialized as parents to focus on their children's mental states rather than their physiology—in other words, why attempt to perceive your child's HR when you can simply ask them how they feel or what they think? As a result, mothers may not be confident that they can interpret their children's physiology, even though they may be more capable than they consciously perceive. It may be beneficial, therefore, to educate mothers on not only how to interpret their children's physiology, but also simultaneously improve their confidence in their abilities to do so as a means to strengthen their understanding of the ties between physiology and mental states. This may encourage mothers to not only consider their children's minds, but also their children's physiology, when determining their children's needs.

Although not initially hypothesized, mothers' certainty about the mental states of their children did significantly relate positively to their children's emotion-behavioral development. As previously exemplified, however, we would expect that mothers who are able to understand their children's mental states are better able to recognize their children's physical and emotional needs, allowing them to recognize when parental support is needed to foster healthy development. Of course, mothers' self-reports of certainty in their abilities to understand their children's mental states does not equate to their actual abilities, and so this result should be interpreted with caution. Contrastingly, for example, mothers' confidence in their abilities to interpret their children's HRs does not significantly relate to their actual abilities. Although we would hope that mothers' self-reports would be indicative of their children's emotion-behavioral development, there is no guarantee. If the direction of this relationship had been flipped and mothers' certainty about the mental states of their children significantly related *negatively* to their children's emotion-behavioral development, this unexpected result could have been partially explained by hypermentalization. While obtaining a high score on the Certainty about Mental States subscale is arguably preferable to a low score, since this would suggest that the parent is conscious of their child's mental states, hypermentalization (i.e., possessing inflated confidence) is maladaptive. The hypermentalizing parent may make inferences about their child's mental states in the absence of observable evidence, resulting in misled assumptions about their child's needs (Luyten et al., 2017).

Relatedly, mothers' certainty about their children's mental states significantly related positively to their subjective interoceptive awareness, more specifically the Attention Regulation subscale of the MAIA-V2. This result was not initially hypothesized yet supports the argument that mothers who report more interoceptive awareness practice more parental reflective functioning. More importantly, this result specifies that while the mother's own interoceptive awareness is relevant to her tendency to mentalize about her children's mental states, it is especially important that she knows how to *appropriately direct attention* to physiology. Healthy body awareness is not defined by unfiltered attention to all signals, but selective attention to relevant signals; however, selective attention does not include purposeful disregard towards unwanted symptoms. For example, an individual may attend to their elevated HR, yet subsequently choose to turn their attention elsewhere, ignore, or distract themselves from this signal to avoid confrontation with their cardiac discomfort. Or, an individual may struggle to control excessive attention to their body, resulting in maladaptive hyperattentive awareness and ruminative thinking about how their body will be in the future. At any single point in time, there are countless bodily signals that can be perceived, and sustaining selective focus can become difficult as numerous stimuli compete for acknowledgement. Mothers must develop an ability to not only regulate attention to their own bodies, but to that of their children—which physiological changes within her child does she need to attend to when her child is upset? Which signals should she ignore, and which should she seek out? How will her child feel in the future in specific contexts or at different times? The mother's ability to successfully navigate and regulate attention to her own body may aid her ability to understand her child's mental states and, similarly, ever-changing physiology.

Results for the Pre-Mentalizing Modes subscale of the PRFQ indirectly support our hypotheses as well. Unlike the PRFQ's other two subscales, higher scores on the Pre-Mentalizing Modes subscale indicate poorer parental reflective functioning. Parents that score highly on this subscale are less likely to consider (e.g., "Often, my child's behavior is too confusing to bother figuring out") or recognize (e.g., "The only time I'm certain my child loves me is when he or she is smiling at me") their children's mental states when attempting to understand their behavior. Rather, parents high on this subscale attribute their children's behavior to malicious intent (e.g., "When my child is fussy, he or she does that just to annoy me") and fail to recognize children as possessing independent minds with desires, emotions, and cognitions. That being said, we would expect the Pre-Mentalizing Modes subscale to significantly relate negatively to children's emotion-behavioral development, which was found. In other words, a mother's tendency to consider her child's mental states increased, emotion-behavioral issues in her child reduced.

Unexpectedly, children's emotion-behavioral issues also significantly related positively to the Autonomic Reactivity subscale of the BPQ-SF. In other words, as mothers' subjective interoceptive awareness of autonomic symptoms increased, so did their children's emotion-behavioral issues. The Autonomic Reactivity subscale prompts mothers to rate the extent to which they perceive changes in their organs innervated by the autonomic nervous system, such as, "My heart often beats irregularly," "After eating, I have digestive problems," and "When I breathe, I feel like I cannot get enough oxygen." Therefore, the

Autonomic Reactivity subscale is not an objective measure of the autonomic nervous system's adaptability, but rather the mother's conscious perceptions of changes related to her system. As a result, we would expect that higher subjective interoceptive awareness of autonomic symptoms to relate positively to children's emotion-behavioral development. One potential reason as to why this result was not found is that possessing higher body awareness is not unconditionally adaptive. The stress and interoception model proposed by Schulz & Vögele (2015), for example, argues that acute and chronic stressors are the initial points in a positive feedback loop, which ignite a range of physiological changes, such as increased production of cortisol and activity in the sympathetic nervous system. Conscious perception of these changes can result in worsening of symptoms, such as elevated HR, nausea, and so forth, resulting in more physiological and psychological stress. As a result, high awareness of autonomic symptoms in mothers may increase symptoms of anxiety and depression, which significantly relates to problematic internalizing and externalizing behaviors in their preschool children (Song et al., 2022). In support of this reasoning, we did find that mothers' scores on the Autonomic Reactivity subscale significantly related positively to their anxiety, as measured by the GAD-7.

Why possessing high body awareness is beneficial for some, yet hurtful for others, might be explained by coinciding interoceptive beliefs. A mother who views her body as unpredictable, misleading, or difficult to control will not perceive her elevated HR as a helpful indicator of what she needs. Rather, a mother with negative interoceptive beliefs and high body awareness may perceive her elevated HR as an indicator of imminent danger and develop worse anxiety (MacCormack et al., 2024). In other words, how well a mother trusts her body may influence the degree to which being aware of her body is helpful for understanding her own needs, as well as her child's needs. In support of this idea, we did find that the Trusting subscale of the MAIA-V2 significantly related negatively to both the Autonomic Reactivity subscale of the BPQ-SF and mothers' anxiety. As mothers' trust in their bodies reduced, bodily awareness of autonomic changes and symptoms of anxiety increased. Potentially, mothers who trust their body may not possess the need to be persistently perceptive of how they feel, given that they entrust their body to react appropriately; however, mothers that do not trust their body may possess heightened awareness as a means to monitor the potential presence of "dangerous" bodily signals. Again, it is important that an individual possess both positive interoceptive beliefs and healthy attention regulation. Being able to control *how* and *when* one pays attention to their body is important for maintaining adaptive interoceptive ability. For example, it is more adaptive to direct one's attention to immediate feelings within the body instead of ruminating about future self-perceptions or how one might feel in the future, as this can feed negative affect (Watkins & Moulds, 2005). Indeed, the Attention Regulation subscale of the MAIA-V2 was significantly related positively to the Trusting subscale ($r(49) = .379$, $p = .006$) and was nearly significantly related negatively to mothers' anxiety ($r(49) = -.256$, $p = .070$). Overall, this supports the idea that possessing high awareness of autonomic changes is more beneficial when the mother trusts her body; if she does not, symptoms of anxiety may worsen, restricting her ability to understand her child's needs. In further support of this argument, we did find that as mothers' trust in their bodies increased, so did their children's emotion-behavioral development. The mother who trusts her body may similarly trust her child's physiology as an accurate indicator of what her child needs.

While mothers' perceived closeness to their children was significantly related positively to their certainty about the mental states of their children, perceived closeness was surprisingly not significantly related to MOMIA. Although requiring further investigation, this result may be partially due to some extreme cases where mothers who perceive themselves as exceptionally close to (or exceptionally distant from) their children are unable to differentiate between their own needs and those of their children. Mothers' perceived closeness to their children did, however, significantly relate positively to the Noticing subscale and negatively to the Not-Distracting subscale of the MAIA-V2. We would expect that interoceptive mothers who notice their body's signals and do not avert attention away from their physiology would likewise value being perceptive of their children's physiology, ultimately nurturing their ability to accurately interpret their children's HRs. However, the current study does not support the argument that perceived closeness is significantly linked to a mother's ability to accurately interpret her child's physiology.

Returning to our discussion of the FMSS, mind-mindedness did not significantly relate to mothers' abilities to accurately interpret their children's HRs, unlike what we hypothesized. As mentioned previously, we would expect, at least, for mind-mindedness to significantly relate positively to parental reflective functioning, which it did not. Instead, mothers' mind-mindedness also significantly related *negatively* to their subjective interoceptive accuracy. This result was especially surprising, given that we would expect mothers' subjective interoceptive accuracy to relate positively to their tendencies to mentalize about their children's mental states. Why higher mind-mindedness would significantly relate to worse self-reported accuracy in perceptions of the body is puzzling and requires further investigation. Even more surprising and contradictory to one of our hypotheses, none of the subjective measures of mothers' interoception significantly related to their abilities to interpret their children's HRs. This includes both measures of subjective interoceptive awareness and subjective interoceptive accuracy. The use of subjective interoceptive measures to quantify mothers' interoceptive ability is an evident limitation, given that subjective measures are imperfect and should not be used to infer ability. That being said, if a significant relationship does exist between a mother's ability to perceive *her own* physiology and her ability to perceive *her child's* physiology, the current study may have failed to detect it due to reliance on subjective interoception measures to quantify the mother's ability to perceive *her own* physiology.

Mothers' confidence in their abilities to interpret their children's HRs, or maternal sensibility, did not relate significantly to their accuracy in doing so. As a result, self-reported confidence in one's ability to interpret others' physiology should not be used to infer actual ability. Maternal sensibility did, however, significantly relate positively to the Noticing subscale of the MAIA-V2. This result may be explained by the idea that as an individual notices their physiology more, their body becomes a more familiar place that is deemed progressively easier to understand.

Contradictory to our hypothesis, mothers' anxiety did not significantly relate negatively to their abilities to interpret their children's HRs; instead, there was no significant relationship. Although mothers' anxiety did not significantly relate to MOMIA, it did significantly relate negatively to several subjective measures of interoception, which is still in line with previous literature. More specifically, mothers' anxiety significantly related negatively to their subjective interoceptive awareness, as measured by the Not-Worrying and Self-Regulation subscales of the MAIA-V2. As previously mentioned, these significant relationships are in addition to mothers' anxiety being significantly related negatively to the Trusting subscale of the MAIA-V2, as well as positively to the Autonomic Reactivity subscale of the BPQ-SF. Mothers' anxiety increasing as their self-regulation and tendencies to not worry about physiology decreases is expected and consistent with previous literature.

One of the most insightful results obtained from a priori correlation analyses was the lack of a significant relationship between mothers' abilities to accurately interpret their children's HRs and their children's emotion-behavioral development. While emotion-behavioral development did significantly relate to subjective measures of the mothers' own interoceptive ability and parental reflective functioning, a similar result was not obtained in relation to MOMIA. This result is theoretically significant in that it suggests that a mother's ability to perceive her own physiology may not necessarily aid her ability to perceive her child's physiology, but instead encourage mindfulness of her child's mental states, which consequently supports their development. A theory such as this is best tested as a mediation model, where (X) a mother's ability to perceive her own physiology, or her own interoceptive ability, leads to her (M) practicing more parental reflective functioning, which in turn (Y) supports her child's emotion-behavioral development. This conceptual model is illustrated in Figure 3. Given the current study's sample size, there is not sufficient power to test this model, yet this would be an interesting future direction for understanding the potential mechanisms through which maternal interoception aids children's emotion-behavioral development.

4.1.2 Regression Analyses

Given the lack of significant relationships between mothers' subjective measures of interoception and their abilities to accurately interpret their children's HRs, we did not create a predictive model for these variables. However, as hypothesized, a mother's parental reflective functioning did significantly relate positively to MOMIA. We found that mothers' certainty in the mental states of their children significantly predicted their abilities to accurately interpret their children's HRs. This result is not only novel, but exciting in that it highlights the interconnectedness between a mother's tendency to think about her child's mind—their emotions, desires, and cognitions—and her ability to consciously perceive her child's physiology. Unexpectedly, a mother's parental reflective functioning served as a more significant predictor of MOMIA than simply asking her how confident she felt about her perceptions. Therefore, future research investigating the role of parental interoception in shaping child outcomes should also consider including measures of parents' mentalization of their children's mental states. Predicting a mother's ability to accurately interpret her child's HR is arguably only relevant if MOMIA significantly relates to her child's emotion-behavioral development. However, MOMIA was *not* significantly related to children's emotion-behavioral development; therefore, identifying predictors of this ability may be futile. Instead, it may be more pertinent to pinpoint predictors of mothers' reflective functioning, since this may serve as a more significant predictor of children's emotion-behavioral development.

Our stepwise regression analysis did find that parental reflective functioning is not only a significant predictor of mothers' abilities to accurately interpret their children's HRs, but also children's emotion-behavioral development, further strengthening the results found from prior simple linear regression and correlation analyses. While mothers' certainty in their children's mental states remained a significant predictor in the stepwise regression, pre-mentalizing modes additionally became a significant predictor of children's emotion-behavioral development. Therefore, the extent to which a mother lacks recognition of her child possessing an independent mind appears to also be relevant when predicting her child's emotion-behavioral development. Regardless of subscale specifics, the significance of parental reflective functioning in understanding maternal interoception and implications for child development is reinforced by regression analyses.

While mothers' abilities to accurately interpret their children's HRs was not a significant predictor of their children's emotion-behavioral development, the most significant predictor in the stepwise regression analysis was the Autonomic Reactivity subscale of the BPQ-SF. Therefore, a mother's subjective interoceptive awareness may generally not be a significant predictor of MOMIA, yet bodily awareness of her autonomic symptoms significantly predicts her child's emotion-behavioral development. Similar to the Pre-Mentalizing Modes subscale, as mothers' awareness of autonomic symptoms increases, their children's emotional-behavioral development is predicted to decrease. Consequently, there may be a use for parental interoception interventions that educate on how healthy body awareness serves as a protective factor for the mother's mental health, but also supports her ability to interpret her child's needs. While it is significant that a mother mentalizes her child's mental states to support their development, our stepwise regression analysis suggests that it may firstly be important that she prioritize maintaining healthy body awareness of her own physiology. Given that these results are correlational, further research is of course first required to determine temporal precedence.

4.2 Interpretation of A Posteriori Analyses

4.2.1 Correlation Analyses

Children's HR data obtained during the first task (i.e., drawing task) contained the least amount of movement artifacts. While all results involving HR data should be interpreted with caution because of the presence of movement artifacts, results and subsequent interpretations drawn from the first task are arguably the most reliable. As pictured in Figure 4, children were instructed in the first task to not use their non-dominant hand, which is where the Shimmer was positioned. The children were reminded by the researcher at the beginning of each new task to not move their hand with the “bracelet” (i.e., Shimmer), yet movement reduction was most successful in the first task, since they simply placed their non-dominant hand on the table.

Differences in results found between a priori and a posteriori analyses could be due to a number of factors. As previously discussed, the presence of movement artifacts can significantly alter HR calculations. However, it may also be that mothers’ abilities to accurately interpret their children’s HRs is dependent on what their children are doing. Although previous research supports that it is easier to perceive one’s own HR when it is elevated (Ring et al., 2015; Körmendi et al., 2021), perceiving others’ HRs when they’re elevated may be more difficult. When separated by task, MOMIA progressively reduced as children’s HRs increased, regardless of whether the task was intended to be frustrating (i.e., puzzle task) or fun (i.e., bean bag tossing game). It may be that mothers are better able to interpret their children’s HRs when their children are closer to their resting state, yet this conclusion cannot be confidently drawn until all HR data is visually inspected for removal of movement artifacts.

A posteriori results do support our initial hypothesis that mothers’ abilities to accurately interpret their children’s HRs significantly relates to their abilities to perceive their own physiology. However, this was only found for the first task (i.e., drawing task), and therefore this conclusion can only be applied to contexts of low physiological arousal. More specifically, mothers' subjective interoceptive awareness significantly related positively to MOMIA in the first task, as measured by the Noticing subscale of the MAIA-V2, BPQ-SF, and the Body Awareness subscale of the BPQ-SF. These results contradict a priori correlation analyses, which did not find any significant relationships between mothers' subjective measures of interoception and their abilities to accurately interpret their children's HRs. Similar to a priori analyses, however, our hypothesis that mothers' subjective interoceptive accuracy would significantly relate to their ability to accurately interpret their children's HRs was not found. While the IAS should already be used with caution when inferring the accuracy of an individual's ability to perceive their *own* physiology, the current study supports the argument that this subjective measure should similarly not be used to quantify the accuracy of an individual's perceptions of *others'* physiology. While objective interoception measures should still take precedence when measuring interoception, the lack of a significant relationship between subjective interoceptive accuracy for *self-perceptions* and MOMIA for *perceptions of others* reveals the need to create new subjective measures to estimate how well an individual believes they perceive others' physiology. For example, a questionnaire may be developed to specifically measure how well a mother believes she interprets her child's physiology. How confident one person feels in their ability to perceive another person's physiology may be dependent on the type of relationship between the perceiver and target; therefore, specific measures may also be needed for different types of dyadic relationships, such as for familial, platonic, and romantic relationships. Regardless, research attempting to quantify a person's ability to perceive others should not rely on measures intended for capturing a person's ability to perceive themselves, since these are different types of perception.

The most drastic difference between a priori and a posteriori correlation analyses is the disappearance of a significant relationship between MOMIA and parental reflective functioning. While the PRFQ and its Certainty about Mental States subscale significantly related positively to mothers' abilities to accurately interpret their children's HRs previously, this significance did not reappear in any of the task-separated analyses. However, mind-mindedness continued to not significantly relate to neither a mother's confidence nor MOMIA in follow-up analyses. Consequently, both a priori and a posteriori analyses do not support our hypotheses that mind-mindedness would be significantly relevant to a mother's ability to interpret her child's HR. Overall, the current study finds partial support of parental reflective functioning being significantly relevant to mothers' own interoceptive ability and their children's development, yet not mind-mindedness.

Follow-up analyses also found that MOMIA only significantly correlates positively to children's emotion-behavioral development in the third task (i.e., bean bag tossing game). This result is similar to, yet not entirely supportive of, prior analyses, which found no significant relationships between MOMIA and the child's emotion-behavioral development. Therefore, both a priori and a posteriori analyses mostly fail to support our hypothesis that mothers' abilities to accurately interpret their children's HRs is significant for their children's emotion-behavioral development. Similarly, both a priori and a posteriori analyses fail to support our hypothesis that a mother's anxiety is significantly related negatively to MOMIA, which requires further investigation. Given that mothers' anxiety significantly relates to measures of their own interoceptive ability (e.g., negatively to the Noticing subscale and positively to the Not-Distracting subscale of the MAIA-V2), we would expect that mothers' abilities to accurately interpret their children's HRs similarly relate significantly and negatively to their anxiety. However, no significant relationship was found. If the ability to perceive one's own physiology is distinct from the ability to perceive others' physiology, it may be that anxiety significantly affects the mother's ability to perceive herself, yet uniquely not her ability to perceive her child. Again, future research is needed to further understand how anxiety differently relates to a mother's ability to perceive herself versus her child.

The other most significant contrast between pre-planned and follow-up results is the emergence of a significant, positive relationship between MOMIA and perceived closeness to her children in the first task. Interestingly, mothers' perceived closeness also significantly related positively to their confidence during the second task (i.e., puzzle task), yet not their accuracy during the second task. As previously theorized, it may be that mothers who are especially close to (or distant from) their children are unable to differentiate between their own physiology and that of their children, resulting in reduced accuracy. Similar to a priori analyses, maternal sensibility in the fourth task did significantly relate positively to mothers' subjective interoceptive awareness, specifically the

Noticing subscale of the MAIA-V2. Unlike a priori analyses, however, maternal sensibility was additionally significantly related positively to the Emotional Awareness subscale of the MAIA-V2 in the fourth task (in addition to perceived closeness in the second task, as previously mentioned).

Given that the purpose of the fourth task was to cause frustration in the children, it is understandable that mothers' confidence in their perceptions during this task is significantly related to their knowledge of the causality between emotional and physiological arousal. Mothers who report possessing high emotional awareness (i.e., "I notice how my body changes when I'm angry") are aware that changes in emotion cause changes in physiology (and vice versa) and therefore may retain their confidence in perceiving physiology that coincides with frustration. Conversely, mothers who report low emotional awareness may become more confused, rather than confident, when attempting to make sense of the cardiac changes occurring in their children as they experience intense negative affect. Therefore, mothers' confidence in their abilities to accurately perceive their children's HRs may be a significant consequence of their prior education on the interconnectedness between emotion and the body. Overall, correlation results obtained from follow-up analyses are mixed and do not entirely agree nor disagree with a priori analyses. Given the current study's limitations (which are later discussed), results should be interpreted cautiously, and future research is necessary to provide greater clarification.

4.2.2 Regression Analyses

While the child's emotion-behavioral development did not significantly relate to MOMIA in a priori analyses, there was a significant predictive relationship between a mother's ability to accurately interpret her child's HRs during the third task (i.e., bean bag tossing game) and her child's emotion-behavioral development. MOMIA progressively reduced from task one to task three, and as mother's accuracy reduced, children's emotion-behavioral problems increased (see Table 6). It was in the third task, however, that MOMIA significantly predicted children's emotion-behavioral development. This result supports our initial hypothesis that mothers' abilities to accurately interpret their children's HRs is significant for understanding their needs and consequently supporting their development. This result is consistent with our previously made reasoning that mothers' abilities to accurately interpret their children's HRs might become increasingly difficult as their children's HRs increase, given that the tasks' intensities gradually increased. Further, this result exemplifies the importance of performing task-separated analyses, given that the presence of a significant relationship involving one specific task can become obscured when MOMIA is averaged across all tasks.

Mothers' abilities to accurately interpret their children's HRs may significantly predict their children's emotion-behavioral development, though this may only be applicable to specific contexts. For example, it may be that there are more significant consequences for the child's emotion-behavioral development when their mother is unable to accurately interpret her child's physiology in contexts of *high arousal*, such as the bean bag tossing game. However, as found in a posteriori correlation analyses, mothers' abilities to accurately interpret their children's' HRs was only significantly related to mothers' own interoceptive ability in contexts of *low arousal* (i.e., drawing task). Therefore, the extent to which a mother's ability to perceive her own physiology helps her perceive her child's physiology, consequently aiding their development, may be limited to specific levels of the child's arousal. Regardless, results from the follow-up simple linear regression support our initial hypothesis that mothers' abilities to accurately interpret their children's physiology may significantly aid their children's emotion-behavioral development. However, again, the extent to which MOMIA supports children's emotion-behavioral development may depend on the level of the child's arousal when they are being perceived by their mother.

Lastly, we performed a follow-up stepwise regression analysis to predict mothers' abilities to accurately interpret their children's HRs during the drawing task. Results found that both mothers' perceived closeness and subjective interoceptive awareness (specifically the tendency to notice bodily sensations) significantly predicts their ability to accurately interpret their children's HRs during the drawing task. Although this result was not achieved with a priori analyses, it does support our initial hypotheses that perceived closeness, as well as the mother's ability to perceive her own physiology, can significantly predict her ability to perceive her child's physiology. Unlike our original hypotheses, however, this result is only applicable to the drawing task. Similar to our previous argument, it may be that mothers' abilities to perceive their own physiology may only significantly relate to their abilities to accurately interpret their children's physiology in specific contexts of low arousal. Additionally, the closeness a mother feels towards her child may become less relevant to helping her interpret how her child feels as her child's HR increases. One potential reason for this may be that a mother who perceives herself as close to her child, yet is experiencing low arousal while her child is in a state of high arousal, may not differentiate between how she feels versus her child; as a result, the mother might underestimate her child's HR. This theoretical relationship may also be possible inversely, where a mother who perceives herself as close to her child, yet is experiencing high arousal while her child is in a state of low arousal, might overestimate her child's HR. Future research is needed to understand the complexities of these significant predictors.

4.3 Limitations

The greatest limitation of the current study that must be emphasized is the presence of movement artifacts in the children's HR data. Visual inspection of the HR data revealed segments of movement artifacts affecting HR calculations, particularly during episodes involving significant hand movement (i.e., lock box task). Thus, follow-up analyses must be conducted that exclude segments with visible movement artifacts as a robustness check. The researchers, as a result, encourage caution when interpreting the preceding results. By conducting follow-up analyses that separate MOMIA by each task, greater reliability is achieved, given that there are less movement artifacts during the first three tasks (see Figure 2). This study introduces the first-ever use of the Shimmer and its optical pulse-sensing probe in child research; as a result, the researchers were unaware of the extent to which the HR data would contain noise or movement artifacts. This presented itself as the greatest limitation, resulting in significant loss of HR data. Moving forward, the researchers do not recommend use of PPG sensors on the hand for child research, ages 3–5, despite its other benefits. Relatedly, how children's HRs were calculated might also pose as a limitation as well. Given that each HR value was calculated by averaging the 60 seconds of preceding HR data, momentary changes in the child's HR might be reported by the mother yet diffused when averaged across this 60-second window. For example, the child might maintain their resting state for the majority of a task, yet experience HR elevation just moments before their mother submits her response; the mother may report this change in her child's HR, yet this concentrated change would become diluted when averaged over 60 seconds. As a result, the mother's accuracy would appear worse than it is. Moving forward, it may be beneficial to calculate the children's HRs using shorter windows to achieve HR calculations that are more sensitive to sudden changes in physiology.

Another limitation of the current study is its sample size, which reduces statistical power and the ability to detect potentially small effect sizes. The researchers originally aimed for an $n = 60$ for the current study, yet this became unattainable due to various external restrictions (e.g., time for recruitment and funding). The researchers' abilities to cover participants' transportation costs to the lab was also restricted. Consequently, our sample may have excluded participants of lower income, limiting the generalizability of our results and statistical power. Unexpected loss of HR data further reduced statistical power for those analyses involving children's HR data, resulting in a sample size as low as 26 for some analyses. Further, the researchers' original intention to examine how perceived closeness and/or mind-mindedness might moderate the relationship between the mother's ability to perceive her physiology and her ability to perceive her child's physiology became unattainable due to the study's current sample size. Before attempting to test these moderation analyses, a larger sample would need to first be acquired.

Additionally, the wording of the instructions given to the mother participants may have introduced potential measurement error. Prior to beginning the study, the mothers are told to report if their child's heartbeat has "changed," which does not specify the point from which the child's HR has changed (i.e., change from RHR versus change from the previous task). As a result, mothers may have been interpreting the word "changed" differently and therefore reporting perceptions of change from a different baseline. However, no mothers submitted a response below the point of "No change" on the smartphone, indicative of a general understanding of the intended instructions (i.e., changed from RHR). In other words, if mothers were interpreting "changed" as from the prior task, we would expect some responses to be submitted below the point of "No change." For example, a child who is well-regulated during the lock box task (i.e., fourth task) might experience HR reduction after the bean bag tossing game (i.e., third task).

4.4 Moving Forward

Improving mothers' abilities to understand their children's physiology and therefore support their emotional needs does not render benefits exclusive to the children. Previous research supports that additional strain can be placed on those that attempt to improve the regulatory capabilities of others; however, helping others regulate their emotions can also improve the affective wellbeing of those engaged in affect-improving extrinsic interpersonal emotion regulation (EIER; Jurkiewicz & Oveis, 2023). EIER can consequently serve as a protective factor against physiological stress by activating the assistant's own emotion regulation, fostering more healthful interactions with others. Improving mother's abilities to understand their children's physiology may be helpful in improving their understanding of the affective states that correspond to the children's physiology. Mothers perceptive to an elevated HR during a frustrating task may engage in more EIER with their children, which not only encourages the child to properly cope, but also improves the mother's own affect and reduces their stress. These improvements in the mother may be due to a heightened self-perception of being a good parent, for example, that accompanies being able to support one's child in times of need. Moving forward, it would be interesting to examine how maternal interoception relates to mothers' affect and physiology before and after engaging in EIER with their child.

Another relevant future direction is to consider the relationship between interoceptive ability and physiological synchrony in dyads. The current study only measured the child's HR, yet it would be interesting to simultaneously measure the mother's HR to examine if those mothers that are better able to perceive their child's HR experience similar physiological change. For example, mothers better able to accurately perceive elevations in their child's HR during frustration tasks may be partially attributable to similar elevations in their own HR; these cues internal to the mother may provide insight into the physiological state of her child. Whether the presence of physiological synchrony is only beneficial if the mother is interoceptive to her own body, however, is something to consider. If mothers' physiologies do change in tune to the physiology of their children, educating mothers on aiming their awareness to their own body may be just as helpful in understanding their children's physiology. Previous research does support that physiological reactivity is dynamic and that mothers' physiology can influence their children's physiology, where mothers exposed to a stressful task experience heightened physiological arousal that becomes mirrored in their infants (Waters et al., 2014). This "mirroring mechanism" is often described in terms of how observing others creates similar neural changes in the observer, and it may be that mothers "mirror" their own physiology or emotions unto their children (Arslanova et al., 2022). However, low-arousal positive states appear to be equally as contagious for infants as high-arousal negative states when interacting with their mother (Waters et al., 2017). Whether the children's physiology is equally contagious to the mother, and affects her ability to understand her child, would be interesting to explore.

This relationship between physiological synchrony and a mother's ability to accurately perceive their child's physiology may further be moderated by the mother's empathy, where mothers able to internalize their child's experience may be better able to understand their child's bodily changes. The topic of empathy's ties to physiological change in dyadic relationships has not been examined in the context of interoception, yet it is not necessarily new (Levenson & Ruef, 1992). Physiological reactivity is dynamic, and as we associate with those around us, can become interdependent on the variable states of others (Palumbo et al., 2017). To what extent physiological synchrony is a result of affect contagion or arousal contagion is not entirely understood, and question remains if "more contagious" emotions are those accompanied by greater physiological reactivity (Herrando & Constantinides, 2021; Tschacher et al., 2014). This thinking is in line with interoception literature that finds that the accuracy of HR perceptions increase as HR does. The question of how influential our separate sensory systems are for understanding others, and how they vary across different social relationships, remains.

New research is now examining how the vagus nerve, which assists self-regulation and enables empathetic responding, may support social sensitivity when dyads experience vagal linkage. Indeed, individuals' vagal synchrony during positive conversations predicts their affect sharing, as well as empathetic accuracy (i.e., how well the empathizer is able to identify the expressor's emotions; Jurkiewicz et al., 2024). Even individuals who've just met can achieve physiological synchrony, revealing that perceived closeness may not completely restrict ability to comprehend the state of others; in other words, mothers may not need to see themselves as close to their child in order to accurately understand their emotions. The ability to model the emotions of another individual, or expressor, is distinctly tied to the parasympathetic system, and experiencing positive empathy may heighten a mother's ability to perceive her child's HR. Other research examining team physiological synchrony finds that as triadic interactions continue, synchrony in members' HR predicts the group's cohesion. Further, if some individuals are not interpersonally regulating, a group's ability to perform well is restricted (Erez & Gordon, 2024). These results suggest that cardiac synchrony across individuals that are able to regulate their emotions supports productive coping and consequently task performance. It may be that HR synchrony between mothers and their children may support the mothers' abilities to not only understand the physiology of their children, but communicate relevant regulatory skills to improve the relationship between them. Interoception-based interventions, for example, might encourage the parent to consider the similarities or differences between their physiology and their child's to improve their connectedness.

Another future direction is to prompt mothers in the moment, at the time of reporting perceptions of their children's HR, their perceptions of their children's affective state. A mother may recognize their child's HR is elevated, for example, yet fail to properly identify the underlying cause of physiological arousal. The mother may misattribute an elevated HR during the puzzle task to excitement or curiosity rather than frustration, consequently hindering her ability to support her child's emotion regulation. This may be all the more relevant in the case of discerning which negative emotions the children are experiencing (ex. is the child frustrated or sad, disappointed or embarrassed, etc.), given parents' abilities to recognize, but also cope, with their children's negative emotions is especially influential in successful emotion socialization and offering supportive strategies to improve their children's regulation (Buck, 1984; Eisenberg et al., 2010). Comparing mothers' emotion perceptions of their children's emotions to an objective measure of the children's emotions can provide insight into whether mothers' abilities to accurately perceive fluctuations in HR do indeed coincide with accurate interpretations of their children's emotions. The researchers did video record all parent-child interactions in the current study; although the mothers did not report their perceptions of their children's emotions in-task, it would nevertheless be interesting to follow-up current analyses with a global code of the children's emotion regulation during the two frustration tasks. This would provide a more objective measure of the children's emotional-behavioral development than the subjective measure utilized (i.e., PPSC), as well as highlight potential discrepancies between the parents' self-reports and their children's in-task regulation.

4.5 Conclusion

Figure 5 provides an excellent example of the phenomenon we sought to identify in the current study—dyadic synchrony between changes in the child's HR and their mother's perceived changes in their child's HR. Not only is the mother able to perceive the magnitude of change in her child's HR, but the direction of cardiac change as well. Arguably, the current study successfully provides novel direction for understanding this type of synchrony; however, it sparks many novel uncertainties as well. The results achieved from a priori and follow-up analyses are not entirely consistent, yet the current study does suggest that a mother's ability to perceive her own physiology does relate to her ability to perceive her child's, which can be utilized to predict her child's emotion-behavioral development.

Interoception changes during motherhood, and the present study suggests that a mother's ability to interpret her own physiology relates to her mentalization of her child's mental states, which may in turn be a unique tool for supporting her child's development. Further, the following study is consistent with the current literature, which found that dysregulated interoception is significantly related to heightened stress, highlighting the relationship between interoception and emotion in the mother which may influence her ability to support her child's needs (Schulz et al., 2015). However, research on interoception across the lifespan and how it changes during motherhood is growing yet incomplete. More research is needed to develop interventions that improve maternal interoception as a tool for supporting children's emotion-behavioral development, and this study begins to build a foundational understanding of how mothers' perceptions of their children's physiology ties to their abilities to perceive themselves.

Table 1

Demographic Characteristics of Participants

	Full sample (n=51) *n (%)*
Parent Characteristics	
Gender	
Female	50 (98.03)
Nonbinary	1 (0.01)
Age, mean (SD)	35 (4.21)
Race	
Asian	3 (5.90)
Hispanic	2 (3.90)
Middle Eastern	1 (2.00)
Mixed/Biracial	4 (7.80)
Pacific Islander	1 (2.00)
White	40 (78.40)
Household Income, median (SD)	$100,000 ($76,525)
Education	
High school diploma or GED	1 (2.00)
Some college (no degree)	3 (5.90)
Associate’s degree	4 (7.80)
Bachelor’s degree	21 (41.20)
Master’s degree	17 (33.30)
Doctoral or professional degree	4 (7.80)
Missing Response	1 (2.00)
Child Characteristics	
Gender	
Female	27 (52.90)
Male	24 (47.10)
Age, mean (SD)	48.80 mos. (10.41)
Race	
Asian	2 (3.90)
Mixed/Biracial	12 (23.5)
White	36 (70.6)
Missing Response	1 (2.00)

Note. This table demonstrates the demographic information for the 51 mothers and children included in the current study. SD = standard deviation; mos. = months.

Table 2

Pearson Correlations and Descriptive Statistics of All Study Variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	*n*	*M*	*SD*
1. MAIA-V2	—																										51	106.58	17.35
2. MAIA-V2, Noticing	.567***	—																									51	3.58	.71
3. MAIA-V2, Not-Distracting	.177	-.178	—																								51	2.02	.90
4. MAIA-V2, Not-Worrying	.304*	-.068	-.004	—																							51	2.45	1.00
5. MAIA-V2, Attention Regulation	.795***	.434**	-.144	.285*	—																						51	2.68	.942
6. MAIA-V2, Emotional Awareness	.593***	.593***	-.078	-.156	.381**	—																					51	3.69	.89
7. MAIA-V2, Self-Regulation	.684***	.360**	-.140	.210	.568***	.423**	—																				51	2.91	.924
8. MAIA-V2, Body Listening	.526***	.328*	-.069	-.042	.352*	.334*	.294*	—																			51	2.55	.95
9. MAIA-V2, Trusting	.552***	.063	.091	.247	.379**	.034	.298*	.339*	—																		51	3.41	1.06
10. BPQ-SF	.126	.375**	-.052	-.257	.206	.197	.096	.156	-.127	—																	51	98.13	25.27
11. BPQ-SF, Body Awareness	.136	.354*	-.032	-.223	.193	.158	.087	.137	-.029	.939***	—																51	68.54	21.60
12. BPQ-SF, Autonomic Reactivity	.029	.204	-.071	-.188	.118	.176	.062	.110	-.290*	.557***	.237	—															51	29.58	8.94
13. IAS	.026	-.037	.077	-.154	.070	.093	-.031	-.016	-.009	.340*	.322*	.182	—														51	42.00	11.97
14. FMSS	.012	-.044	-.123	.171	.070	.002	.000	.052	.000	-.190	-.196	-.062	-.442**	—													50	.51	.10
15. PRFQ, Pre-Mentalizing Modes	-.004	.177	-.073	-.094	.036	.067	-.164	.113	-.115	.140	.051	.273	-.017	.058	—												51	1.62	.52
16. PRFQ, Certainty about Mental States	.298*	.228	-.249	.041	.399**	.164	.215	.195	.140	.059	.053	.038	.013	.094	-.089	—											51	4.14	1.12
17. PRFQ, Interest & Curiosity in Mental States	.062	.010	.131	.126	-.168	.208	.038	.131	-.097	-.201	-.228	-.018	-.016	-.022	.000	.126	—										51	6.02	.77
18. PPSC	-.151	.004	-.119	-.101	-.081	.094	-.210	.176	-.303*	.240	.069	.512***	.177	-.077	.505***	-.309*	-.003	—									51	7.74	4.64
19. IOS Scale	-.014	.305*	-.361**	-.172	.083	.093	-.018	.042	.145	.079	.167	-.179	-.013	-.038	.093	.277*	-.172	-.210	—								51	4.92	1.29
20. GAD-7 Scale	-.361**	.073	-.193	-.590***	-.256	.161	-.281*	.037	-.387**	.222	.093	.404**	.165	.051	.020	.046	.091	.263	.113	—							51	7.82	4.39
21. MOMIA [a]	.039	.033	-.127	.073	.098	.287	-.004	-.165	-.136	.201	.216	.030	.188	-.138	-.141	.383*	.209	-.014	.096	-.040	—						43	-.21	.41
22. Maternal Interoceptive Sensibility [b]	.152	.342*	-.007	-.261	-.010	.219	.171	.191	.026	.045	.074	-.051	-.033	-.118	.089	-.201	.003	-.066	.170	-.032	-.024	—					50	66.40	8.77
23. Number of Children	.133	-.068	.007	.008	.154	.108	.120	.073	.145	.148	.186	-.030	.362**	.096	-.151	.060	-.220	-.068	-.037	-.044	.149	-.080	—				51	2.33	1.12
24. Household Income (thousand)	-.137	-.099	.058	-.358*	-.107	-.085	-.103	.018	-.007	-.002	.002	-.012	-.310*	.126	-.112	-.016	-.114	-.269	-.039	.221	-.225	.234	-.147	—			49	125.44	76.52
25. Mother's Age (years)	.021	.025	-.058	.018	.145	-.039	.004	-.052	.043	.184	.224	-.012	.211	-.065	-.165	.003	-.287*	-.086	.121	.050	-.005	.051	.498***	.148	—		51	35.00	4.21
26. Child's Age (months)	.030	.091	.074	-.060	.058	.042	.137	-.260	.044	.279*	.333*	-.017	.135	-.040	.074	-.215	-.164	.127	.020	.013	.225	.037	.316*	-.224	.160	—	51	48.80	10.41

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

[a] MOMIA was first quantified for each mother by creating a Pearson correlation between her responses to the first question (i.e., "Has your child's heartbeat changed?") and her child's HRs at the time of parental reports.

[b] All 11 confidence ratings in response to the second question (i.e., "How confident are you in your previous answer?") were first averaged for each mother.

Table 3

Predicting MOMIA from the Certainty about Mental States Subscale

Variable	B	β	*SE*	*t*	95% CI		*p*
					LL	*UP*	
MOMIA	-.801		.229	-3.506	-1.263	-.340	.001
Certainty about Mental States Subscale (PRFQ)	.138	.383	.052	2.658	.033	.244	.011

Note. R^2 = 14.7%, Adjusted R^2 = 12.6%. CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

Table 4

Stepwise Multiple Linear Regression Results for Predicting Children's Emotion-Behavioral Development

Model	R^2	Adjusted R^2	Model *p*	Predictors	B	β	*SE*	*t*	*p*
1	.262	.247	< .001	Autonomic Reactivity Subscale (BPQ-SF)	.265	.512	.064	4.167	< .001
2	.406	.381	< .001	Autonomic Reactivity Subscale (BPQ-SF)	.210	.404	.060	3.493	.001
				Pre-Mentalizing Modes Subscale (PRFQ)	3.468	.395	1.015	3.416	.001
3	.491	.458	< .001	Autonomic Reactivity Subscale (BPQ-SF)	.220	.424	.056	3.907	< .001
				Pre-Mentalizing Modes Subscale (PRFQ)	3.193	.364	.955	3.343	.002
				Certainty about Mental States Subscale (PRFQ)	-1.204	-.293	.430	-2.799	.007

Note. Children's emotion-behavioral development, the dependent variable, is quantified using the PPSC.

Table 5
Pearson Correlations for Task-Separated Objective Maternal Interoceptive Accuracy & Maternal Sensibility

Variable	T1 Acc.	T2 Acc.	T3 Acc.	T1 Sens.	T2 Sens.	T3 Sens.	T4 Sens.
1. MAIA-V2	.082	-.163	.102	.107	.027	.139	.158
2. MAIA-V2, Noticing	.501**	.005	.164	.043	.200	.277	.468***
3. MAIA-V2, Not-Distracting	-.147	-.201	-.294	.171	-.241	.120	-.091
4. MAIA-V2, Not-Worrying	-.105	-.211	-.371	-.164	-.166	-.176	-.216
5. MAIA-V2, Attention Regulation	.066	-.005	.258	-.032	.020	-.040	.058
6. MAIA-V2, Emotional Awareness	.251	.036	.241	.017	.202	.122	.286*
7. MAIA-V2, Self-Regulation	.107	-.218	.302	.018	.243	.103	.072
8. MAIA-V2, Body Listening	-.083	-.191	.132	.245	.013	.103	.141
9. MAIA-V2, Trusting	-.060	-.119	-.041	.025	-.047	.065	.029
10. BPQ-SF	.382*	.191	.216	.017	.106	-.123	.218
11. BPQ-SF, Body Awareness	.399*	.120	.141	-.024	.189	-.110	.233
12. BPQ-SF, Autonomic Reactivity	.125	.218	.241	.106	-.157	-.082	.053
13. IAS	-.118	.247	.339	.055	.049	-.262	.161
14. FMSS	-.059	-.126	-.314	-.118	.024	-.109	-.137
15. PRFQ, Pre-Mentalizing Modes	.054	.283	.299	.114	-.008	.037	.124
16. PRFQ, Certainty about Mental States	.094	.123	-.092	-.039	-.111	-.267	-.085
17. PRFQ, Interest & Curiosity in Mental States	-.129	-.164	-.075	.008	.016	-.044	.025
18. PPSC	.041	.157	.444*	.061	-.100	-.138	.056
19. IOS Scale	.503**	.099	-.049	-.041	.318*	.010	.197
20. GAD-7 Scale	.121	.272	.176	-.029	.085	-.158	.061
21. MOMIA [a]	.298	.203	.184	.114	.085	-.253	.071
22. Maternal Interoceptive Sensibility [b]	.083	.085	.185	.595***	.685***	.747***	.640***
23. Number of Children	-.248	.070	-.078	.000	.005	-.104	-.143
24. Household Income (thousand)	-.069	.034	-.228	.169	.198	.204	.029
25. Mother's Age (years)	.171	.234	-.100	-.099	.263	-.030	-.025
26. Child's Age (months)	.227	-.139	.110	-.177	.196	-.016	.116

Note. Instead of presenting objective maternal interoceptive accuracy as a single score, the following table presents mothers' performance and confidence during each of the four tasks. T = task; Acc. = objective maternal interoceptive accuracy; Sens. = maternal sensibility.

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

[a] MOMIA was first quantified for each mother by creating a Pearson correlation between her responses to the first question (i.e., "Has your child's heartbeat changed?") and her child's HRs at the time of parental reports.

[b] All 11 confidence ratings in response to the second question (i.e., "How confident are you in your previous answer?") were first averaged for each mother.

Table 6

Descriptive Statistics for Task-Separated MOMIA & Maternal Sensibility

Variable	*n*	*M*	*SD*
Task 1 Accuracy	36	.039	.782
Task 2 Accuracy	40	.028	.730
Task 3 Accuracy	26	.011	.722
Task 1 Sensibility	50	54.35	11.85
Task 2 Sensibility	50	70.05	13.18
Task 3 Sensibility	50	69.75	14.47
Task 4 Sensibility	50	74.01	12.60

Note. This table demonstrates the descriptive statistics for the task-separated objective maternal interoceptive accuracy and maternal sensibility variables created for a posteriori analyses. MOMIA is quantified by creating a correlation between the mother's perceptions of her child's HR and her child's HR at the time of response (see Data Analysis under Method). As a result, the means in the current table for Task 1–3 Accuracy should be interpreted as Pearson coefficients. SD = standard deviation.

Table 7

Predicting Children's Emotion-Behavioral Development from Task-Three MOMIA

Variable	B	β	*SE*	*t*	95% CI		*p*
					LL	*UP*	
Children's Emotion-Behavioral Development (PPSC)	7.465		.925	8.073	5.556	9.374	.001
Task Three Objective Maternal Interoceptive Accuracy	3.167	.444	1.305	2.428	.475	5.860	.023

Note. R^2 = 19.7%, Adjusted R^2 = 16.4%. CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

Table 8

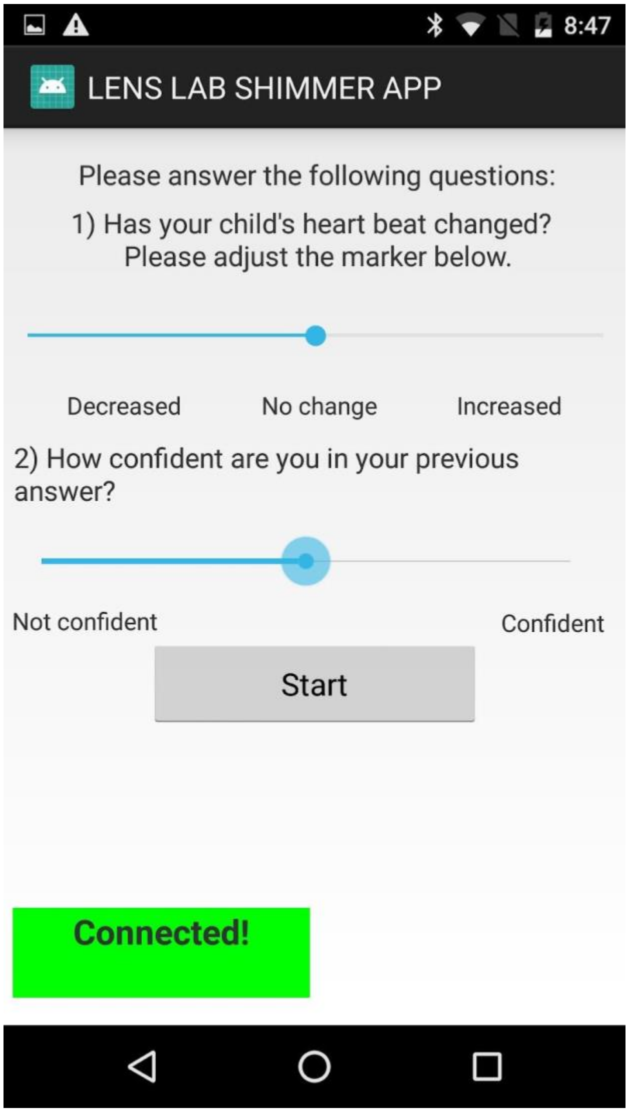
Stepwise Multiple Linear Regression Results for Predicting Task-One MOMIA

Model	R^2	Adjusted R^2	Model *p*	Predictors	B	β	*SE*	*t*	*p*
1	.253	.231	.002	IOS Scale	.277	.503	.082	3.395	.002
2	.371	.333	< .001	IOS Scale	.204	.372	.081	2.514	.017
				Noticing Subscale (MAIA-V2)	.405	.368	.163	2.490	.018

Note. For model 2, VIF = 1.147 and Tolerance = .872.

Figure 1

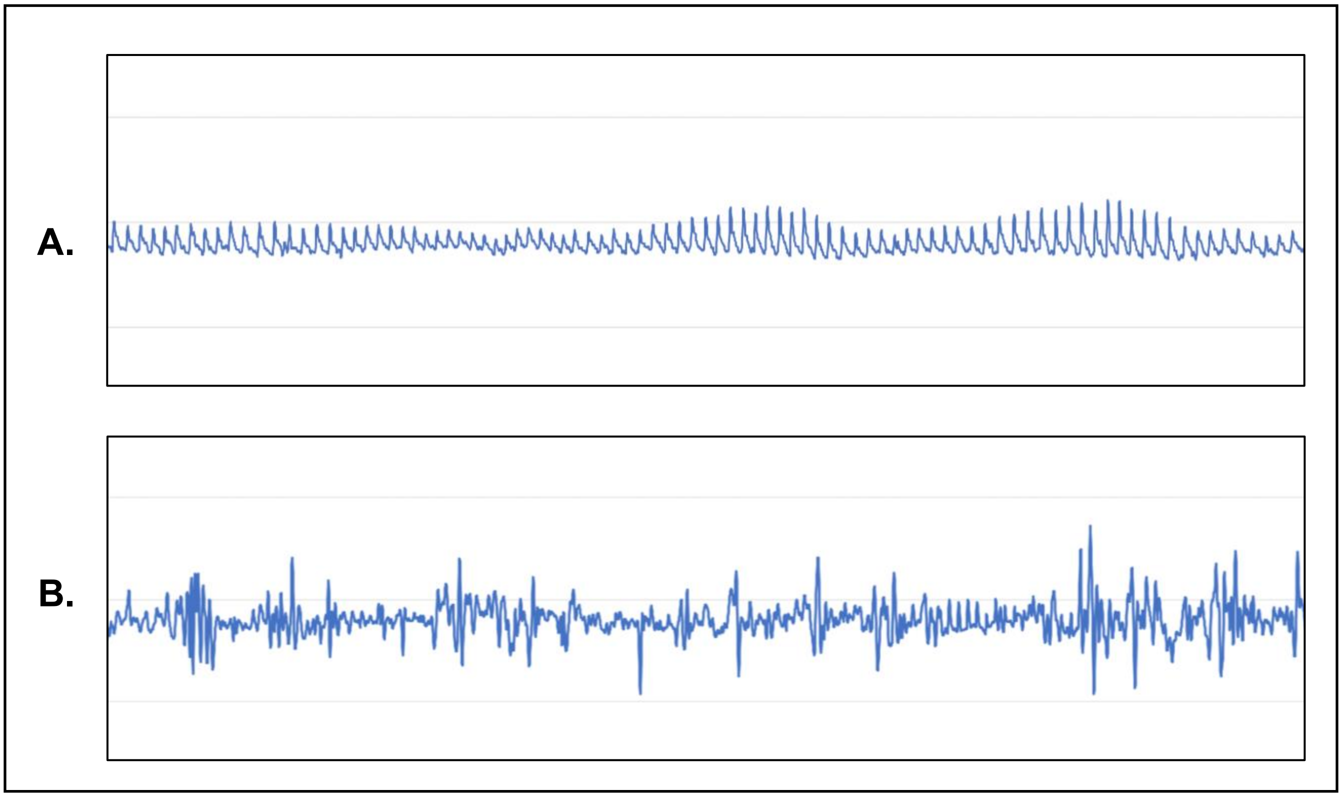
User Interface Presented to the Mother



Note: This figure shows how the questions were presented to the mother on the smartphone while her child engaged in the four tasks with the researcher.

Figure 2

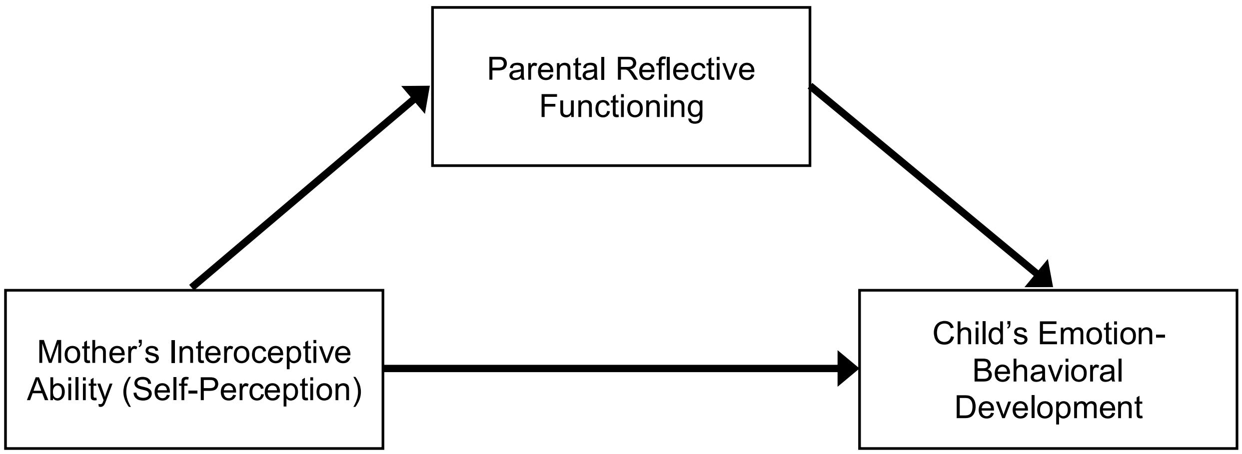
Greatest Limitation: The Presence of Movement Artifacts in Children's HR Data



Note. The preceding figure provides an example of the presence and absence of movement artifacts during different tasks for the same child. Both part **A.** and part **B.** present one-minute of HR data that was recorded prior to the submission of the mother's responses. Part **A.** shows the HR data before the mother's first response during task one (i.e., drawing task). Part **B.** shows the HR data before the mother's eleventh response during task four (i.e., lock box task). HR data was visualized using Microsoft Excel for Mac, Version 16.29.

Figure 3

Conceptual Model: Parental Reflective Functioning as a Mediator



Note. A mother's ability to perceive her own physiology, or her own interoceptive ability, may lead her to practice more parental reflective functioning. In turn, increased mentalization of her child's needs may improve her child's emotion-behavioral development.

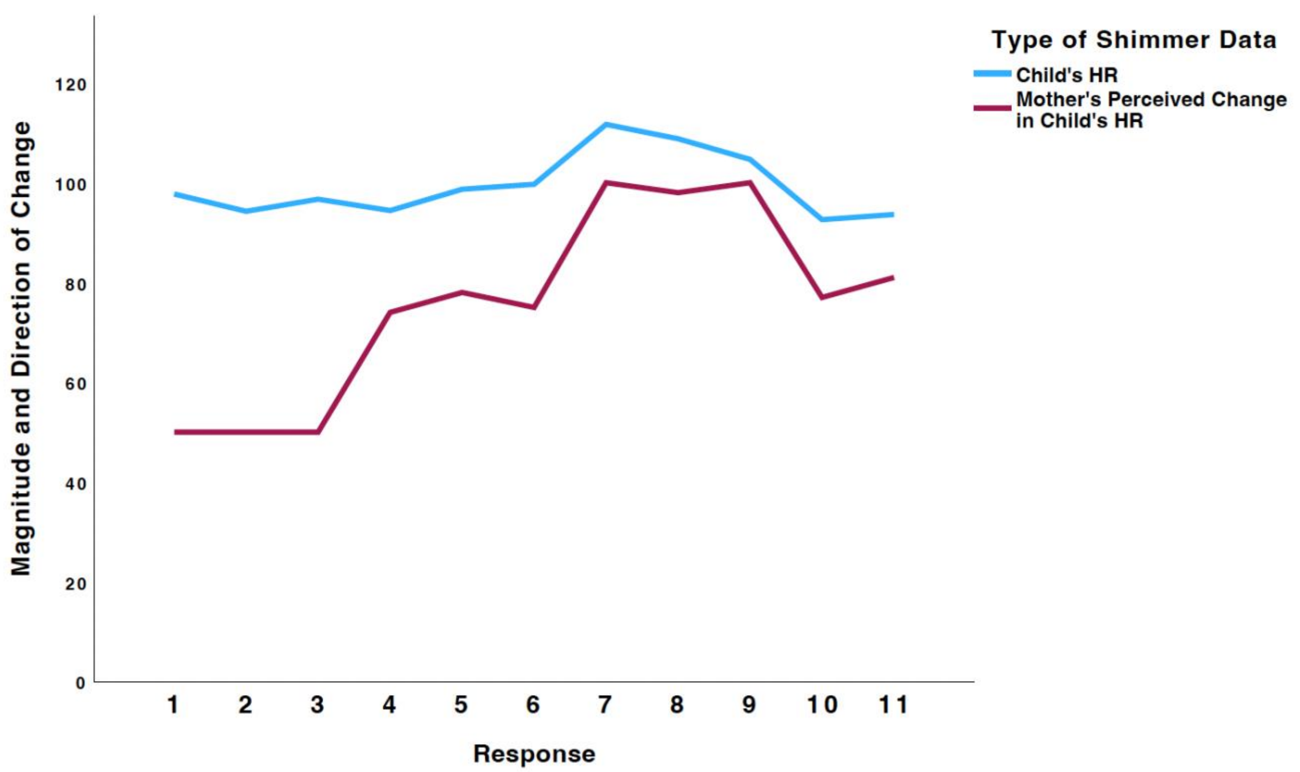
Figure 4

Child's Position During the First Drawing Task

Note: Movement artifacts were least present in HR data collected during the first task (i.e., the drawing task). Children were mostly immobile during this task, as they were instructed to sit at the table and draw using the hand without the "bracelet" (i.e., Shimmer). Disclaimer: The mother provided consent to use the above picture.

Figure 5

Dyad M027: Synchrony Between Mother's Perceived Changes in Child's HR and Child's HR



Note. The preceding graph from dyad M027 provides an excellent example of synchrony between changes in the child's HR and the mother's perceived changes in her child's HR. The mother reports her perception of change between -100 and +100, while the child's HR is displayed in BPM. There was a significant, positive relationship between the child's HR and the mother's perceived change in the child's HR ($r(10) = .69$, $p = .01$).

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