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„Development of interoceptive sensitivity across cardiac and respiratory modalities in the first year of life"

Verfasst von / submitted by

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Introduction

While you are reading this Master's thesis, your heart will beat approximately 3.400 times[1], but will you notice it? Because the heartbeat is originating from within the body, and it is related to the physiological condition of the body, it is considered as an interoceptive signal (Craig, 2002, 2009; Garfinkel et al., 2015). Interoception refers to the representation of the internal state of the body (Ceunen et al., 2016; Chen et al., 2021). Interoception is relevant for every human being, as it is associated with important bodily functions like energy regulation, memory, affective and emotional experience, and the experience of the self (Quigley et al., 2021). However, even though interoception is important for the socio-cognitive development of infants, little is known about its development in the first years of life. Therefore, the present study will investigate the development of interoception across cardiac and respiratory modalities in infancy.

What is interoception?

There has been an extensive debate about the exact definition of interoception, ever since the word was first used in scientific literature by Sherrington in 1906 (Ceunen et al., 2016; Khalsa et al., 2018; Sherrington, 1906). Currently, consensus exists upon interoception as the conscious or unconscious perception of the physiological condition, i.e., state, of the entire body (Berlucchi & Aglioti, 2010; Ceunen et al., 2016; Craig, 2002, 2009; Garfinkel et al., 2015). Interoception is considered as an umbrella term for the experience of the bodily states (Ceunen et al., 2016), which is a complex process executed by the central nervous system (CNS) that allows the organism to sense, interpret, and integrate signals from within the body (Ceunen et al., 2016; Khalsa et al., 2018). Most interoceptive signals go unnoticed (Critchley & Harrison, 2013) and some come to consciousness only during malaise (Berlucchi & Aglioti, 2010). Interoceptive signals relate to sensations that originate from within the body, like heart rate, glucose levels, building up of carbon dioxide in the bloodstream, temperature, itch, respiration, and pain (Craig, 2002; Feldman Barrett & Simmons, 2015). Interoception can be differentiated from proprioception, which is the reflection of the position of the body in space, and exteroception, the perception of the external environment (Craig, 2003; Garfinkel et al., 2015).

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[1] This approximative value was calculated by using the average reading speed of approximately 200 words per minute and a heartbeat rate of 80 beats per minute. The Master's thesis consists of around 8.400 words (without reference list and appendices).

Interoception becomes relevant in everyday life, because it interacts with emotion, cognition, and behavior (Craig, 2003, 2009; Garfinkel et al., 2015). It might be even regarded relevant for survival, because of its crucial functions such as perceiving changes in physiology and energy status of the body, and the maintenance of homeostatic and allostatic functioning (Craig, 2011; Khalsa et al., 2018; Quigley et al., 2021). In adulthood, interoception might influence emotional processing (Craig, 2003; Seth & Friston, 2016; Wiens, 2005; Zamariola et al., 2019), self-regulation (Khalsa et al., 2018), instinctive and volitional behavior (Critchley & Harrison, 2013), and decision making (Dunn et al., 2012; Werner et al., 2009). The pathogenesis of various somatic and mental health disorders like eating disorders, anxiety disorders, and addiction might be affected by the dysfunction of interoception (Harshaw, 2015; Martin et al., 2019; Murphy et al., 2017; Verdejo-Garcia et al., 2012). Because of its functions, interoception is associated with psychological well-being, thus, focusing on interoception could be one important starting point for the improvement of therapeutic measurements (Hanley et al., 2017).

Garfinkel and Critchley (2013) have proposed a model of interoception, which proposes three distinct and dissociable dimensions of interoceptive processing: Interoceptive accuracy, sensibility, and awareness. *Interoceptive accuracy* is a stable trait, which refers to differences in objective interoceptive behavioral performance. *Interoceptive sensibility* describes the individual's subjective, self-evaluated belief of how internal sensations are experienced. Therefore, when interoception is assessed with self-report questionnaires, Garfinkel and Critchley (2013) would refer to the construct as interoceptive sensibility, even when the authors of the measures refer to it as interoception (Mehling et al., 2018). Finally, the metacognitive awareness of interoceptive sensitivity is called *interoceptive awareness* (Garfinkel & Critchley, 2013). Interoceptive awareness describes, how well subjective confidence (i.e., sensibility) predicts objective ability (i.e., sensitivity) within an individual. Interoceptive accuracy might need higher level cognitive processing. Therefore, it is usually substituted by the more implicit form *interoceptive sensitivity* in infancy research. As a consequence, this study will be using the latter, infant-related label (Maister et al., 2017). With infants, it remains impossible to measure interoceptive sensibility linguistically, and as a consequence, it is also impossible to assess interoceptive awareness.

Measurements of interoception

An important and intriguing challenge in investigating interoception is its measurability. In adults, the interoceptive sensitivity of detecting internal bodily sensations is typically measured by heartbeat detection tasks (Brener & Ring, 2016). In experimental settings, using heartbeat tracking or heartbeat discrimination tasks, participants are instructed to detect or perceive their own heartbeat and report its frequency (Garfinkel et al., 2015; Schandry, 1981). Heartbeat perception may function as a good indicator of interoception, because it might also portray an individual's interoceptive sensitivity of other organs. Empirical evidence shows correlations between heartbeat and gastric awareness (Herbert et al., 2012) suggesting that interoceptive information is processed within broadly the same neural areas (Berntson & Khalsa, 2021; Craig, 2002, 2003). However, the current evidence is somewhat inconsistent. Garfinkel et al. (2016) were able to find a positive relation between cardiac and respiratory measures of interoceptive awareness in healthy adults, but they weren't able to demonstrate the same for interoceptive sensitivity in the same sample. Even though heartbeat tasks are the standard method, it might be misleading to solely focus on heartbeat detection when measuring interoception. Heartbeat detection tasks might not be reliable at measuring interoceptive sensitivity, as the accuracy rate for resting heartbeat detection is less than 40 %, a limitation that other, more invasive procedures might overcome (Khalsa et al., 2009). Also, exteroceptive somatosensory information could potentially contribute to sensitivity of own heartbeat (Jones et al., 2021; Khalsa et al., 2009). So while some researchers consider heartbeat detection tasks as convenient, objective empirical measures for interoceptive sensitivity, because they are easily conducted, conclusively interpreted, and non-invasive (Schandry, 1981), others are more concerned with the validity of heartbeat detection tasks and are hesitant when interpreting cardiac sensitivity as interoception.

Therefore, measuring interoceptive sensibility could be a useful complementary method to achieve more reliable interoceptive information. Measures of the interoceptive sensibility ought to portray the individual's belief in interoceptive ability, and the degree to which one feels engaged by interoceptive signals. This can be achieved via self-report questionnaires, or alternatively, by indexing subjective aspects during an objective interoceptive task, i.e., assessing the confidence of interoceptive sensitivity (Garfinkel & Critchley, 2013). There are many validated and reliable interoception questionnaires for adults (e.g., Mehling et al., 2018). However, as the perceived sensibility to bodily changes is assessed, these measures do not address whether the sensibility is objectively accurate. Also, questionnaires might be difficult to complete, because they require people to be capable of explicitly expressing internal processes. As a consequence, data quality of self-report measures might be limited and might not adequately depict interoception.

Interoceptive awareness can be quantified through analytic approaches, by combining data from interoceptive sensitivity and sensibility (Garfinkel & Critchley, 2013).

Interoception in development

In infancy, interoception is related to the development of behavioral, emotional, and cognitive functions. Interoception might be a prerequisite for important bodily and cognitive functions (Murphy et al., 2017). Through interoception, self-regulation, maintaining homeostasis, and guiding behavior according to internal states might become possible (Fotopoulou & Tsakiris, 2017; Maister et al., 2017; Murphy et al., 2017). Current research indicates that in infancy, interoception is relevant for both socio-emotional and physical development, and for experience of reward, motivation, and arousal (Fotopoulou & Tsakiris, 2017; Maister et al., 2017). Interoceptive awareness has been observed to be positively related to automatic imitation, and it is potentially related to imitation learning outcomes of infants (Ainley et al., 2014). Subsequently, interoceptive sensitivity might influence the ability to distinguish between self and other (Tsakiris et al., 2011). Researchers have been arguing that both, self-touch (Georgie et al., 2019) and early interactions with primary caregivers (Fotopoulou & Tsakiris, 2017) could contribute to the infant's initial sensorimotor representations, and the development of interoception. Little is known about the developmental trajectories of interoception, but researchers assume a dynamic developmental process of interoception in infancy and childhood (Koch & Pollatos, 2014).

Until recently, measuring interoceptive sensitivity was restricted to participants from elementary school aged children onward due to language barriers and comprehension problems (Koch & Pollatos, 2014). To assess interoceptive sensibility in childhood and adolescence, adapting the language of validated adult questionnaires might be an easy way to apply existing measures for younger participants (Jones et al., 2021). An infant heartbeat detection task, "Infant Heartbeat Task, iBEAT", was developed by Maister et al. (2017) that measures infants' implicit interoceptive cardiac sensitivity through a preferential looking paradigm. Looking is one of the first behaviors expressed by newborns, and it is able to give insights into the mind long before language has been developed (Gredebäck et al., 2010). In the "iBEAT" task, infants are presented with images on a screen that move in or out of synchrony with their own heartbeats. In Maister et al.'s (2017) study, five-month-old infants looked significantly longer at stimuli moving out of synchrony with their heartbeat than stimuli moving in synchrony with their heartbeat. This implies that at a very early age, infants show sensitivity to interoceptive signals, while integrating them with external visual-auditory signals. Maister et al. (2017) also suggest that emotional cues might affect sensitivity to interoceptive signals. Further neurobehavioral evidence of interoceptive sensitivity in the first year of life exists, but is somewhat inconsistent. In a close replication study of the "iBEAT" task conducted by Weijs et al. (2019), their study sample of 5- to 7-month-old infants visually preferred the condition in which stimuli moved in synchrony to own heartbeat, contrary to previous findings.

While researchers were able to demonstrate first evidence of interoceptive cardiac sensitivity in infants (Maister et al., 2017; Weijs et al., 2019), evidence on whether heartbeat detection is a valid predictor of interoceptive sensitivity in the first year of life is currently missing. Given the controversy of interpreting cardiac sensitivity as interoception in adulthood, it remains unclear, whether interoceptive sensitivity across different modalities (i.e., heartbeat and respiration) is related in infancy. Investigating interoception across distinct modalities is essential and could lead to advances in the understanding of the development of interoception.

Parental influences on the development of interoception

It has been suggested by Fotopoulou and Tsakiris (2017) that the development of interoception in infants might be greatly influenced by early interactions with primary caregivers. Mother-infant interactions are often characterized by body-to-body exchanges (e.g. tactile contact during the exchange of diapers, feeding), which might facilitate multisensory integration, inter-corporal connections, bodily attunement, and the development of interoceptive sensitivity (Montirosso & McGlone, 2020). Because mothers regulate their infants' diet and regulate their infants' arousal with activities such as singing and touch, interactions with mothers might play an essential role in shaping early behavior in infants (Atzil et al., 2018), and in promoting interoceptive sensitivity (Della Longa et al., 2020; MacCormack et al., 2020; Montirosso & McGlone, 2020). It might even hold true that maternal postpartum depression or anxiety might lead to more intrusive or anxious parental behavior, which is associated with infant's future mental health, and might constantly dysregulate infant's allostasis (Atzil et al., 2011). Recent research about maternal influences proposes maternal interoceptive sensibility to be a significant predictor for infant social affective skills related to interoception (i.e., emotion regulation, self-control) in third graders (MacCormack et al., 2020). Furthermore, greater parental interoceptive sensitivity in the infants' first year of life was able to predict lower child somatic symptoms six years later

(Abraham et al., 2019). It remains unclear, however, whether and to what extent maternal interoception already influences infants in the first year of life.

Study aims

Evidence on the development and of interoceptive sensitivity is still inconsistent. Also, it remains unclear if maternal interoceptive sensibility influences the early developmental process in the first year of life. Therefore, this study focuses on the question of whether interoceptive sensitivity capabilities are already present in 9-month-old infants. Moreover, no study to date examined whether interoceptive sensitivity towards respiratory signals is already present in the first year of life, and whether interoception in the cardiac domain correlates with interoception in the respiratory domain in early infancy. We aim to examine heartbeat detection capabilities using the "iBEAT" paradigm (Maister et al., 2017). Further, by introducing the novel method "iBREATH", which has been developed by the research team, this study aims to demonstrate respiration detection capabilities in 9-month-olds. Subsequently, it is of interest how these capabilities might be related, which could contribute to the understanding of interoception across different modalities. Finally, we investigate whether maternal interoceptive sensibility might serve as a relevant predictor of infants' interoceptive capabilities.

Research questions and predictions

The following main research questions were investigated in this study, addressing important research gaps:

1. *Do 9-month-old infants display an implicit sensitivity to interoceptive cardiac signals at group level?*

   It was observed that 5-month-old infants show significant differences in the duration of looking times at stimuli beating in or out of synchrony to their own heartbeat (Maister et al, 2017). We expected to observe visual preference for asynchronous stimuli, i.e., implicit interoceptive cardiac sensitivity, in the current sample of 9-month-old infants.
2. *Do 9-month-old infants display an implicit sensitivity to interoceptive respiratory signals at group level?*

   Because 5-month-old infants displayed interoceptive cardiac sensitivity (Maister et al, 2017), we expected infants to show a similar looking behavior towards stimuli moving in and out of synchrony to respiratory rhythm.

3. *How are interoceptive sensitivity across different modalities such as heartbeat and respiration related in 9-month-old infants?*
   Given the evidence about the independence between cardiac and respiratory interoceptive sensitivity in adults (Garfinkel et al., 2016), we expected interoceptive cardiac sensitivity to be unrelated to interoceptive respiratory sensitivity in 9-month-old infants.
4. *Does maternal interoceptive sensibility predict infant interoceptive sensitivity?*
   We expected that important dimensions of maternal interoceptive sensibility ("Not-Distracting", "Attention Regulation", "Emotional Awareness", and "Self-Regulation"), as quantified by the "Multidimensional Assessment of Interoceptive Awareness Questionnaire 2" (MAIA-2; Mehling et al., 2018) will predict interoceptive sensitivity to heartbeat or respiration rhythm in 9-month-old infants.

Methods

Sample

The present study was embedded within the "Mind the Body" project. The data collection took place from September 2020 until July 2021. Initially, 72 mothers and their infants participated in the current study. The final study sample consisted of N = 40 infants (*M* = 9.85 months, *SD* = 0.37 months, 13 girls) and their mothers (*M* = 34.68 years, *SD* = 5.18 years). Thirty-two of the initially recruited mother-infant dyads had to be excluded from further analysis due to infants' non-completion of the "iBEAT" and "iBREATH" paradigm (*n* = 16), bad data quality (*n* = 5), or insufficient number of artefact-free, outlier-free trials (*n* = 11). Twelve infants had usable data from both measurements, 25 infants were eligible for the data analysis of the "iBEAT" paradigm and 27 were considered for the analysis of "iBREATH". *Figure 1* displays the inclusion criteria and the number of participants in the study sample. Optimal sample size calculations were initially conducted using G*power for a medium to large effect size one-tail correlation design ($d = .6$, $\alpha = .05$, $1- \beta = .95$) resulting in 21 mother-infant-dyads. The acquired sample size of infants who have adequate data in both paradigms was thus too small for the conducted statistical measures.

Only full-term infants (i.e., infants born in the 37th week or later; > 2,500 g) were included in the data analysis. The reported APGAR scores after 10 minutes were in a normal range (scores from 9-10). Infants had no chronic diseases or developmental disorders. The majority of mothers were primiparous (64.7 %), and about one third were multiparous (35.3 %). Most mothers of the 40 included infants were of White European origin (95 %). 80 %

reported their infants were exclusively exposed to German language at home, 14.29 % came from households where parents spoke German and another language, and 5.7 % indicated that none of the parents spoke German to the infant. The parental educational and socio-economic status was high, with 71.43 % of mothers, and 54.29 % of the second parent having obtained University degrees. Three mothers indicated that they were single parents.

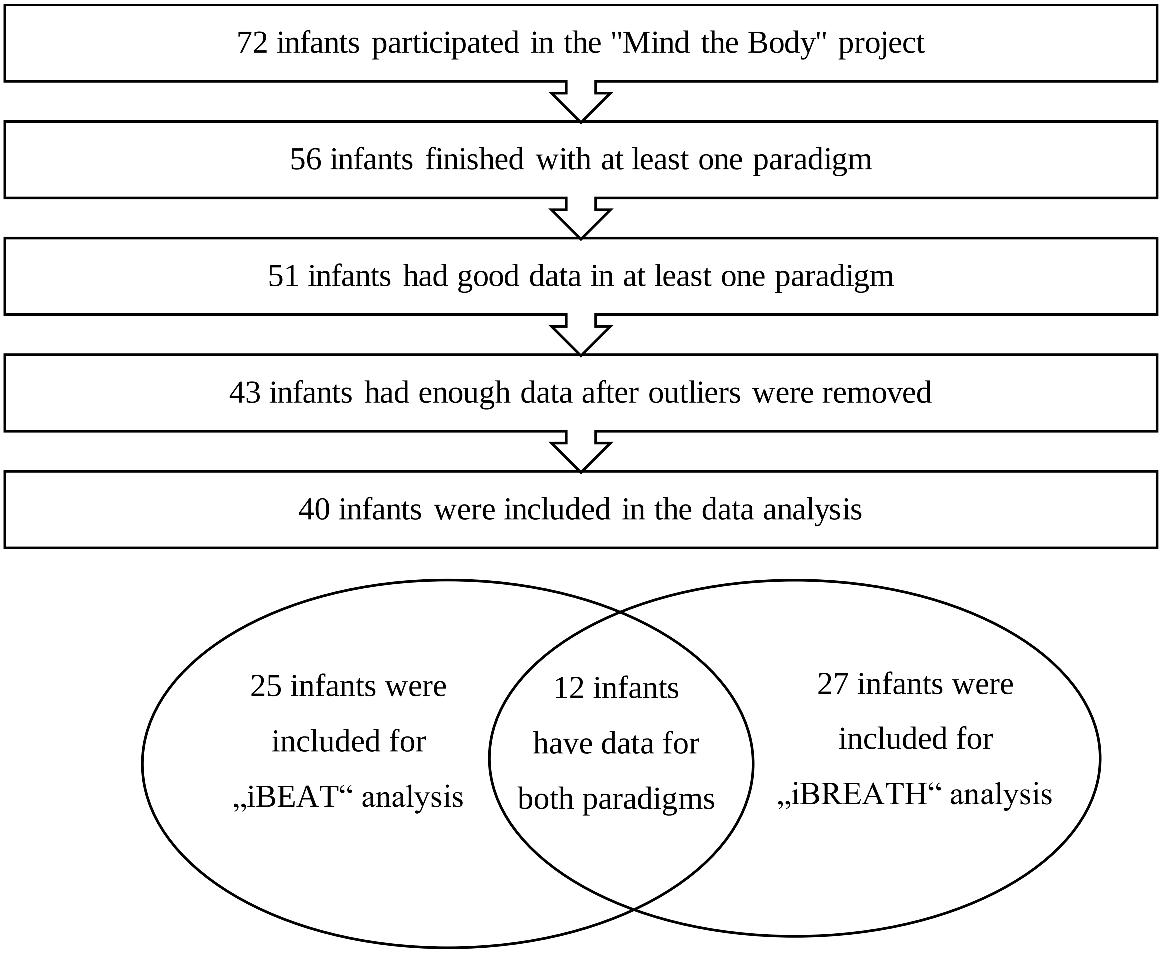

Figure 1: The number of participants in the study sample

Participants were recruited in hospitals and midwife courses from the city of Vienna, online via social media. For their participation, the families received either a 15€ voucher for a drugstore or a book about children research of a similar value. They were also given a fixed compensation for travelling expenses of 6€. Infants received a small gift and a participation certificate. The mothers provided written informed consent for themselves and the infants. All experiments were approved by the local ethics committee of the University of Vienna.

Procedure

Mothers and infants were welcomed in a preparation room, where they gave written informed consent after being informed about the study's aims and procedures. Then, they were led to the experimental room, and given time to arrive, get comfortable, and address any remaining questions. One session took about 2-3 hours and consisted of several experiments, including the infant interoceptive sensitivity tasks "iBEAT" and "iBREATH". Further, a task about the development of empathy, a dual-fNIRS social interaction task, and a language development task were conducted (not reported here). The experiments were conducted in a randomized order, giving as many breaks as needed by mothers or infants. Subsequent to the testing session, mothers were asked to complete an online questionnaire, which contained a part about general information, and validated self-report questionnaires. Mothers could choose to complete the questionnaire in the preparation room or at home.

Infant heartbeat detection task "iBEAT"

The "iBEAT" task measures infant interoceptive sensitivity, and comprises a sequential looking paradigm, where infants differentiate between infant-friendly stimuli moving up and down synchronously or asynchronously (± 10 %) to own cardiac rhythms, while the stimuli movement was accompanied by a rhythmic sound (Maister et al., 2017).

The current study's experimental setup and procedure was adopted from the task and instructions by Maister et al. (2017). After attaching three disposable AgCl electrodes on the chest and stomach, infants were placed in a "Maxicosi" car seat approximately 60 cm away from a display, which was integrated to an EyeLink 1000 Plus eyetracker. Mothers were placed on a chair behind them and instructed to look at the screen with a neutral expression, and not to interact with their infants (i.e., not point at the screen, or talk to them; *Figure 2*).

The two-lead ECG setup was monitored throughout the whole task using Powerlab and Bioamp. ECG R-peaks were identified using Powerlab's "Fast Response Output" function (ADInstruments, www.adinstruments.com). The experiment was conducted via custom script, implemented in Matlab 2018a (MathWorks, Natick, MA). For each infant, a threshold was set, which indicated the onset of each R wave in the ECG trace. Subsequently, a custom script Arduino (Arduino, www.arduino.cc) sent a signal about the exceeding of a threshold to the display computer. In the synchronous condition, the stimulus moved according to the signal received from Arduino, whereas in the asynchronous condition, the custom script produced a cardiac-like movement, which varied ± 10 % to the speed of the previous synchronous trial.

Figure 2. Set-up of eye-tracking experiments. For eye-tracking experiments (i.e., “iBEAT”, “iBREATH”), infants were placed approx. 60 cm away from a display. Mothers were seated on a chair behind them and instructed to not interact with their infants.

The experiment consisted of two conditions, where stimuli appeared either on the left, or the right side of the screen. The characters moved either synchronously or asynchronously to infant heartbeat. Whereas Maister et al. (2017) alternated between synch and asychn conditions, the order in our setup was semi-randomized. We followed the procedure, as described by Maister et al. (*Figure 3;* 2017). The task started after we achieved a steady ECG signal, where R peaks were identified by Powerlab’s “Fast Response Output”, and successful eye tracker calibration of the eye fixations. At the beginning, a central fixation clip was shown to attain the infant’s attention. Then, infants were presented a character, beating in or out of synchrony to the infant’s heartbeat, for a minimum duration of 5 s. The continued presentation of the character depended on the infants’ attention (i.e., continued fixation at the screen). The character remained on the screen for a maximum of 20 s, or terminated earlier if the infant looked away from the character for longer than three consecutive seconds. Afterwards, the fixation clip was shown to re-engage the infant’s attention, and the next trial began. The “iBEAT” task was either terminated after the infant did not look at the screen for four consecutive trials, or when the experimenters or the mothers observed that the infant became too tired or fussy (Maister et al., 2017).

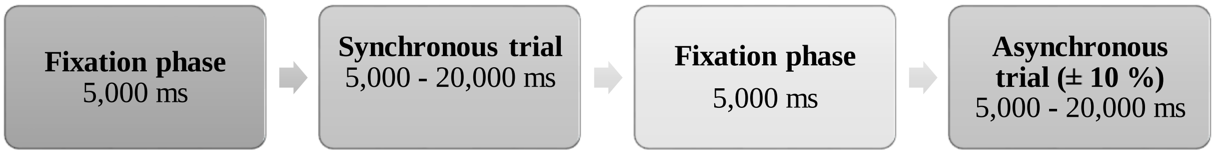

Figure 3. "iBEAT" paradigm procedure. In the sequential looking paradigm "iBEAT", infants viewed characters that moved in synch or asynchronously to their own cardiac rhythms, while sitting in a car seat approximately 60 cm away from the screen. Length of trials depended on infant attention with a minimum screen time of 5,000 ms and a maximum of 20,000 ms. In between trials, there was a fixation phase of 5,000 ms, which used attention-grabbing stimuli to re-engage infants. The order of the two conditions was semi-randomized.

Infant respiration detection task "iBREATH"

The "iBREATH" paradigm was created to measure implicit respiration rhythm detection in infants, i.e. interoceptive sensitivity to own respiration signals. The development of "iBREATH" was based on the "iBEAT" task: Stimuli were expanding either synchronously or asynchronously (± 10 % speed) to the infants' respiratory rhythm, while looking behavior was recorded. Expansion movement was accompanied by the sound of waves or rainfall. Respiratory signal was measured using a respiratory belt transducer (ADInstruments, www.adinstruments.com), which detects changes in chest diameter resulting from breathing. The eye tracking experiment followed the same procedure and used the same instructions as "iBEAT".

The experiment was conducted through a custom script in Matlab 2018a (MathWorks, Natick, MA). During synchronous trials, the respiratory signal was picked up by Powerlab's direct output (ADinstruments, www.adinstruments.com) and transmitted to an Arduino (Arduino, www.arduino.cc). Each time a new frame was presented on the screen, the custom script read and processed the signal. A logarithmic scaling function was applied to each sample to amplify samples with low-amplitude. Further, the signal was smoothed based on a Gaussian low pass filter to reduce jitter, by using the current breath sample and a fixed number of preceding ones (window; window_size = *X*). The processed breath sample value was mapped to the size of a stimulus that was presented on-screen and to the volume of an accompanying sound. In the asynchronous condition, respiration frequency was varied ± 10 % of the average frequency of the previous synchronous trial. In order to avoid major perceptual differences between stimuli, the amplitude was not varied, equaling the average amplitude of the previous trial. The properties were fulfilled by the calculation of a sine-based approximation of the breath recording, which could be varied in speed by multiplying it with a given factor.

Synchronous and asynchronous conditions were semi-randomized. In each trial, the stimulus was either on the left, or on the right side of the screen. After an adequate respiratory signal was observed, the calibration was started to capture the eye fixations. Afterwards, the task was started, which was structured like the “iBEAT” task, with an initial attention getter and stimuli that remained according to the infant’s attention (see above; Maister et al. (2017). Again, the experiment was aborted after infants did not sufficiently pay attention, or were getting tired.

Eye tracking data processing

ECG data were visually inspected for artifacts in a custom dashboard programmed in JAVA. “iBEAT” trials were excluded from the further analysis, if the heartbeat signal was lost, or when it was not detected by Powerlab’s “Fast Response Output”, as the signal on the screen did not move according to heartbeat signal in those cases. Similar, for “iBREATH” data pre-processing, trials were excluded via visual inspection, if the respiration signal was lost at any point during the trial, or when there were artifacts in the respiration signal, which lead to alternations in the presented stimuli that were not explained by breathing rhythm. For the participants to be included in the statistical analysis, they had to have at least four remaining valid trials with trials from both conditions left, after the data cleaning for either one of the paradigms.

Multidimensional Assessment of Interoceptive Awareness 2

Participants’ socio-demographic data were acquired using a parental background information questionnaire. It includes information regarding the child, the birth, the child’s health condition and parental education and occupation.

Maternal interoceptive sensibility was measured using the German and English versions of the eight dimensional “Multidimensional Assessment of Interoceptive Awareness 2” questionnaire (MAIA-2; Mehling et al., 2018). MAIA-2 is a validated, 37-item, state-trait, self-report questionnaire, which is able to measure multidimensional facets of interoception, that might also be relevant in health-related settings (“Noticing”, “Not-Distracting”, “Not-Worrying”, “Attention Regulation”, “Emotional Awareness”, “Self-Regulation”, “Body Listening” and “Trusting”). Even though Mehling et al. (2018) describe it as a measure to obtain information about interoceptive awareness, the construct corresponds to interoceptive sensibility within the scope of the three dimensional model of interoception (Garfinkel et al., 2016). MAIA-2 has been translated and validated in various languages, has been adapted for children and adolescents, and is a commonly used interoceptive sensibility measure (Jones et al., 2021). Participants were asked to indicate on a 6-point rating scale (from 0 "never" to 5 "always"), how often each statement applies to them generally in daily life. An example item reads: "I notice where in my body I am comfortable" (Mehling et al., 2018). Higher scores reflect higher interoceptive sensibility in daily life. Internal consistency was adequate to high for each dimension, with internal consistency ranging from Cronbach's α = .69 to .85 (*Table 1*).

Additionally, the questionnaire that mothers were asked to complete consisted of other validated measures (i.e., "Infant Behavior Questionnaire – Revised Very Short Form", "Barkin Index of Maternal Functioning Questionnaire", "Parental Reflective Functioning Questionnaire", "Positive and Negative Affect Schedule", and "Milestones Of Normal Development in Early Years") that are not reported here.

Table 1: Questionnaire

Multidimensional assessment of Interoceptive Awareness 2		
Subscale	*Items*	*α*
Noticing	4	.73
Not-Distracting	6	.82
Not-Worrying	5	.69
Attention Regulation	7	.84
Emotional Awareness	5	.79
Self-Regulation	4	.73
Body Listening	3	.85
Trusting	3	.83

Authors: Mehling et al. (2018)

Statistical analysis

Statistical analysis was conducted using RStudio 1.4.1114 (RStudio Team, 2021). The level of significance was set at α = .05. Following Maister et al.'s (2017) analysis, outliers in the looking time data were defined as trials, in which individual looking time was greater than two standard deviations away from the group mean for that condition. These outliers were excluded from the sample. Participants were also excluded from the analysis if they did not have sufficient trials that were longer than 5,000 ms, or when they had less than four trials with good quality, as indicated by the visual inspection of ECG data (*Figure 1*).

The first two research questions investigated whether our sample showed implicit interoceptive sensitivity at group level and were addressed by two-sided, paired sample *t*-tests. The mean looking duration to synchronous stimuli was compared to the mean looking duration to asynchronous stimuli. In a further exploratory analysis, we included outlier trials and log-transformed infant looking-times before statistical analysis, which is a common technique to deal with skewness in the data (Csibra et al., 2016). Finally, because there were some participants with only few overall trials, and looking time decreased across time, linear mixed-effects models using function *lmer* from the package "Linear Mixed-Effects Models using 'Eigen' and S4" (lme4; Bates et al., 2015) were defined to both control for trial number and individual trial sum (The ManyBabies Consortium, 2020). We weighted each observation by the reciprocal of its estimated variance, which helped to efficiently analyze data from all infants, including the ones with only a small number of valid trials, and to account for non-constant variance in the response variable (Foley, 2019; Stahl et al., 2010).

For the third research question, which explored the relationship of interoceptive sensitivity across modalities, a discrimination score was calculated for both paradigms, reflecting the absolute proportion difference between looking times in the asynchronous and synchronous conditions (see Maister et al., 2017). Subsequently, due to the violation of parametric assumptions (i.e., "iBEAT" discrimination scores were not normally distributed), the non-parametric Spearman correlational method was conducted to analyze, whether the discrimination scores of the "iBEAT" and "iBREATH" tasks were positively related.

The fourth research question focused on the influence of maternal interoceptive sensibility on infant interoceptive sensitivity and was examined using linear regression. Infant log-transformed interoceptive sensitivity scores of "iBEAT" and "iBREATH" were regressed on the subscales "Not-Distracting", "Attention Regulation", "Emotional Awareness", and "Self-Regulation" of maternal interoceptive sensibility (MAIA-2; Mehling et al., 2018).

The analysis code is available at:
https://mega.nz/folder/JzJSRBAL#mHQVcwTKjEefAhhaZcChwA

Results

"iBEAT" paradigm

Twenty-five infants (*M* = 9.79 months, *SD* = 0.37 months, 33.3 % girls) were included in the analysis concerning "iBEAT" paradigm. Because trial time and looking time were highly correlated ($\rho = .9$, $p < .000$), the analysis solely included information about looking time. At group level, infants looked 4,951 ms (*SD* = 2,280 ms) on average at the asynchronous stimulus and 5,553 ms (*SD* = 2,710 ms) at the stimulus beating in synchrony to their own heartbeat. There were slightly more valid asynchronous trials as compared to synchronous trials: 5.12 vs. 4.88 trials, respectively (*Table 2*). A paired-sample *t*-test was applied to statistically test, whether there is a visual preference for a specific condition. At group level, infant looking times to synchronous and asynchronous stimuli did not differ significantly, ($t = 1.45$, $p = .16$, $d = 0.24$; *Figure 4*).

Exploratory analysis showed that by including outliers and log-transforming looking times, differences between trials remained insignificant in the resulting sample of $n = 27$ infants ($t = 1.64$, $p = .11$, $d = 0.25$).

Further, we observed that looking time decreased significantly across trials ($\rho = -.44$, $p < .000$), indicating that infants generally habituated to the experimental stimuli. While this is consistent for the overall sample and across trials, it might bias results for included infants with only few valid trials. As there are quite a few infants with few trials (the range of individual trial sum is 4 - 24), we carried out a weighted regression to directly address this issue (Bates et al., 2015). Weighted regression is a common method in infancy research, especially when individual sum of trials differs across the sample (Stahl et al., 2010; The ManyBabies Consortium, 2020). In a linear mixed-effects model with a dependent factor log looking time, which included trial number and subject as random effect, and condition, trial number, and the interaction term of condition and trial number, the main effect of type (i.e., synchronous and asynchronous) was not significant at explaining log looking time ($\beta = .21$, t = 1.23, p = .22). When applying inverse variance weights to the model, conditions remained insignificant at explaining log looking time ($\beta = .2$, t = 1.17, p = .24). Trial number was significantly negatively related to log looking time in both models. The unweighted and weighted models did not differ significantly at explaining log looking time. To sum up, the results of the linear mixed-effect models were in line with the conducted paired-sample *t*-tests. There was no significant difference in length of looking time towards the two conditions, even after controlling for trial number and putting more weight on data from infants with more valid trials.

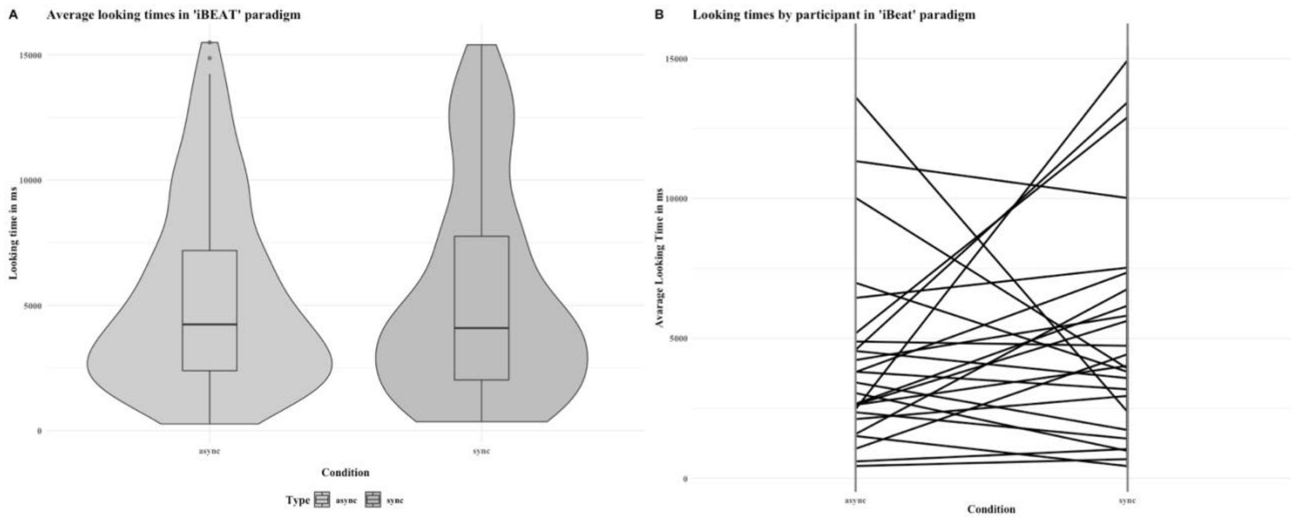

Figure 4. "iBEAT" paradigm looking times. The x-axis indicates the respective condition, asynchronous or synchronous. The y-axis indicated the duration of the looking time in ms.
A) Boxplot visualization and estimation of probability density function of average looking time per condition.
B) Strip-chart visualization of individual differences in looking behavior.

"iBREATH" paradigm

For the analysis of "iBREATH" data, 27 infants (*M* = 9.84 months, *SD* = 0.40 months, 29.16 % girls) were included. Infants looked 6,240.30 ms (SD = 2,242.06 ms) on average at the asynchronous stimuli and 6,674.89 ms (SD = 2,823.53 ms) at the synchronous stimuli. There were more valid asynchronous than synchronous trials (5.19 vs. 4.63 trials; *Table 2*). The paired sample *t*-test indicated that there was no visual preference (i.e., significant longer looking time) towards a specific condition at group level ($t = 0.95$, $p = .35$, $d = 0.17$; *Figure 5*).

In the exploratory analysis where outliers were included and the looking times were log-transformed to deal with skewness of data, the results remained robust at group level of the included $n = 28$ infants. No visual preference of a specific condition was observed ($t = 1.54$, $p = .14$, $d = 0.25$).

Again, we also observed habituation to stimuli, as looking time decreased across trials ($\rho = -.30$, $p < .000$). Like in "iBEAT", this was consistent across participants, but might have biased results from participants with only a few included trials. Because individual valid trials range from 4 to 26, a weighted regression model was carried out as an exploratory analysis to control for trial number and trial index. Type (i.e., synchronous or asynchronous) remained insignificant at explaining log looking time in the linear mixed model, which included trial number and subject as random effect, and condition, trial number, and the interaction term of condition and trial index (β = .22, t = 1.27, p = .22). The changes were marginal after the appliance of inverse variance weights (β = .19, t = 1.36, p = .17). In congruence with the paired-sample t-tests, the linear mixed models also indicate that there is no significant difference in length of looking times, even after controlling for time number and applying weights according to the sum of included trials per person.

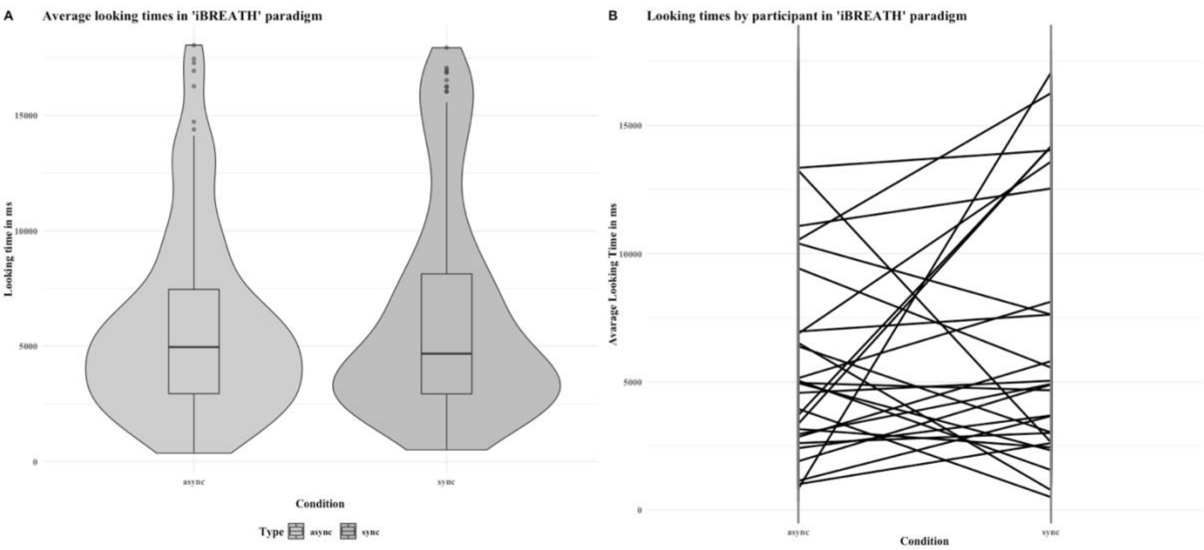

Figure 5. "iBREATH" paradigm looking times. The x-axis indicates the respective condition, asynchronous or synchronous. The y-axis indicated the duration of the looking time in ms.
A) Boxplot visualization and estimation of probability density function of average looking time per condition.
B) Strip-chart visualization of individual differences in looking behavior.

Table 2: Descriptive statistics of "iBEAT" and "iBREATH"

Looking times (LT) of eye-tracking paradigms (n = 25)				
Paradigm	*M*	*SD*	*Range*	*Average trials*
"iBEAT"				
Asynchronous	4,950.57	2,279.88	438; 11,659	5.12
Synchronous	5,552.68	2,709.65	1,626; 10,528	4.88
"iBREATH"				
Asynchronous	6,240.30	2,242.06	2,600; 11,572	5.19
Synchronous	6,674.89	2,823.53	503; 11,426	4.63

Note: Means (*M*), standard deviations (*SD*), range and average number of trials per condition are reported.

Relation of interoceptive sensitivity across modalities

To assess the relationship between cardiac and respiratory interoceptive sensitivity, discrimination scores were calculated reflecting absolute proportion difference between average looking times to stimuli that were synchronous and asynchronous (see Maister et al., 2017). The data of twelve infants was eligible for the statistical analysis of the relationship between the "iBEAT" and "iBREATH" discrimination scores (*Figure 6*). Because "iBEAT" discrimination scores were not normally distributed (W = 0.82, $p < .01$) Spearman's rank correlation was computed to assess the relationship between the "iBEAT" and "iBREATH" discrimination scores. There was a slightly positive, but insignificant relationship between the two variables ($\rho = .20$, $p = .26$).

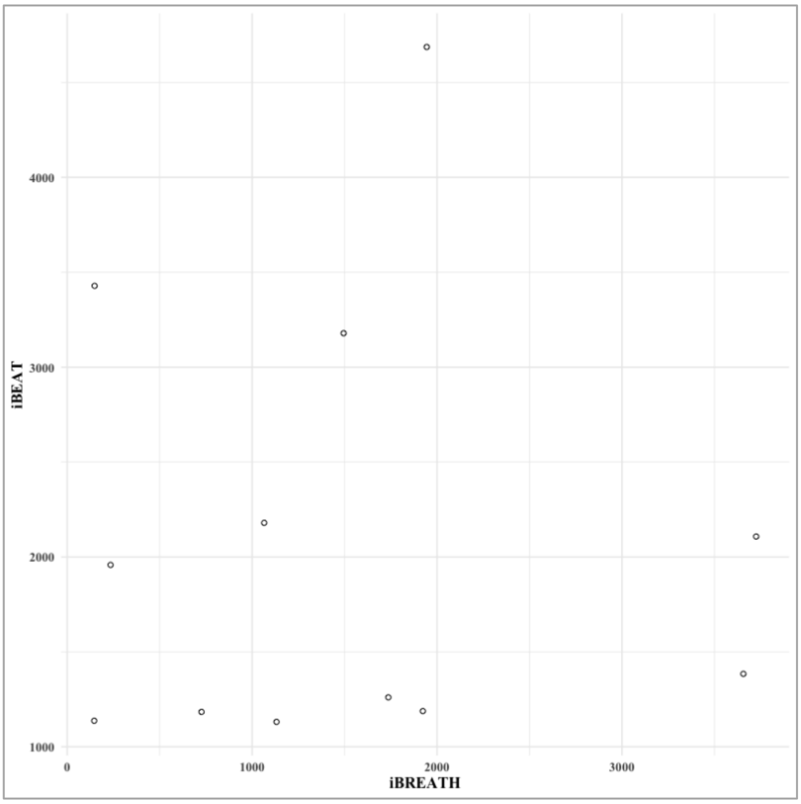

Figure 6. Relation between "iBEAT" (y-axis) and "iBREATH" (x-axis) difference scores.

Influence of maternal interoceptive sensibility

The influence of maternal interoceptive sensibility was investigated through multiple linear regression (*Table 3*). The assumptions of multiple regression (i.e., linearity, normality, homoscedasticity, absence of outliers or high leverage points) were tested and sufficiently met. Log-transformed difference scores of "iBEAT" and "iBREATH" were regressed on dimensions of maternal interoceptive sensibility (MAIA-2; Mehling et al. 2017). Because of multicollinearity, only the dimensions “Not-Worrying, “Attention Regulation”, “Emotional Awareness”, and “Self-Regulation” of interoceptive sensibility have been included, as these have also been especially relevant in other, clinical studies (see Barbato et al., 2021; Eggart & Valdés-Stauber, 2021; Eng et al., 2020; Hielscher & Zopf, 2021). None of the included dimensions were significant at explaining some variation of infant log-transformed interoceptive cardiac sensitivity (“iBEAT”). While higher “Emotional Awareness” was significant positively associated with infant interoceptive respiratory sensitivity (“iBREATH”), β = 1.24, *SD* = 0.27, *p* < .000, other dimensions of maternal interoceptive sensibility remained insignificant at explaining log-transformed infant “iBREATH” discrimination scores.

Table 3: Influence of maternal interoceptive sensibility

Multiple linear regression models		
	Dependent variable: Log infant interoceptive sensitivity	
Included MAIA-2 dimensions	*Interoceptive cardiac sensitivity (“iBEAT”)*	*Interoceptive respiratory sensitivity (“iBREATH”)*
Not-Worrying	-0.33	-0.17
	(0.29)	(0.21)
Attention Regulation	0.14	0.43
	(0.29)	(0.30)
Emotional Awareness	-0.29	1.24***
	(0.30)	(0.27)
Self-Regulation	-0.09	-0.35
	(0.22)	(0.23)
R^2	0.13	0.70
Adjusted R^2	-0.09	0.63
F-statistic (df = 4; 16)	0.60	10.84

Note: * *p* < .05; ** *p* < .01; *** *p* < .001

Discussion

Interoceptive processing is highly relevant for emotional, social, and cognitive functioning (Quigley et al., 2021). Yet, despite its importance across the lifespan, little is known about its development in the first year of life. Therefore, this study aimed to extend existing research concerning the development of interoception. We investigated whether 9-month-old infants show implicit interoceptive sensitivity towards cardiac stimuli and respiratory stimuli. To our knowledge, we were the first ones to investigate implicit interoceptive respiratory sensitivity in infancy. Then, we examined how interoceptive sensitivity across these two modalities is related in infancy. Finally, we tested how four specific dimensions of maternal interoceptive sensibility are related to infant interoceptive sensitivity. Overall, we could not find evidence for implicit interoceptive sensitivity to either of the included interoceptive signals (heartbeat or respiratory rhythm) in our study sample contrary to Maister et al.'s (2017) findings for implicit interoceptive sensitivity. Additionally, we did not find a relationship between cardiac and respiratory interoceptive sensitivity in our sample. Finally, whereas most dimensions of maternal interoceptive sensibility were unrelated to infant interoceptive sensitivity, we showed that "Emotional Awareness" explains infant interoceptive respiratory sensitivity.

In contrast to previous studies, we did not find empirical evidence of implicit interoceptive sensitivity in infants. Previous findings of preferential looking paradigms showed interoceptive cardiac sensitivity in 5-month-old infants at group level, as infants preferred asynchronous stimuli (Maister et al., 2017). Whatsoever, we found no evidence that infants looked significantly longer at the asynchronous condition, which could imply that infants in the present study were not able to integrate cardiac interoceptive information with stimuli in the environment. Several potential explanations for these findings exist.

First, the recently developed "iBEAT" paradigm by Maister et al. (2017) is often regarded as a methodological advance of measuring interoceptive sensitivity through heartbeat detection in very early infancy. But it remains unclear whether it is adequate at measuring interoception, as heartbeat detection might be facilitated by exteroceptive somatosensory information (Jones et al., 2021). Further, due to the missing replications of the results, it remains ambiguous, how well the measure is validated. In psychology, only very few empirical findings are directly or conceptually replicated (Makel et al., 2012), and the replicability of findings in infancy research might be even lower. Infant studies that use preferential looking paradigms often come with a small sample size, because experiments are time consuming, expensive, and difficult to conduct. Still, replications is very essential (Oakes, 2017). The replication of "iBEAT" by Weijs et al. (2019) led to a preference towards synchronous stimuli, which adds uncertainty towards the interpretability of Maister et al.'s (2017) findings. To achieve better understanding of these heterogeneous results regarding implicit interoceptive cardiac sensitivity, more studies are necessary. Concerning interoceptive respiratory sensitivity, it remains unclear, whether the novel "iBREATH" paradigm is adequate at measuring interoception in infants due to the same reasons (i.e., unvalidated measure, exteroceptive information, missing replications).

Second, there are methodological reasons. Outlier removal, as performed by Maister et al. (2017) is highly controversial in psychology. Removing outliers in the statistical analysis for the comparison of means might severely increase Type I errors, where an effect that is actually not present in the underlying population has been observed (Bakker & Wicherts, 2014). Non-parametric tests that include outlier trials, or parametric tests with outliers and log-transformed variables could lead to higher statistical power (Bakker & Wicherts, 2014; Csibra et al., 2016). Our exploratory analysis showed that when outlier trials (i.e., trials with individual looking time greater than two standard deviation from group mean) were included to the analysis, looking time across conditions still did not differ significantly, but statistical power increased.

Third, our analysis indicated – even after conducting an exploratory analysis – that infants did not show interoceptive sensitivity at group level. Therefore, despite previous findings, implicit interoceptive sensitivity might not exist in 9-month-old infants. Interoception is difficult to measure in humans. In infancy, adequate paradigms have only been developed quite recently, and the early development of interoception remains understudied (Murphy et al., 2017). The few previous studies of interoception in infancy resulted in heterogeneous findings, included a small sample size, and possessed over low statistical power (Maister et al., 2017; Weijs et al., 2019), which could have potentially lead to biased conclusions. Interoception is a highly complex process where many areas of the brain are involved. The integration and interpretation of external and internal stimuli are important prerequisites for its development (Craig, 2009; Koch & Pollatos, 2014). During interoceptive processing, the brain does not only receive interoceptive information, but it also regulates internal environments of the body through descending pathways (Berntson & Khalsa, 2021; Craig, 2003). The developmental process in infancy and childhood could be dynamic and variable (Koch & Pollatos, 2014). Neural circuits underlying interoception might only be developed in later childhood. For that reason, it is possible that infants' brains are not mature enough for interoceptive sensitivity, especially as other cognitive functions associated with interoception like memory, learning and decision making, are also developed at a later timepoint (Dunn et al., 2012; Khalsa et al., 2018; Werner et al., 2009).

Fourth, due to the complexity of the development of interoception in infancy, age-related changes might add to the explanation of the current findings. 9-month-olds did not show interoceptive sensitivity, even though it has been observed in infants who are remarkably younger. Due to the dynamics of the process and the variance of developmental trajectories in infancy, one cannot rule out the possibility that infants at the age of nine months might be less sensitive to interoceptive cardiac signals than infants, who are remarkably younger. For example, trust in one's own body might decrease with age (Jones et al., 2021), and interoceptive cardiac sensitivity might improve with age in middle childhood (Murphy et al., 2019). However, more elaborate empirical evidence is required to further pursue this theory.

In our sample of 9-month-old infants, interoceptive cardiac and respiratory sensitivity have been observed to be unrelated, which is consistent with previous research in healthy adults (Garfinkel et al., 2016).

First, it might be important to discuss our findings within the three-dimensional framework of interoception as described by Garfinkel and Critchley (2013). While cardiac and respiratory interoceptive sensitivity across these modalities had discrepancies, interoceptive awareness has been observed to be positively related across cardiac and respiratory axes in healthy adults (Garfinkel et al., 2016). Additionally, it has been suggested by Garfinkel and Critchley (2013) that interoceptive sensitivity is only related in individuals with a high degree of interoceptive awareness. Hence, unrelated interoceptive sensitivity across two modalities does not consequently mean that cardiac and respiratory interoception are unrelated across all three dimensions of interoception (i.e., sensitivity, sensibility, awareness).

Second, due to the dynamic developmental trajectories of interoception in childhood (Koch & Pollatos, 2014), interoceptive sensitivity of distinct modalities could develop at different time points. The complex multisensory integration of interoceptive signals (Ceunen et al., 2016) might not develop simultaneously for all modalities. This could explain a missing positive relation between cardiac and respiratory interoceptive sensitivity in 9-month-olds. More research is necessary to better understand, how interoceptive capabilities across different modalities might be related in infancy and across different developmental stages.

Third, our findings indicate that researchers who traditionally assume heartbeat detection to be very closely related to the detection of other inner-bodily signals should be careful when making inferences. It might be erroneous to interpret infant heartbeat or respiratory rhythm detection capabilities as interoceptive sensitivity. Using heartbeat tasks to measure interoception has been discussed controversially (Brener & Ring, 2016) and it remains unclear how exteroceptive signals that arise from heartbeats might affect interoceptive processing (Jones et al., 2021; Khalsa et al., 2009). Still, observing independence between cardiac and respiratory interoceptive sensitivity in infancy should not lead to the potentially wrong conclusion that interoceptive sensitivity is necessarily independent across all modalities. In adults, it is assumed that cardiac and gastric interoception are positively related (Herbert et al., 2012). Therefore, it needs further investigation, how interoception across different modalities is related in infancy. Technological advancements could help to develop novel measures that are applicable even in early infancy. Measures of interoception should contemplate the multidimensionality and multimodality of interoception to adequately depict interoceptive processing capabilities in infancy.

As opposed to what previous research has suggested (Fotopoulou & Tsakiris, 2017; MacCormack et al., 2020), a relation between maternal and infant interoception could not be observed. However, while all included dimensions of maternal interoceptive sensibility were unrelated to infant interoceptive sensitivity towards cardiac signals, higher values in the dimension of "Emotional Awareness" were associated with higher infant interoceptive sensitivity towards respiratory signals. In the current study, behavioral (i.e., sensitivity) and self-reported (i.e., sensibility) dimensions of interoception were compared. Because the dimensions of interoception might have distinct and dissociable contributions to behavior (Garfinkel & Critchley, 2013), one needs to be cautious when interpreting these findings.

The results indicate that the development of early interoceptive sensitivity might be facilitated by mothers, who are more aware of their positive and negative emotions in the body (i.e., "Emotional Awareness"). There are several explanations for this. Being aware of own emotions might influence maternal behavior to be more sensitive towards infants during touch, looking behavior, or infant directed speech (Abraham et al., 2019; Perry et al., 2016). Caregivers with higher interoceptive and emotional awareness might thus be able to create an environment where the development of infant interoception is promoted (MacCormack et al., 2020). Further, neuronal evidence is congruent with the observed relation between maternal emotional processing and infant interoceptive development. In the postpartum period, maternal neural activation of areas of the brain that are especially relevant for emotional processing (i.e., limbic structures and amygdala; Phan et al., 2002), have been observed to contribute to a better modulation of children's somatic symptoms six years later (Abraham et al., 2019).

Still, many questions regarding the relation between parental and infant interoception remain unanswered (Montirosso & McGlone, 2020). It remains unclear, how the different dimensions of maternal interoception may impact the development of interoception in different stages in infancy. Observing real life interactions between caregivers and infants, while measuring bodily signals (e.g., ECG) might be especially interesting and could lead to new insights about the relation between maternal and infant interoception.

Limitations and future directions

There are some limitations of the current study. Taking up to three hours, the experimental setup was quite long. Mother-infant-dyads had to complete many tasks which are unusual in contrast to other infancy research studies. This might have impacted data quality or led to incompletion of relevant experiments. The sample size of the study was small, and there are only few infants with valid data in both, "iBEAT" and "iBREATH", tasks. Additionally, as the mostly well-educated, Western, and democratic mother-infant-dyads took part in the study, the homogeneity of socio-economic variables in our sample might have contributed limited representativeness.

To better interpret the heterogeneous findings concerning infant interoceptive sensitivity, further research about the development of interoception in infancy is needed. A bigger sample size would lead to higher statistical power. Until now, infant interoceptive sensitivity was measured exclusively through the observation of eye movement. Previous research paves the way for new perspectives for future investigations, which could also include a neurological perspective by applying methods that measure brain activity. It could be investigated, whether neural areas and circuits that have been associated with interoception in adulthood are also active during infant interoception tasks. Technological advances might make it easier to non-invasively measure interoception in infants and adults in the future. Concerning parental influences on infant interoception, the current study was solely focused on the influence of maternal interoceptive sensibility as measured through self-report questionnaires. Interoceptive sensibility and sensitivity might only be related in people with high interoceptive awareness (Garfinkel & Critchley, 2013), and future research could investigate how the behavioral aspects of maternal interoception like heartbeat detection (i.e., interoceptive sensitivity) is related to their infant's interoceptive sensitivity.

Conclusion

This study investigated the development of interoceptive cardiac and respiratory sensitivity in 9-month-old infants. In contrast to other studies, infants in the first year of life did not express implicit interoceptive sensitivity towards cardiac and respiratory signals at group level. Further, individual cardiac and respiratory interoceptive sensitivity were unrelated. Finally, most dimensions of maternal interoceptive sensibility were unrelated to infant interoceptive sensitivity. The present study added to the current research on the development of interoception in the first year of life. Studying the development of interoception is important to gain a deeper understanding of the development of important cognitive, social, and emotional functioning in infancy.

Even though you have most probably not felt your heartbeat around 3.400 times while you were reading this study, you probably gained a deeper understanding of the broader relevance of interoception. Interoception influences various important bodily functions of humans, and research about its development could add valuable information about human behavior and the pathogenesis of diseases later in life.

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Appendix

A. Abstract

Interoception, the perception of internal, visceral bodily changes, is related to important cognitive functions and may influence emotional experiences and behavior. In infancy, it is especially relevant, but little is known about its development in the first year of life. Through preferential looking paradigms, this study investigated whether 9-month-old infants (*N* = 40, 13 girls) show implicit interoceptive sensitivity towards cardiac and respiratory signals, addressed how interoceptive sensitivity across these modalities is related, and assessed the influence of maternal interoception on infant interoceptive sensitivity. In the sample, no empirical evidence of interoceptive sensitivity and no statistical relation between cardiac and respiratory sensitivity was observed. Finally, it was examined that the dimension "Emotional Awareness" of maternal interoceptive sensibility was related to infant interoceptive respiratory sensitivity. The results add valuable information concerning interoceptive processing across different modalities and its development in the first year of life.

B. Zusammenfassung

Interozeption, die Wahrnehmung innerer, viszeraler Körperveränderungen, hängt mit vielen kognitiven Funktionen zusammen und kann emotionale Erfahrungen und Verhaltensweisen beeinflussen. Im Säuglingsalter ist interozeptive Verarbeitung besonders wichtig für die Entwicklung von emotionalen, sozialen und kognitiven Funktionen. Trotz der Bedeutung von Interozeption ist wenig über die Entwicklung im ersten Lebensjahr bekannt. Anhand von Blickverhaltensexperimenten untersuchte diese Studie, ob 9 Monate alte Säuglinge (N = 40, 13 Mädchen) eine implizite interozeptive Sensitivität (objektive Verhaltensdimension von Interozeption) gegenüber Herz- und Atemsignalen aufweisen. Außerdem wurde untersucht, wie die interozeptive Sensitivität über die Modalitäten Herzschlag und Atemrhythmus hinweg zusammenhängt, und ob mütterliche interozeptive Sensibilität (subjektive Wahrnehmung von Interozeption) einen Einfluss der auf die interozeptive Sensitivität von Säuglingen hat. In der Stichprobe wurden keine empirischen Hinweise auf eine interozeptive Sensitivität und kein statistischer Zusammenhang zwischen kardialer und respiratorischer Sensitivität beobachtet. Während mütterliche interozeptive Sensibilität weitestgehend unabhängig von der kindlichen interozeptiven Sensitivität ist, hängt die Dimension „Emotionales Gewahrsein“ der mütterlichen Interozeption positiv mit der Atemrhythmuswahrnehmung der Säuglinge zusammen. Die Ergebnisse liefern wertvolle Informationen über die interozeptive Verarbeitung über verschiedene Modalitäten und ihre Entwicklung im ersten Lebensjahr.

C. Figures

D. Tables