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Review

Associations between parent–infant interactions, cortisol and vagal regulation in infants, and socioemotional outcomes: A systematic review

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ABSTRACT

Emotional regulation in early infancy develops mainly through social interactions with caregivers and is a key process in socioemotional functioning. The use of physiological measures such as vagal tone and cortisol can help researchers understand what underlies this association between parent–infant interaction, emotion regulation, and socioemotional functioning. This review integrates 39 studies from four databases. We first examine associations between parent–infant interactions and physiological measures of emotion regulation in children aged 0–24 months. We then examine the association between these physiological measures and children's socioemotional outcomes. The results provide insights into which aspects of parent–infant interactions are associated with the physiological functioning of infants and which socioemotional outcomes in infants may be influenced by this functioning.

1. Introduction

Social interactions in infancy, especially parents-infant interactions, are crucial for infants' socioemotional functioning, as they shape the development of emotion regulation abilities. These regulation abilities are observable at a physiological level, through neuroendocrine or biological indicators. Studies have been conducted to establish associations between the quality of early parents-infant interactions, physiological regulation and socioemotional outcomes in infants. In order to synthetize the results of these studies, we conducted a systematic literature review.

Emotion regulation is defined as a "process responsible for monitoring, evaluating and modifying emotional reactions, especially their intensive and temporal features, to accomplish one's goal" (Thompson, 1994, p. 27). Poor ability to regulate emotions is predictive of developmental disturbances such as externalizing or internalizing symptoms (Cole & Deater-Deckard, 2009; Cole & Hall, 2008a, 2008b; Cole, Michel, & Laureen O'Donnell, 1994; Cole, Luby, & Sullivan, 2008; Eisenberg & Fabes, 2006; Eisenberg et al., 1997; Halligan *et al.* 2013; Thompson, 1991). Emotion regulation has intrinsic and extrinsic components, with a strong influence of the environment and on the environment (Campos, Mumme, Kermoian, & Campos, 1994). In the first months of life, infants have immature emotion regulation abilities and they need the adult to regulate their emotions. Emotions in infants can function as messages sent to the caregivers; in response, caregivers adapt their behaviors so that the environment of the infant is modified, as well as their internal state (Cole, Martin, & Dennis, 2004; Field, 1994; Tronick, 1989). It is through the repetition of this process that infants learn to

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understand their own internal states and how to regulate emotions. The majority of emotional regulation skills are built in the early years of life. After this initial stage in which emotions are entirely regulated by adults, as infants grow up, a process of co-regulation involving the infants and their parents takes place. Finally, infants progressively become capable of self-regulation (Sameroff, 2004). Thus, there is a crucial interpersonal component in infants' emotion regulation. As a consequence, the quality of the early relational context, especially the interactions with caregivers, has a major influence on the development of emotion regulation abilities (Cole et al., 2004; Morris, Steinberg, Silk, Myers, & Robinson, 2007).

The quality of early interactions depends on the parents' ability to understand the infant's emotional states and needs and to adjust their behavior accordingly. Research studies and clinical scholars have identified the characteristics of an interaction that will benefit the child. First, the interaction needs to be synchronous, defined as a social match between the mother's and the infant's behavior, allowing for harmony in social exchange (Brazelton, Koslowski, & Main, 1974; Stern, 1985). This match is an adjustment of the communication in the rhythm, nature, and emotional tone of the exchange. However, in parent-infant interactions, interactive mistakes are likely to happen (Tronick & Gianino, 1986). Synchrony in parent-infant interactions is a process resulting from repairs these moments of mismatch that arise from these interactive mistakes (Beeghly, Fuertes, Liu, Delonis, & Tronick, 2011). Second, parental behavior also needs to be contingent on the infant's behavior. Contingency is defined as adequacy of the parent's response to the infant signals, in the type of response, and in the temporal delay (Ainsworth, Bell, & Stayton, 1974; Bell & Ainsworth, 1972). Third, the level of stimulation provided by the parent must be adapted to the baby's age and state to ensure an optimal level of arousal in the baby in order to interact. During an interaction, the parent interprets the infant's signals to provide optimal stimulation and the infant reinforces the parent's behavior by remaining attentive and receptive. For example, if the infant is highly aroused, the parent will lessen the stimulations so that the baby is able to lower his or her arousal. In contrast, interactions involving maladjusted parenting behaviors cause stress in the infant and, in turn, repeated stressful experiences might have negative consequences for infant development in the long run. For example, when an infant is overwhelmed by the interaction, parents who are unable to read their infant's signals continue with the activity rather than adjusting their behavior to the infant's state. When parents do not respond adequately, or do not repair interactive mistakes quickly enough, their behaviors might be stressful for the infant and they do not provide him/her the support to develop its self-regulation abilities. Finally, parental sensitivity is the parent's ability to perceive and understand the infant's signals in order to respond to these signals (Ainsworth, 1967) in an appropriate way. Investigators report that parental sensitivity is also an important predictor of the child's attachment (Belsky, Rovine, & Taylor, 1984; Braungart-Rieker, Garwood, Powers, & Wang, 2001; Braungart-Rieker et al. 2014; Campbell et al. 2004; Isabella, Belsky, & Von Eye, 1989; Isabella & Belsky, 1991; McElwain & Booth-LaForce, 2006) and therefore another indicator of the quality of the interaction. Thus, studies have shown that several qualitative aspects of parent-child interactions can influence the child's social-emotional functioning. It is now clear that emotion regulation is the process through which better quality of early parent–infant interactions is related to better socioemotional functioning, referring to the abilities to regulate thoughts, emotions, and behaviors.

To date, most studies have assessed emotion regulation in infants through the observation of behaviors (e.g., qualified in terms of emotional reactivity, negative affectivity, and regulatory behaviors) (Crugnola et al. 2011; Diener, Mangelsdorf, McHale, & Frosch, 2002; Manian & Bornstein, 2009; Thomas et al. 2017). However, observational measurements have a limitation: Observed behaviors are influenced by physiological or neural processes involved in emotion regulation. An access to these physiological functioning is therefore necessary to more comprehensively understand the processes through which parent–infant interaction is related to infant outcomes. Studies have been dedicated to the measurement of physiological indicators of these processes, with physiological measures recorded during stressful situations (Bazhenova, Plonskaia, & Porges, 2001; Cordero et al., 2016; Jansen, Beijers, Riksen–Walraven, & de Weerth, 2010; Jones-Mason, Alkon, Coccia, & Bush, 2018; Provenzi, Giusti, & Montirosso, 2016; Stifter & Corey, 2001).

The two most studied physiological markers of emotion regulation are cortisol and vagal tone. These two markers represent two different neurophysiological systems that are influenced by stress. The first system, the hypothalamus-pituitary-adrenal axis, plays a central role in the body response to stress (Kirschbaum & Hellhammer, 1989) and is associated with emotion regulation (Gilbert, Mineka, Zinbarg, Craske, & Adam, 2017). The amount of cortisol, a hormone produced by the adrenal glands when humans experience stress, can be used as a measure of the activity of adaptation of the hypothalamus-pituitary-adrenal axis to stress (Helhammer, Wüst, & Kudielka, 2008). When humans are exposed to stressful situations, salivary cortisol increases. The second system is the autonomic nervous system, which is composed of two subsystems: the parasympathetic and the sympathetic nervous system. The parasympathetic nervous system is associated with growth and restoration systems, whereas the sympathetic nervous system is associated with the mobilization of resources to meet environmental demands. They are therefore two systems with antagonistic effects whose responses allow individuals to physiologically adapt to their environment. Vagal tone is an indicator of the parasympathetic modulation of the organs, particularly the heart. According to the polyvagal theory (Porges, 1995, 2001), vagal tone responds to environmental demand through an increase or a decrease in its influence in order to mobilize the necessary metabolic resources. For example, when the environment is safe, high vagal tone (i.e., high parasympathetic influence) will lower the heart rate, promote calm, and allow the individual to engage socially, a process called the "vagal brake." In turn, when an individual is confronted with social stress, a decrease in vagal tone, which corresponds to a decrease in parasympathetic influence (Moore & Calkins, 2004), is likely to occur. The release of this "vagal brake" allows the individual to engage physiological resources, such as an increase in cardiac output (i.e., increase in heart rate), to cope with external demands. Vagal tone is associated with emotional functioning and is considered as an indicator of emotional regulation abilities (Gottman & Katz, 2002; Gentzler, Santucci, Kovacs, & Fox, 2009; Porges, Doussard–Roosevelt, & Maiti, 1994; ; Zisner & Beauchaine, 2016). In most studies, vagal tone is indexed by the respiratory sinus arrhythmia, which is related to changes in heart rate that accompany breathing. Vagal tone is reflected in the amplitude of the heart rate associated with the breathing rate. The study of these two neurophysiological circuits gives a fairly accurate picture of how an individual regulates his or her functioning in situations of stress, threat, danger, or challenge, and therefore these circuits are perfectly suited to the study of emotional regulation capacities.

Several conclusions can be drawn from the aforementioned studies: First, the development of emotion regulation abilities strongly depends on the quality of early parent–infant interactions. Second, emotion regulation can be indexed by physiological measures of vagal tone and cortisol. Third, emotion regulation is one of the key processes that explains an infant's socioemotional outcomes. Many studies have been published on the links between parent–infant interactions and outcomes related to emotional regulation abilities in infancy that have used physiological measures and therefore the results can be compared. However, no systematic review, to our knowledge, has been conducted that synthesizes the results of these studies.

2. Aim of the study

Our goal is to systematically review evidence for (a) an association between parent–infant interactions and physiological emotion regulation in infants and (b) an association between physiological emotion regulation in infants and their socioemotional outcomes. The results will provide a better understanding of how early parent–infant interactions influence physiological measures and how physiological measures in turn influence children's socioemotional outcomes.

3. Method

In this systematic review, we followed the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines (Moher, Liberati, Tetzlaff, Altman, & the PRISMA Group, 2009). Studies were identified through a systematic search of four electronic databases: PsycInfo, PubMed, Embase, and Web of Science. A list of terms was established related to infancy and early toddlerhood (e.g., "infant," "early childhood," "baby," "neonate"), physiological measures (e.g., "psychophysiology," "autonomic nervous system," "heart-rate variability," "vagal tone," "cortisol"), parent-child interactions (e.g., "parenting," "parent child relations,

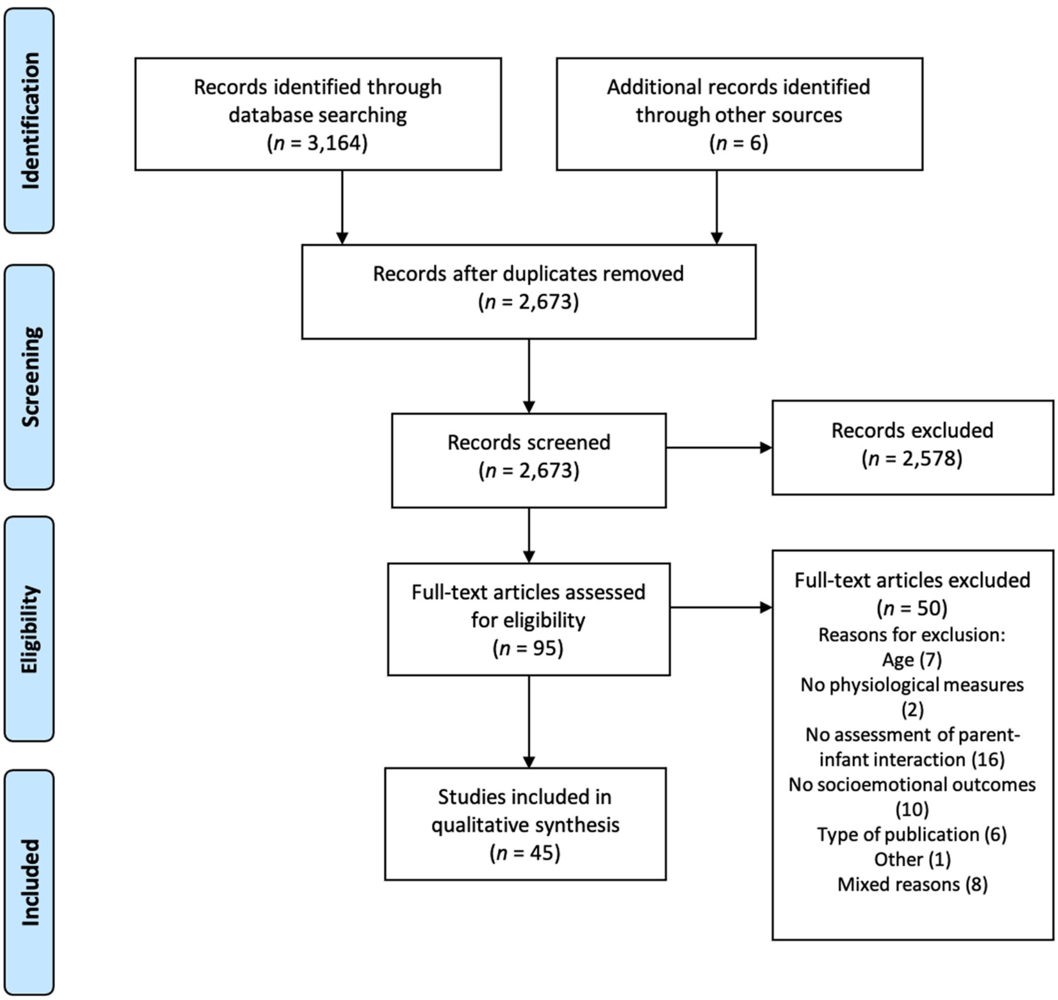

Fig. 1. PRISMA Flow Diagram.

" "family interaction," "family relation"), and socioemotional outcomes (e.g., "emotional regulation," "emotional response," "socio-emotional functioning," "emotional adjustment"). For each database, we found specific terms and added them to the list. Terms were then assembled into a search equation. Each search equation in each of the databases therefore contained the same terms, so that only the format of the equation was adapted to the different databases. Search equations are available in the supplementary material. The inclusion criteria for the studies were as follows: (1) targeted children between 0 and 24 months, as this is an age when emotional regulation is most dependent on other people; (2) included a physiological measure of salivary cortisol and/or vagal tone; (3) included a systematic assessment of parent-child interaction; (4) assessed a child's socioemotional outcomes concurrently or in later stages of development; (5) involved children without any medical condition or functional disorders that possibly affected emotion regulation (e.g., Down syndrome, autism); (6) were peer reviewed; and (7) were published in English or French, since these are the languages spoken by the authors.

The initial search and extraction from the databases was conducted on March 5, 2020. The search was conducted again for an update on September 1, 2021. References were imported in an EndNote (version X8; Thomson Reuters, New York, NY, USA) database by one reviewer (first author), which allowed us to identify and remove duplicates. From this point, each step in the selection of studies was done by two individuals separately (first and second authors). Studies were first selected on the basis of titles/abstracts according to the inclusion criteria. After the first and second authors read the full text, studies that did not meet the inclusion criteria were excluded. For each study, coders specified the reason for exclusion. When there were several reasons, a "mixed" code was specified. A third coder (third author) was involved to resolve the few disagreements between the two coders.

The studies were screened to review support for the associations between (a) parent–infant interaction and physiological emotion regulation and (b) physiological emotion regulation and infant socioemotional outcomes. Moreover, we required the included studies to measure these associations in temporal order. As the quality of parent–infant interactions are thought to be important in the development of physiological emotion regulation, parent–infant interactions have to be measured before or at the same time as physiological measures. As physiological regulation influences socioemotional outcomes, physiological measures have to be measured before or at the same time as the socioemotional outcomes. The association between parent–infant interaction and an infant's socioemotional outcomes will not be addressed in this review, as this association is already well documented in the literature (Cooke, Kochendorfer, Stuart–Parrigon, Koehn, & Kerns, 2019; Leclère et al., 2014). Moreover, this association could have been explored only partially, as most studies concerning this association did not use physiological measures.

4. Results

4.1. Studies included

A total of 3164 records were extracted from the databases. After we removed duplicates, the remaining 2667 records were assessed for eligibility on the basis of title/abstract selection. A total of 2578 records that did not meet inclusion criteria were then excluded. Of the 89 articles included, 39 were selected after reading the full-texts. Six additional articles were identified through other sources (e.g. expert communication), which leads to 45 articles included in this review, with the data being derived from 39 studies. (Fig. 1).

4.1.1. Methodological characteristics

4.1.1.1. Samples characteristics. Some of the studies included in the review reported little or no information on the characteristics of the samples, making it impossible to synthetize and report precise percentages of these characteristics. Most of the studies included in this review were conducted in the United States of America. There were also studies from Israel, Canada, Germany, Italy and Norway. Not all the studies described samples characteristics. Samples' ethnicity was mostly Caucasian/European American. Some of the samples were also equally European American and African American, Israeli, African American, Hispanic or multicultural. Most of the studied sampled were from middle class, and some other studies with a focus on low income population. Studied populations were also mostly highly educated, with most of the mothers and fathers having completed a high school degree or more. Finally, the average age of the mothers in these studies ranged from $M = 23.57$ years to M = 34 years. The average age of the fathers ranged from $M = 30.28$ years to $M = 32$ years.

4.1.1.2. Type of physiological measurement. Most studies assessed physiological regulation by using either vagal tone (25) or salivary cortisol (19), whereas only one study used both measurement methods (1). In all of the studies that included a measure of vagal tone, the index of vagal activity was respiratory sinus arrhythmia. Physiological measurements were recorded during different paradigms (e.g., emotion induction tasks, social interaction).

4.1.1.3. Type of parent–infant interactions. The paradigms used for observation of parent–infant interactions varied across studies. The more frequently used were the Still-Face paradigm (13), free play (19), and Strange Situation paradigm (6). Studies also considered interactions during, before, or after different tasks, which were more often tasks eliciting frustration or semi-structured interactions (5). Finally, a few studies considered the parent–infant interaction during inoculation (2) or stimuli presentation (1). The assessments of the interactions were parenting behaviors, parental sensitivity, attachment classification, synchrony, reparation, responsiveness, matching of affective states, or reciprocity. We present the results according to four types of relational or interactive processes targeted by the studies in the evaluation of the quality of interactions: dyadic interactional patterns, parental sensitivity, parental behavior, and

Table 1
Studies Included in the Review.

Study	Sample	Physiological measure	Interaction paradigm	Socioemotional outcomes	Interaction – Physiological measure	Physiological measure – Outcomes
Ahnert, Gunnar, Lamb, and Barthel (2004)	70 children (*M* = 14.9 months)	Salivary cortisol	Strange Situation; attachment classification	Emotional reactivity	Differences in cortisol levels for secure and insecure groups when the mother is present.	×
(Bader et al., 2021)	141 mother-infant and 125 father-infant (12 months)	Salivary cortisol	Strange situation, Parents-infant interaction; parental sensitivity	Emotional reactivity	Cortisol baseline and reactivity are not associated with parental sensitivity. Only cortisol recuperation is correlated with maternal sensitivity.	Cortisol is associated with emotional reactivity in different ways in mother and father interaction.
Blair et al. (2008)	1292 children (*M* = 7.6 months; *M* = 15.7 months)	Salivary cortisol	Mother-infant interaction; parental behaviors	Emotional reactivity	Positive parenting in infancy predicted cortisol in infancy and in toddlerhood.	×
Blair et al. (2015)	1021 children (24 month)	Salivary cortisol	Mother-infant interaction; parental sensitivity	Emotional reactivity	Cortisol negatively associated with positive parenting and positively associated with negative parenting.	Cortisol reactivity and recovery positively associated with negative emotional reactivity.
Braarud & Stormark (2006)	37 children (*M* = 13.4 weeks)	Salivary cortisol	Interaction during inoculation procedure; parental behaviors	Emotional reactivity	Infant's cortisol levels increased more when the mothers showed more soothing after than before the injection.	×
Braren, Perry, Ursache, and Blair (2019)	1292 children (*M* = 7.72 months; *M* = 15.60 months; *M* = 24.82 months)	Salivary cortisol	Mother-infant interaction; parental behaviors	Emotional reactivity	Positive parenting negatively correlated with cortisol baseline and negative parenting positively correlated with cortisol baseline.	Emotional reactivity positively associated with cortisol reactivity.
Bugental, Martorell, and Barraza (2003)	44 children (*M* = 17.56 months)	Salivary cortisol	Strange Situation; parental behaviors	Toddler Behavior Assessment Questionnaire	Negative parenting is positively correlated with cortisol.	×
Calkins and Fox (1992)	52 children (*M* = 2 days; *M* = 5.04 months; *M* = 14.45 months; *M* = 24.67 months)	Vagal tone	Strange situation; attachment classification	Toddler Behavior Assessment Questionnaire	No association between attachment and vagal tone.	No relation between vagal tone and inhibition.
Calkins and Johnson (1998)	73 children (18 months)	Vagal tone	Mother-infant interaction; parental behaviors	Emotional reactivity	×	No relation between negative emotional reactivity and vagal tone.
Calkins, Smith, Gill, and Johnson (1998)	65 children (24 months)	Vagal tone	Mother-infant interaction and tasks; parental behaviors	Emotional reactivity; regulatory behaviors	Negative parenting is negatively associated with vagal reactivity.	Associations between vagal tone and regulatory behaviors.
Cho and Buss (2017)	124 children (*M* = 24.43 months, *SD* = 0.47)	Vagal tone	Mother-infant interaction; parental behaviors	Infant-Toddler Social and Emotional Assessment	Maternal comforting behaviors is positively correlated with vagal reactivity.	Vagal tone is not related to inhibition or separation distress.
Conradt and Ablow (2010)	95 children (*M* = 20.99 weeks, *SD* = 2.55)	Vagal tone	Still-Face paradigm; parental behaviors	Emotional reactivity; Infant Behavior Questionnaire	Maternal sensitivity after the Still Face paradigm predicts vagal tone recovery.	×
Degnan, Calkins, Keane, and Hill–Soderlund (2008)	447 children (24 months)	Vagal tone	Mother-infant interaction; parental behaviors	Emotional reactivity; Child Behavior Checklist	Maternal sensitivity is not correlated with vagal tone.	Vagal reactivity is positively correlated with negative emotional reactivity. No direct association between vagal tone and disruptive behaviors.
		Vagal tone		Emotion regulation		

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Table 1 (*continued*)

Study	Sample	Physiological measure	Interaction paradigm	Socioemotional outcomes	Interaction – Physiological measure	Physiological measure – Outcomes
Eiden, Schuetze, Shisler, and Huestis (2018)	247 children (2 months; 9 months; 16 months; 24 months)		Mother-infant interaction; parental sensitivity		Maternal sensitivity is not correlated with vagal tone.	Vagal reactivity is negatively correlated with emotion regulation. Vagal reactivity in infancy is predictive of lower emotion regulation in toddlerhood.
Erickson, MacLean, Qualls, and Lowe (2013)	53 children (from 6 to 8 months)	Salivary cortisol	Still-Face paradigm; parental behaviors	Emotional reactivity	×	Cortisol reactivity is negatively correlated with positive emotional reactivity and is not related to negative emotional reactivity.
Feldman (2006)	71 children (birth; 3 months)	Vagal tone	Mother-infant interaction; synchrony	Emotional reactivity	×	Lower vagal tone is related to more crying.
Feldman (2015)	125 children (birth; 3 months; 6 months; 12 months; 24 months; 5 years; 10 years)	Vagal tone	Parents-infant interaction; synchrony	Emotion regulation	×	Vagal tone is positively correlated with and predicted emotion regulation in the first year.
Feldman and Eidelman (2009)	126 children (birth; 3 months; 6 months; 12 months; 24 months; 5 years)	Vagal tone	Mother-infant interaction; parental sensitivity	Social engagement	×	Vagal tone has an effect on social engagement.
Feldman et al. (2009)	100 children (9 months)	Salivary cortisol	Mother-infant interaction; parental sensitivity; parental behaviors	Social engagement	Cortisol is negatively correlated with lower maternal sensitivity; maternal sensitivity predicts cortisol reactivity.	×
Feldman, Singer, and Zagoory (2010)	53 children (*M* = 25.65, *SD* = 1.30)	Salivary cortisol; vagal tone	Still-Face paradigm; synchrony (touch)	Regulatory behaviors	Vagal tone is positively correlated with touch synchrony and negatively correlated with touch mysynchrony; cortisol is positively correlated with touch mysynchrony.	×
Finger, Schuetze, and Eiden (2014)	216 children (4–8 weeks; 7 months; 13 months; 18 months; 24 months)	Vagal tone	Mother-infant interaction; parental sensitivity	Child Behavior Checklist	×	Vagal tone baseline is positively correlated with internalizing and externalizing behaviors; vagal withdrawal is not.
Fong, Measelle, Conradt, and Ablow (2017)	58 children (*M* = 17.56 months, *SD* = 1.73)	Salivary cortisol	Strange Situation; attachment classification	Brief Infant-Toddler Social and Emotional Assessment	Attachment is not correlated with cortisol baseline.	Cortisol baseline is not correlated to behavior problems.
Graham, Ablow, and Measelle (2010)	77 children (*M* = 20.99 weeks; *SD* = 2.55)	Vagal tone	Still-Face paradigm; parental sensitivity	Infant Behavior Questionnaire	Maternal sensitivity is not correlated with vagal tone.	×
Haley and Stansbury (2003)	43 children (*M* = 23.56 weeks; *SD* = 2.87)	Salivary cortisol	Still-Face paradigm; parental sensitivity	Emotional reactivity	Parent responsiveness is not associated with cortisol.	Cortisol baseline is positively correlated with negative affect.
Ham and Tronick (2006)	12 children (5 months)	Vagal tone	Still-Face paradigm; parental behaviors	Emotional reactivity	×	Vagal tone increase after stress is associated with more distress regulation.

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Table 1 (*continued*)

Study	Sample	Physiological measure	Interaction paradigm	Socioemotional outcomes	Interaction – Physiological measure	Physiological measure – Outcomes
Ham and Tronick (2009)	18 children (5 months)	Vagal tone	Still-Face paradigm; parental behaviors	Emotional reactivity	Synchrony is positively correlated with vagal tone after stress.	Negative affect is negatively correlated with vagal tone during normal interaction, but not following stress.
Hofheimer, Wood, Porges, Pearson, and Lawson (1995)	52 preterm children (35 and 42 weeks gestational age)	Vagal tone	Mother-infant interaction; parental behaviors	Emotional reactivity; regulatory behaviors	×	Vagal tone predicts lower distress and more attention to the mother.
Holochwost, Gariépy, Propper, Mills-Koonce, and Moore (2014)	95 children (6 months, 12 months)	Vagal tone	Still-Face paradigm, Mother infant interaction; parental sensitivity, parental behaviors	Infants' disorganization	Vagal tone is not correlated with maternal sensisitivy or maternal behaviors.	Vagal tone is positively correlated with infants' disorganization
Kalomiris et al. (2019)	119 children (M = 14.08)	Salivary cortisol	Strange Situation paradigm; parental behaviors	Observed toddler anxious behaviors	Cortisol is not correlated with parenting behaviors	Cortisol is not correlated with anxious behaviors.
Kiel and Kalomiris (2016)	117 children (M= 24.78 months; SD = 0.73)	Salivary cortisol	Mother-infant interaction; parental behaviors	Toddler anxiety (Infant-Toddler Social and Emotional Assessment)	Cortisol is not correlated with maternal comforting behavior; unsolicited comforting behavior predicted cortisol reactivity.	Cortisol reactivity is not correlated with anxiety.
Letourneau, Watson, Duffett-Leger, Hegadoren, and Tryphonopoulos (2011)	50 children (M = 4.90 months)	Salivary cortisol	Mother-infant interaction; parental behaviors	Infant interactive qualities	Maternal interactive behaviors reduced the overall concentration of cortisol and promote a decline of cortisol over the day	×
Martinez-Torteya et al. (2014)	153 children (7 months)	Salivary cortisol	Mother-infant interaction; parental behaviors	Emotional reactivity	Cortisol negatively correlated with positive parenting and positively correlated with negative parenting.	Infants' physiological reactivity is associated with behavioral regulation after the still-face paradigm.
Moore (2009)	48 children (M = 6.81 months, SD = 0.68)	Vagal tone	Still-Face paradigm; parental behaviors	Emotional reactivity	Maternal behaviors are not correlated with vagal tone.	Vagal tone reactivity is negatively correlated with negative emotional reactivity.
Moore et al. (2009)	152 children (6 months)	Vagal tone	Mother-infant interaction; Still-Face paradigm; parental behaviors	Emotional reactivity	Maternal sensitivity is not correlated with vagal tone.	Vagal tone is negatively correlated with negative affect during normal play and positively correlated with positive affect during normal play and after stress.
Muller et al. (2015)	46 children (3–4 months)	Salivary cortisol	Still-Face paradigm; synchrony	Regulatory behaviors	Cortisol is positively correlated with latency to repair during play and negatively correlated with positive social match during reunion.	Cortisol reactivity is positively correlated with self-comforting behaviors after stress.
Perry, Calkins, and Bell (2016)	230 children (5 months; 10 months)	Vagal tone	Mother-infant interaction; parental sensitivity	Regulatory behaviors	Maternal sensitivity at 5 months predicts vagal withdrawal at 10 months.	Vagal withdrawal predicts maternal-orientation behaviors.
Perry, Dollar, Calkins, and Bell (2018)	388 children (5 months; 10 months; 24 months)	Vagal tone	Mother-infant interaction; parental behaviors	Emotional reactivity	Negative parenting behavior is not related to vagal tone.	Vagal tone at 5 months is positively associated with negative emotional affectivity at 10 months.
Pratt, Singer, Kanat–Maymon,	122 mother-infant dyads	Vagal tone		Emotional reactivity	Synchrony is positively correlated with vagal	Negative emotional reactivity is positively

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Table 1 (*continued*)

Study	Sample	Physiological measure	Interaction paradigm	Socioemotional outcomes	Interaction – Physiological measure	Physiological measure – Outcomes
and Feldman (2015)	(*M* = 20.32 weeks, *SD* = 5.7)		Still-Face paradigm; parental behaviors		withdrawal and predicted vagal withdrawal.	correlated with vagal withdrawal and negatively associated with vagal tone during reunion.
Provenzi et al. (2015)	94 children (4 months)	Vagal tone	Still-Face paradigm; synchrony	Emotional reactivity	Vagal tone is not correlated with reparation rate. Less reparation rate in non-suppressor infants.	Vagal tone is not correlated with emotional reactivity. Non-suppressor had higher negativity than suppressor.
Skibo, Sturge-Apple, and Suor (2020)	220 mother-infant dyads (18 months; 42 months; 60 months)	Vagal tone	Mother-infant interaction; parental behaviors	Effortful control; emotion regulation	Vagal tone correlated with maternal harsh behaviors.	Vagal tone at 18 months is positively correlated with emotion regulation at 60 months.
Somers et al. (2021)	210 mother-infant (24 weeks)	Vagal tone	Mother-infant interaction; parental behaviors	Social engagement; emotional reactivity	Vagal tone predicted mother-driven coregulation.	Vagal tone and changes in vagal tone predicted aspects of emotion regulation during mother-infant interaction.
Sun, Measelle, and Ablow (2021)	105 mother-infant (5 months, 17 months, 5 years)	Salivary cortisol	Strange Situation; attachment classification	Child Behavior Questionnaire; effortful control	Cortisol is not related to attachment.	Cortisol is not related to effortful control.
Sweet, McGrath, and Symons (1999)	60 children (6 months or 18 months)	Vagal tone	Interaction during immunization; parental sensitivity	Infant Characteristics Questionnaire	Infant vagal tone is not correlated with maternal sensitivity.	×
Wagner, Mills-Koonce, Willoughby, Cox, and Family Life Project Key Investigators (2019)	1234 mother-infant (6 months, 15 months, 7 years)	Salivary cortisol	Mother-infant interaction; parental sensitivity and parental behaviors	Disruptive Behavior Disorder Rating Scale; Inventory of Callous-Unemotional traits	Baseline cortisol negatively correlated with maternal sensitivity but not harsh intrusion. Cortisol reactivity did not correlate with parenting measure.	Baseline cortisol correlated with empathic-prosocial behaviors but not with conduct problem or callous-unemotional behaviors. Cortisol reactivity is not related to any measured outcome.
Wu and Feng (2020)	1141 mother-infant (6 months, 15 months, 24 months)	Salivary cortisol	Mother-infant interaction; parental behaviors	Emotional reactivity; regulatory behaviors	Cortisol reactivity correlated with negative emotionality. Higher cortisol reactivity when mothers are engaged in the interaction; poorer cortisol reactivity when mothers are intrusive in the interaction.	Cortisol reactivity is correlated with orientation to the mother at 6 months, but not later.

Note. X = not considered in the study

attachment. Dyadic interactional patterns is a category regrouping several dyadic processes such as synchrony, reparation, and matching (Provenzi, Scotto di Minico, Giusti, Guida, & Müller, 2018). These categories were derived from the different measures in the included studies. Some measures did not fit into these categories. Thus, they are not reported in the narrative synthesis of results, but appear only in the summary table of included studies (Table 1).

4.1.1.4. Type of measurement of socioemotional outcomes. The socioemotional outcomes assessed were heterogenous. Some of the outcomes were assessed during observational situations (29), using coding systems. Others were assessed by using questionnaires (10). Finally, some studies considered both observation and questionnaire (6). The studies considered outcomes such as emotional reactivity, distress regulation, regulatory behaviors, social engagement, inhibition, or symptoms (e.g., anxiety, disruptive behaviors). Results regarding the association between physiological measures and socioemotional outcomes are presented in four categories, derived from the different measures in the included studies: emotional reactivity, distress regulation, regulatory behaviors, and symptoms. Emotional reactivity refers to the positive and/or negative emotions expressed by the infant in response to a situation (Fox, 1989). Distress regulation refers to the ability of the infant to regulate distress and recover from a stressful situation (Ham & Tronick, 2006). The regulatory behaviors are behaviors, adaptive or not, that the child actively uses to regulate himself (Conradt & Ablow, 2010). Finally, the symptoms are referring to the display of internal or external problems, such as anxiety or behaviors problem (Yahav, 2002). We also added a category for studies that used a global index of emotion regulation as an outcome; this indicator combines aspects of several of the categories previously presented. Again, some measures did not fit into these categories and appear only in the summary table of included studies (Table 1).

4.2. Narrative synthesis of the results

4.2.1. Parent–infant interaction and physiological emotion regulation

Of the 45 studies, 37 tested the influence of the quality of parent–infant interactions on physiological emotion regulation.

4.2.1.1. Dyadic interactional patterns. Four studies investigated the associations between dyadic interactional patterns, with indicators such as touch synchrony/asynchrony, latency to repair interactive mistakes, or moments of affective matching and physiological emotion regulation (Feldman et al., 2010; Müller, Zietlow, Tronick, & Reck, 2015; Pratt et al., 2015; Provenzi et al., 2015). All the studies considered only mother-infant interactions. Regarding cortisol, two studies investigated this association. There was no association between touch synchrony and cortisol (Feldman et al., 2010), but there was a positive correlation between touch asynchrony and cortisol ($r = .27$; Feldman et al., 2010) and between latency to repair and cortisol ($r = 0.30$; Muller et al., 2015). Cortisol was also negatively correlated with positive social matches after stress, but not during free play ($r = -0.29$; Muller et al., 2015). Three studies considered the association between dyadic characteristics of the interaction and vagal tone. Dyadic synchrony was positively associated with vagal withdrawal, but not with vagal recovery, and predicted vagal withdrawal during social stress (Pratt et al., 2015). Touch synchrony was positively associated with vagal tone, whereas touch asynchrony was negatively associated with vagal tone ($r = 0.33$ and $r = -0.28$, respectively; Feldman et al., 2010). Finally, dyadic matching of affective states and dyadic reparations were more frequently observed in dyads with optimal vagal functioning (Provenzi et al., 2015). Dyadic synchrony/asynchrony seem to be associated with infants' physiological regulation.

4.2.1.2. Parental sensitivity/responsiveness. Thirteen studies investigated the association between parental sensitivity and physiological emotion regulation (Bader et al., 2021; Conradt & Ablow, 2010; Eiden et al., 2018; Feldman et al., 2009; Graham et al., 2010; Haley & Stansbury, 2003; Ham & Tronick, 2009; Holochwost et al., 2014; Letourneau et al., 2011; Moore et al., 2009; Perry et al., 2016; Sweet et al., 1999; Wagner et al., 2019). Out of these studies, only one considered father-infant interactions. Of these studies, five tested the association between parental sensitivity and cortisol. Two studies found a negative association between maternal sensitivity and cortisol levels ($r =$ from -0.11 to -0.32; Feldman et al., 2009; Wagner et al., 2019), whereas the other study did not find any association (Haley & Stansbury, 2003). Two studies found that maternal sensitivity predicted cortisol levels (Feldman et al., 2009; Letourneau et al., 2011). One study showed that maternal sensitivity negatively correlated with cortisol levels 40 min after a stressor ($r = -0.24$; Bader et al., 2021). The only study which considered paternal sensitivity showed no association between fathers' sensitivity and cortisol reactivity (Bader et al., 2021). Seven studies considered the associations between marental sensitivity and vagal tone. No associations were found between observed maternal sensitivity during free play and vagal tone baseline or withdrawal (Conradt & Ablow, 2010; Eiden et al., 2018; Ham & Tronick, 2009; Holochwost et al., 2014; Moore et al., 2009; Perry et al., 2016; Sweet et al., 1999), and only one study found an association between maternal sensitivity during free play and vagal tone withdrawal ($r = 0.15$; Perry et al., 2016). Two studies found that maternal sensitivity observed after a stressful situation predicted vagal tone recovery from stress (Conradt & Ablow, 2010; Ham & Tronick, 2009), whereas one study showed the opposite result, with a decrease in vagal tone following social stress when the mother is sensitive (Moore et al., 2009). Finally, one study did not find an association between maternal sensitivity and vagal tone following a stressful situation (Graham et al., 2010). Another study reported a longitudinal association between the two variables such that a higher maternal sensitivity at 5 months predicted higher vagal tone at 10 months (Perry et al., 2016). Results tend to show that maternal sensitivity is particularly important during moments of stress for the infant.

4.2.1.3. Parental behavior. Fourteen studies tested the influence of parenting behaviors on physiological emotion regulation (Blair et al., 2008, 2015; Braren et al., 2019; Bugental et al., 2003; Calkins et al., 1998; Degnan et al., 2008; Holochwost et al., 2014; Kalomiris et al., 2019; Letourneau et al., 2011; Martinez-Torteya et al., 2014; Moore, 2009; Perry et al., 2018; Skibo et al., 2020; Wagner et al., 2019). All the studies considered only the mother's parental behaviors. Regarding cortisol, nine studies tested this association. Of these studies, three demonstrated negative correlations between positive parenting behaviors and cortisol baseline and reactivity ($r =$ from -0.09 to -0.32; Blair et al., 2015; Braren et al., 2019; Martinez-Torteya et al., 2014), whereas other studies reported negative correlations between positive parenting and cortisol baseline ($r =$ from -0.11 to -0.13; Braren et al., 2019) but not reactivity (Braren et al., 2019; Kalomiris et al., 2019). Two study reported that positive parenting predicted cortisol levels (Blair et al., 2008; Letourneau et al., 2011), whereas one did not find such results (Braren et al., 2019). Four studies reported a positive correlation between negative parenting and cortisol baseline and reactivity ($r =$ from.07 to.30; Blair et al., 2015; Braren et al., 2019; Bugental et al., 2003; Martinez-Torteya et al., 2014), one showed a positive correlation only between negative parenting and cortisol baseline ($r = 0.07$; Braren et al., 2019), and three studies showed no association between negative parenting and cortisol (Braren et al., 2019; Kalomiris et al., 2019; Wagner et al., 2019). One study showed that emotional unavailability was a significant predictor of cortisol baseline but not cortisol reactivity (Bugental et al., 2003). Two studies considered parental harshness as a predictor of cortisol reactivity and found significant results (Blair et al., 2015; Bugental et al., 2003). One study showed that the frequency of spanking predicted cortisol reactivity (Bugental et al., 2003). Finally, one study showed that negative parenting did not predict cortisol reactivity (Braren et al., 2019). Regarding vagal tone, six studies tested this association. One study demonstrated no association between positive parenting behavior and vagal tone (Calkins et al., 1998). One study reported a positive correlation between negative parenting behavior and vagal tone baseline ($r = .18$; Skibo et al., 2020), another study reported a negative correlation between negative parenting and vagal tone suppression ($r = -0.32$; Calkins et al., 1998), whereas four studies showed no association between negative parenting and vagal tone (Degnan et al., 2008; Holochwost et al., 2014; Moore, 2009; Perry et al., 2018). Results indicate that cortisol levels are influenced by parental behavior, whereas this does not seem to be the case for vagal tone.

4.2.1.4. Attachment. Four studies tested the association between attachment and physiological emotion regulation (Ahnert et al., 2004; Calkins & Fox, 1992; Fong et al., 2017; Sun et al., 2021). These studies considered only mother-infant attachment. Three studies tested the association between attachment status and cortisol: Two showed no influence of attachment status on cortisol baseline (Fong et al., 2017; Sun et al., 2021), whereas the other showed differences in cortisol levels depending on attachment status when the mother is present during a stressful situation (Ahnert et al., 2004). One study tested the association between attachment status and vagal tone but found no association (Calkins & Fox, 1992). Results tend to show no association between physiological measures and attachment.

4.2.2. Physiological emotion regulation and infant outcomes

Of the 45 studies, 35 tested the association between physiological emotion regulation and infant socioemotional outcomes.

4.2.2.1. Emotional reactivity. Seventeen studies tested the association between physiological emotion regulation and emotional reactivity (Bader et al., 2021; Blair et al., 2015; Braren et al., 2019; Calkins & Johnson, 1998; Degnan et al., 2008; Erickson et al., 2013; Feldman, 2006; Haley & Stansbury, 2003; Ham & Tronick, 2009; Hofheimer et al., 1995; Martinez-Torteya et al., 2014; Moore, 2009; Moore et al., 2009; Perry et al., 2018; Pratt et al., 2015; Provenzi et al., 2015; Wu & Feng, 2020). Six studies investigated the association between cortisol and emotional reactivity. One study showed that baseline cortisol is positively associated with negative emotional reactivity ($r = 0.33$; Haley & Stansbury, 2003), whereas another study showed negative correlations between baseline cortisol and negative emotional reactivity ($r = -0.11$; Blair et al., 2015) and two studies showed no correlation between baseline cortisol and negative emotional reactivity (Blair et al., 2015; Braren et al., 2019). Four studies showed that cortisol reactivity is positively associated with negative emotional reactivity ($r =$ from.08 to.33; (Bader et al., 2021; Blair et al., 2015; Braren et al., 2019; Wu & Feng, 2020), whereas four studies showed no association between cortisol reactivity and negative emotional reactivity (Bader et al., 2021; Blair et al., 2015; Erickson et al., 2013; Martinez-Torteya et al., 2014). One study showed that cortisol reactivity during stressor predicted negative emotionality during parent-infant interaction after stressor inversely for mothers and fathers, higher levels of cortisol during stress was related to higher negative emotionality during mother-infant interaction, whereas is was related to lower negative emotionality during father-infant interaction (Bader et al., 2021). Regarding the association between cortisol and positive emotional reactivity, one study tested this association and found a negative correlation between cortisol reactivity and positive emotional reactivity ($r =$ from -0.59 to -0.60; Erickson et al., 2013). Ten studies investigated the links between vagal tone and emotional reactivity. During free interaction or non-stressful tasks, two studies found that negative affect is negatively correlated with vagal tone ($r =$ from -0.21 and -0.59; Ham & Tronick, 2009; Moore et al., 2009), whereas one study found no association between vagal tone and negative emotional reactivity (Perry et al., 2018; Pratt et al., 2015). Moreover, one study showed that higher vagal tone is predictive of lower negative emotional reactivity during interaction (Hofheimer et al., 1995). One study showed that vagal tone was positively associated with positive emotional reactivity during normal interactions ($r = 0.26$; Moore et al., 2009). Three studies found a positive association between vagal tone and negative emotional reactivity during stressful situations ($r =$ from.15 to.29; Calkins & Johnson, 1998; Degnan et al., 2008; Pratt et al., 2015), whereas one study found no such association (Calkins & Johnson, 1998; Provenzi et al., 2015). Finally, one study found a negative association between vagal tone and negative emotional reactivity after a stressful situation ($r =$ from -0.31 to -0.34; Moore, 2009; Pratt et al., 2015), whereas two studies found no correlation between vagal tone and negative emotional reactivity after such a situation (Ham & Tronick, 2009; Provenzi et al., 2015). Two studies showed that infants with low vagal tone or low vagal withdrawal had higher negative emotional reactivity (Feldman, 2006; Provenzi et al., 2015). One study showed a positive correlation between vagal tone and positive emotional reactivity after stress ($r = 0.27$; Perry et al., 2018). One study showed that vagal tone at 5 months is positively correlated with negative emotionality at 10 months and can predict negative emotional reactivity at 10 months (Perry et al., 2018). Results are contrasted regarding the association between cortisol and emotional reactivity and do not allow to draw conclusions. However, results show a convergence between vagal tone and emotional reactivity.

4.2.2.2. Distress regulation. One study tested the association between vagal tone and distress regulation (Ham & Tronick, 2006) and showed that a greater increase in vagal tone following stress is related to better distress regulation.

4.2.2.3. Regulatory behaviors. Six studies investigated the association between physiological emotion regulation and regulatory behaviors (Calkins et al., 1998; Ham & Tronick, 2009; Hofheimer et al., 1995; Muller et al., 2015; Perry et al., 2016; Wu & Feng, 2020). Two studies investigated the association between cortisol and regulatory behaviors: One study showed a positive correlation between cortisol reactivity and self-comforting behaviors after a stressful situation ($r = 0.38$; Muller et al., 2015) and one showed that cortisol reactivity correlated with orientation to the mother at 6 months old, but not at 15 or 24 months old (Wu & Feng, 2020). Four studies tested the association between vagal tone and regulatory behaviors. One study found that vagal tone was negatively correlated with aggression/venting and positively associated with distraction ($r = -0.25$ to -0.29 and $r = -0.26$, respectively; Calkins et al., 1998), whereas another did not find any association between vagal tone and distraction (Perry et al., 2016). Higher vagal tone predicted higher attention to the mother (Hofheimer et al., 1995) and was negatively associated with looking at the environment ($r = -0.44$; Ham & Tronick, 2009). Vagal tone withdrawal at 10 months was also positively associated with maternal orientation behaviors ($r = 0.22$; Perry et al., 2016), whereas this was not the case for baseline vagal tone or for vagal withdrawal at 5 months. Results tend to show that cortisol and vagal tone are associated with regulatory behaviors.

4.2.2.4. Symptoms. Seven studies investigated the association between physiological emotion regulation and symptoms (Degnan et al., 2008; Feldman, 2015; Finger et al., 2014; Fong et al., 2017; Kalomiris et al., 2019; Kiel & Kalormis, 2016; Wagner et al., 2019). The four studies on the association between cortisol and symptoms found no direct association with behavior problems (Fong et al., 2017; Wagner et al., 2019) or with anxiety (Kalomiris et al., 2019; Kiel & Kalormis, 2016). Of the three studies considering vagal tone and symptoms, one study found that baseline vagal tone, but not vagal withdrawal, was positively correlated with internalizing and externalizing behavior problems ($r = 0.29$ and.27, respectively; Finger et al., 2014), whereas two studies found no association between vagal tone baseline and behavior problems (Degnan et al., 2008; Feldman, 2015). Results show no association between physiological regulation and symptoms.

4.2.2.5. Global index of emotion regulation. Five studies considered a global index of emotion regulation abilities as a socioemotional outcome (Eiden et al., 2018; Feldman, 2015; Skibo et al., 2020; Somers et al., 2021; Sun et al., 2021). One study considered the association between cortisol and effortful control—defined as the ability to use attentional resources and to inhibit behavioral responses in order to regulate emotions (Rothbart, Ahadi, & Hershey, 1994)—and found no association between them (Sun et al., 2021). Four studies investigated the association between vagal tone and emotion regulation. Two studies showed that baseline vagal tone at birth is positively correlated with emotion regulation ($r =$ from.24 to.33) and predicted emotion regulation in the first year (Feldman, 2015) and emotion regulation at 5 years old (Skibo et al., 2020). One study showed that vagal withdrawal in a stressful situation is negatively correlated with emotion regulation ($r = -0.18$) and predicted emotion regulation (Eiden et al., 2018). Finally, one study showed that vagal tone predicted some aspects of emotion regulation during free play such as volatility in positive (but not negative) affects, carryover of negative (but not positive) affects, and feedback loops between positive and negative affects, whereas changes in vagal tone predicted equilibrium in positive and negative affects and feedback loops from positive to negative affect (Somers et al., 2021). Results show that vagal tone is associated with emotion regulation.

5. Discussion

5.1. Parent–infant interaction and physiological emotion regulation

Results regarding the association between parent–infant interaction and physiological measures of emotion regulation were heterogenous. A few conclusions can, however, be drawn. First, dyadic synchrony was shown to be associated with physiological functioning. The more synchronous a dyad is, the better the physiological regulation seems to be. This is in line with the idea that synchrony, as an index of the quality of co-regulation processes between parent and infant, is central for the development of socio-emotional and regulatory capacities (Harrist & Waugh, 2002). Second, it seems that physiological measures (especially cortisol levels) are sensitive to the lack of synchrony. This illustrates that a lack of synchrony in parent–infant interactions may be stressful for infants. This finding was already reported in studies with the Still-Face paradigm (Tronick, Als, Adamson, Wise, & Brazelton, 1978), but the addition of physiological measurements confirms what has been already observed in infant behaviors. Nonetheless, these results do not allow us to indicate a direction for these associations. Only one of the included studies showed that dyadic synchrony predicted physiological regulation.

Considering parental sensitivity, most of the study findings converge to the conclusion that maternal sensitivity during regular interactions (i.e., free play) is not associated with physiological regulation. However, some studies reported an association between maternal sensitivity and physiological regulation for stressful situations, although the direction of this association differed. Maternal sensitivity might be more important during moments when infants need help to regulate emotion. Maternal sensitivity to distress has already been shown to be an important factor in children's socioemotional functioning, whereas this was not the case for maternal sensitivity when children were not distressed (Leerkes, Blankson, & O'Brien, 2009). The results presented in this review confirm the crucial influence of maternal sensitivity during stressful situations. This is in line with the idea that sensitive mothers are those who are able to give their infant a response appropriate to his or her needs, which is an important predictor of the infant's emotional functioning (Cooke et al., 2019). The only study that considered paternal sensitivity showed no association with infants' physiological regulation.

Considering parental behaviors, contrasting results were found for the two physiological measures. Cortisol levels were associated with parental behaviors, such that positive parenting lowered the cortisol level, whereas negative parenting behaviors heightened cortisol levels. This is not the case for vagal tone. It is also unclear whether parental behavior can predict physiological measures. The variety of parental behavior observed does not permit us to draw clear conclusions about exactly which parental behaviors could explain physiological regulation.

Attachment does not seem to be directly associated with physiological measurements. There is, however, a difference in cortisol levels during stressful situations, depending on attachment type when the mother is present. The interpretation of these results might be that the mother acts as a buffer against stress activation. These results are in line with the idea that securely attached children consider the mother's presence as a protection from stressful situations (Bowlby, 1958). This result is also in line with what was previously discussed about the importance of maternal sensitivity during stressful situations.

These results indicate that the quality of mother-infant relationships is associated with physiological functioning. Moreover, it seems that this is particularly the case when infants need help to regulate emotion, such as in stressful situations. This is in line with the idea that young children are unable to regulate emotion and that they need help from adults to do so (Tronick, 1989). However, the presented results do not allow us to draw clear conclusions about the degree to which the interactions are predictive of emotional functioning. More studies should be dedicated to identifying the extent to which early interactions predict physiological regulation.

5.2. Physiological emotion regulation and socioemotional outcomes

Results considering the association between physiological emotion regulation and socioemotional outcomes were also heterogenous. Contrasting results of studies on emotional reactivity were again found, but they mostly converged toward an association between physiological regulation and the expressed emotion. The associations between cortisol and negative emotional reactivity especially differed. Considering vagal tone, the direction of the association seemed to change, depending on the situation (normal interaction, stressful situation). These results confirm the association between vagal functioning and expressed emotions (Porges, 1995) and that the physiological arousal might determine the range of behavioral responses available (Porges, 2001). The results for positive emotionality are a good example of this. Indeed, physiological levels must be optimally regulated for the infant to be able to express positive emotions, such that cortisol levels should be low and vagal tone should be high in order to be in a physiological state that allows these positive emotions. There were some age differences in the studies. The association between vagal tone and distress displayed seemed to be weaker for 24-month-old infants than it was for younger infants. Whereas the correspondence between emotional expression and emotional experience is important in infancy, it tends to decrease across toddlerhood (Izard & Malatesta, 1987; Malatesta et al., 1989), confirming that the expression of emotion becomes more regulated with development. Again, the only study that considered the father showed that the association between cortisol response during stress and negative emotionality differed in mother-infant and father-infant interactions. For mothers, an increase in cortisol during stress is related to more negative emotionality in a mother-infant interaction a few minutes later, whereas it is related to less negative emotionality in a father-infant interaction. These differences between mothers and fathers need to be investigate.

Physiological regulation of vagal tone is related to behavioral regulation of distress. The studies that used a global index of emotion regulation showed an association between vagal tone and emotion regulation and that vagal tone could predict emotion regulation. Moreover, studies showed that physiological regulation is positively associated with self-comforting behavior. Two conclusions can be drawn from this result. First, physiological reactivity indicates stress and a need to regulate emotion. Second, physiological activation also determines the type of behavior available to regulate emotion, this being particularly the case for vagal tone. According to the polyvagal theory (Porges, 1995, 2001), when vagal tone is high, it promotes calm and allows affiliative and social behaviors. With the decrease of parasympathetic influences due to vagal withdrawal, physiological resources are mobilized, allowing stronger emotional reactions and fight-or-flight behaviors. Vagal influence therefore determines the variety of behavior that one has access to. The studies also showed age differences in the association between vagal tone and regulatory behaviors: The association between vagal tone and distraction behavior during stress seemed to be stronger at 24 months old than it was earlier in life. This shift in regulatory behaviors might be explained in two ways. On the one hand, there is a decreasing need to maintain the interaction with the parent as the infant develops. Indeed, when infants are very young, the behaviors that might push the caregiver away are not adaptative, although infants need to be close to the adult in order to be protected (Cassidy, 1994). On the other hand, the development of regulatory behaviors such as active engagement with objects or the environment increases with age (Bridges & Grolnick, 1995).

Considering symptoms, results tended to indicate no association between physiological regulation and symptoms. Only one study found a positive association between vagal tone baseline and internalized and externalized symptoms. This absence of a direct association between physiological measures and symptoms might emphasize the need to consider the environment in which the infant is growing up in order to explain psychological functioning. This is in line with the idea that symptoms in young children are more often related to a disturbance in the relation with their caregivers (Sameroff & Emde, 1989; Sroufe, 1979) and underlines the importance of considering the environment in which the child develops to understand its functioning.

Studies show that physiological regulation is associated with emotional expression and regulation. Physiological regulation might therefore be a key process in interindividual differences in emotion regulation.

5.3. Synthesis

This review provides evidence for the association between early parent–infant interactions and physiological regulation. The results underline the importance of qualitative early interactions in the development of adequate physiological regulation. We also found an association between physiological regulation and socioemotional outcomes. This highlights the usefulness of physiological measures in the study of socioemotional development and functioning. It also underlines how physiological regulation can influence observed behaviors. In this review, variables of interest were explored by pairs. A few studies examined three variables together. However, these results were not presented because most of them were not in line with the temporal criterion for the various measures (i.e., parent–interaction before or at the same time as physiological measurement, and physiological measurement before or at the same time as socioemotional outcomes). Since the results presented show associations between parent-child interactions and physiological regulation, as well as between physiological regulation and socioemotional outcomes, physiological emotion regulation might be considered an intermediate variable. Only four of the studies met this criterion and considered physiological measures as a moderator of the association between parent–infant interaction and socioemotional outcomes. One study showed that higher dyadic reparation of interactive mistakes was associated with less negative emotionality only for infants who experienced vagal withdrawal during a Still-Face paradigm (Provenzi et al., 2015). The second study showed that maternal insensitivity predicted children's effortful control only when baseline vagal tone was low (Skibo et al., 2020). The third study showed that cortisol reactivity moderates the relation between parental behaviors and the evolution of anxious behaviors in children (Kalomiris et al., 2019). Finally, one study showed that cortisol and cortisol reactivity moderate the influence of parental behaviors on conduct problem and callous-unemotional behaviors, as well as the association between maternal sensitivity and conduct problem (Wagner et al., 2019). All of the other studies investigated moderation effects of parent–infant interaction (Ahnert et al., 2004; Blair et al., 2015; Degnan et al., 2008 Finger et al., 2014; Fong et al., 2017; Pratt et al., 2015; Sun et al., 2021; Wu & Feng, 2020) or of infant socioemotional outcomes (Feldman, 2006) as moderators. No studies explored any mediation effect. However, in line with the presented results and the theoretical framework, it might be of interest to consider physiological measures of emotion regulation as the mediator between the well-documented association between early parent–infant interactions and socioemotional outcomes. Further studies should fill this gap.

6. Limitations

There are some limitations of this review. First, the interaction paradigms and the assessments of these interactions were heterogenous. Although this allows one to observe aspects that are not due to one specific standardized situation of interaction in particular, this makes it even more difficult to draw clear conclusions. Second, the assessments of outcomes were heterogenous, which leads to numerous different measures and ways of assessing the results that might have prevented us from drawing a clear conclusion. Moreover, these two first points prevented us from performing a meta-analysis. Most of the studies were conducted in the United States of America and included mainly middle class and highly educated European Americans. Only a minority of the studies examined populations of other ethnicities, or populations with lower levels of education and income. This finding raises the question of the generalizability of the results, especially since parental behaviors and expectations in terms of emotional regulation may vary culturally. Finally, the interactions were mostly limited to mother-infant interactions. Only two studies considered the father; one of them did not consider differences between the mother and the father, and the other one showed some differences between the mother and the father. More studies should be conducted in order to investigate these differences. No study has considered the family as a whole, for example, by observing infant regulation during mother-father-infant interactions. This point is of particular interest because studies have shown that family-level processes are important factors that explain a unique proportion of variance in infant outcomes and whose influence seems to run above and beyond parenting behavior only (Belsky, Putnam, & Crnic, 1996; Teubert & Pinquart, 2010).

7. Conclusions

The completion of this review is important because it synthesizes what has already been done in the studies conducted so far and identifies what is still missing in the understanding of the physiological processes that may underlie the associations between early parents-infant interactions and socioemotional functioning. This review also underlines the importance of dyadic synchrony in the early years of life in the physiological functioning of infants. In addition, it shows the importance of parental sensitivity, especially when the situation requires the infant to regulate emotion. Two results confirmed the importance of dyadic processes in the development of emotion regulation. However, further studies need to investigate family interactions rather than mother-infant interactions. This review also shows an association between physiological measures and observed emotional behavior, which confirms the value of physiological indexes in the study of socioemotional functioning. Finally, this review highlights the importance of considering factors specific to the child, such as physiological and behavioral measures, as well as the social environment in which the infant is developing in order to better understand his or her functioning. In view of this conclusion, further studies should explore the hypothesis of a mediating role of physiological regulation relative to emotion regulation in the association between early parent–infant interaction and socioemotional outcomes.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.infbeh.2022.101687.

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