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BREASTFEEDING PREDICTS VAGAL REGULATION
DURING A SOCIAL STRESSOR

A Thesis in
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by
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ABSTRACT

Breastfeeding, an early nurturing behavior common to mammals, serves to soothe infants and relax mothers. However, little is known about how breastfeeding gets under the skin—whether mechanisms are behavioral or physiological, or whether apparent breastfeeding effects are due to environmental factors often confounded with feeding method. The gustatory-vagal hypothesis proposes that early nutritive sucking facilitates regulation of physiological state and contributes to infants’ ability to co-regulate socially. Therefore, due to the unique neuromusculature involved in breastfeeding, regulatory effects may be due in part to infant-mother mutual vagal stimulation, which may serve as an early physiological co-regulatory process. The current study investigated relations between breastfeeding and mothers’ and 6-month-old infants’ vagal regulation during a social stressor (the Face-to-Face Still-Face Paradigm), controlling for potential confounds associated with breastfeeding (maternal sensitivity and demographic variables). Breastfed infants experienced greater vagal withdrawal during the reunion episode of the FFSFP relative to non-breastfed infants, suggesting more effective regulation. Breastfeeding mothers showed greater augmentation of vagal tone than non-breastfeeding mothers during the normal play and experienced lower physiological arousal throughout the task. Effects were independent of maternal sensitivity and of demographic variables. Together, findings suggested that mutual vagal stimulation during breastfeeding may be a physiological co-regulatory process that promotes infants’ and mothers’ self-regulation and that effects are not due to self-selection factors related to feeding method.
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Abbreviations

AIC: Akaike information criterion
ANOVA: Analysis of variance
ANS: Autonomic nervous system
DCHDS: Durham Child Health and Development Study
FFSFP: Face-to-Face Still Face Paradigm
GLM: General linear model
HP: Heart period
IBI: Interbeat interval
ICC: Intraclass correlation coefficient
INR: Income-to-needs ratio
MLM: Mixed linear model
PNS: Parasympathetic nervous system
REML: Restricted maximum likelihood
RSA: Respiratory sinus arrhythmia
SES: Socioeconomic status
SNS: Sympathetic nervous system
Introduction

In the early postpartum months, before infants have developed the ability to self-regulate their behavioral or physiological systems, mothers use their own bodies to organize their infants’ responses to the environment. While mother-infant physiological co-regulation is theorized to support infants’ developing self-regulation, little research has investigated the mechanisms by which dyads co-regulate physiology and whether physiological co-regulation predicts self-regulation. One archetypal early nurturing behavior through which mammalian mothers and infants may co-regulate is breastfeeding. In addition to its nutritional function, mothers and infants use breastfeeding to calm, communicate, and connect. In human and animal postpartum studies, breastfeeding is part of a suite of evolved maternal-infant behaviors\(^1\) that function to regulate infant and mother physiological and behavioral processes (Champagne & Meaney, 2001; Feldman, 2007d; Hrdy, 1999; Winberg, 2005), facilitate warm caregiving by the mother (Winberg, 2005), and establish the infant’s first social relationship (Blass, 1994). A large body of work has linked breastfeeding with benefits in physical, cognitive, and social-emotional domains.\(^2\) However, much remains unknown about how breastfeeding facilitates physiological regulation in infants and whether it contributes to co- and self-regulatory capabilities in infants and mothers. Therefore, the current study theorized that breastfeeding may serve as a physiological co-regulatory process that supports the development of effective physiological self-regulation and investigated its relations to mothers’ and infants’ physiological responses to later social stress.
Conceptual Framework

The current study was informed by a conceptual framework composed of research findings from pediatric, self-regulation, parenting, and psychophysiological literatures (see Figure 1).

The development of self-regulation is theorized to involve the hierarchical organization of physiological, emotional, behavioral, and cognitive systems that allow the child to modulate his or her internal state and, eventually, external behavior (Calkins, 2011; Feldman, 2007; Kopp, 1982). While self-initiated regulation begins to emerge in toddlerhood (Kopp, 1982), research indicates that the foundations of those abilities are laid in infancy (Calkins, 2011; Feldman, 2007c; Moore et al., 2009). Early physiological and behavioral regulatory strategies are largely caregiver-dependent and grow increasingly child-initiated over the first years of life (Cohn & Tronick, 1987; Feldman, 2007c). According to this biopsychosocial perspective, two key contributors to regulatory development are caregiver-infant co-regulation and the vagal system, through which the parasympathetic nervous system regulates cardiac responses to stress (Moore & Calkins, 2004; Moore et al., 2009).
Research indicates that co-regulation and vagal development are related: the vagal system appears to be particularly sensitive to environmental influences in the first months of life (Bornstein & Suess, 2000; Field, Pickens, Fox, Nawrocki, & Gonzalez, 1995; Moore & Calkins, 2004; Porter, 2003; Propper et al., 2008), and infant vagal regulation in response to disruption of mother-infant co-regulation has been observed in infants as early as three months of age (Moore & Calkins, 2004). However, little is known about the mechanisms by which caregiving behaviors may influence psychophysiological development.

Existing work has largely explained relations between breastfeeding and social-emotional correlates as being due to greater maternal sensitivity—and therefore heightened regulatory support—offered by breastfeeding mothers. Indeed, prior research has demonstrated that maternal sensitivity is related to infants’ and mothers’ physiological regulation (Moore et al., 2009). Still other work has questioned whether breastfeeding effects can in fact be explained by environmental factors associated with feeding method—such as race or socioeconomic status—that contribute to psychophysiological development (Propper, 2012). However, these demographic factors may operate through their effects on parenting behavior, thus reinforcing the theory that maternal sensitivity explains the effects of breastfeeding. Therefore, within the biopsychosocial framework, links between breastfeeding and infant regulatory development may be partially explained by maternal sensitivity and related demographic factors, and breastfeeding may also influence infant regulatory development both indirectly (via relations with mother physiology) and directly (via stimulation of the infant vagus and associated neuroanatomical structures).

The gustatory-vagal hypothesis (Porges & Furman, 2011; Porges & Lipsitt, 1993), discussed in more detail below, offers a potential physiological mechanism by which
breastfeeding may directly affect regulatory development. The hypothesis proposes that nutritive sucking stimulates the vagus, facilitating physiological regulation before infants have developed the ability to co-regulate by social means. Indeed, because the vagus innervates anatomical structures involved in both infants’ and mothers’ breastfeeding physiology (e.g. sucking, swallowing, breathing, digestion, and enteric hormone production; DiPietro, Larson, & Porges, 1987; Porges and Lipsitt, 1993; Winberg, 2005) and has been theorized to facilitate regulation during social interaction later in development (Porges, 2007; Porges & Furman, 2011), vagal stimulation during breastfeeding may facilitate mother-infant physiological co-regulation and, in doing so, contribute to individuals’ vagal development.

Research on the physiology of breast- and bottle-feeding has revealed important differences between the neuromuscular mechanics of the two feeding methods. However, while a small body of work has provided empirical backing for the gustatory-vagal hypothesis, (DiPietro, Larson, & Porges, 1987; Lappi et al., 2007; Porges & Furman, 2011; Porges & Lipsitt, 1993; Portales et al., 1997; Suess et al., 2000), to date, literature searches identified no published studies examining whether breastfeeding or not breastfeeding during the first months of life are associated with differential infant vagal regulation in response to social stress or how the unique action of breastfeeding (as opposed to bottle-feeding) may influence vagal development. Furthermore, while several studies have found relations between breastfeeding and maternal vagal regulation (Altemus et al., 2001; Mezzacappa, 2004, 2005; Uvnas-Moberg and Winberg, 1989), no published research was found investigating whether and how maternal vagal stimulation during breastfeeding relates to maternal regulation during social exchanges with the infant outside of feeding. Therefore, the current study aimed to take a first step in investigating whether breastfeeding contributes to the development of infants’ and mothers’ self-regulation by
examining whether breastfeeding infants and mothers exhibited different patterns of behavioral or physiological regulation than non-breastfeeding infants and mothers, and whether the effects of breastfeeding were explained by or were independent of maternal sensitive behavior and demographic factors associated with breastfeeding.

The Polyvagal Theory and The Gustatory-Vagal Hypothesis

The Polyvagal Theory (Porges, 2001, 2007; Porges, Doussard-Roosevelt, & Maiti, 1994; Porges & Furman, 2011) proposes a neurophysiological framework for conceptualizing social, affective, and communicative behavior. Grounded in an evolutionary perspective, the theory posits that the mammalian autonomic nervous system (ANS) is comprised of three branches hierarchically organized according to their phylogenetic age. Mammals have evolved this more nuanced system to adaptively respond to social demands and engage in affiliative behavior.

The phylogenetically youngest branch of the ANS is the myelinated vagus, which originates in the nucleus ambiguus. The myelinated vagus is a component of the parasympathetic nervous system (PNS) and exercises more dynamic regulation on the cardiac pacemaker than the older, unmyelinated vagal branch originating in the dorsal motor nucleus. The myelinated vagus, henceforth referred to simply as the vagus, also enervates musculature of the face, mouth, and throat, thereby contributing to both social and ingestive behaviors (Porges, 2001; Porges & Lipsitt, 1993). This third branch of the autonomic nervous system is unique to mammals and has evolved to allow modulation of physiological mobilization and immobilization (metabolic expenditure and conservation) required during engagement in socially or emotionally stressful situations (Porges, 1995, 2001, 2007).

Development of vagal regulation. This ability to dynamically self-regulate develops ontogenetically just as it developed phylogenetically (Bar-Haim, Marshall, & Fox, 2000;
Bornstein & Suess, 2000; Izard et al., 1991; Patriquin, Lorenzi, Scarpa, & Bell, 2013; Porges & Furman, 2011; Propper et al., 2008). Vagal tone, which reflects the myelinated vagus’ control of the heart, can be measured beginning at 30 to 32 weeks gestational age and undergoes rapid development in the final trimester of pregnancy and first months postpartum (Feldman, 2007c; Porges, 1995). Consistent with principles of neuroplasticity, the ontogenetic development of the myelinated vagus appears to be influenced by environmental inputs over time. Individual differences in vagal regulation can be seen in infancy and have been associated with poverty (see Propper, 2012 for a review), parental conflict (Moore, 2010), parent-infant synchrony (Feldman & Eidelman, 2007; Moore & Calkins, 2004), maternal depression (Feldman & Eidelman, 2009; Field et al., 1995), and maternal sensitivity (Moore et al., 2009; Propper et al., 2008).

Together, these findings on the course of and influences on vagal development suggest that the first months of life may represent a period during which the vagal system is particularly sensitive to environmental conditions. While existing research has examined an assortment of proximal and distal environmental influences on vagal development, one variable that has thus far received little attention is breastfeeding, a recurrent and fundamental element of many infants’ daily lives and a known regulatory strategy during this period (Porges & Furman, 2011; Porges & Lipsitt, 1993).

**The gustatory-vagal hypothesis.** Mammals are unique in their use of breastfeeding just as they are unique in their phylogenetic development of the myelinated vagus. Indeed, Porges and others have proposed that early feeding behavior and vagal development may be functionally linked: According to the gustatory-vagal hypothesis (Porges & Furman, 2011; Porges & Lipsitt, 1993), nutritive sucking facilitates regulation of psychophysiological state in the first weeks of life by stimulating the vagus. Over the course of their first year, infants develop cortical control
of the vagus, which facilitates soothing by non-feeding social behaviors (Porges & Furman, 2011).

In accordance with the gustatory-vagal hypothesis, empirical studies have found that infants experienced vagal withdrawal (withdrawal of the vagal brake) during nutritive sucking, whether breast- or bottle-feeding (Lappi et al., 2007; Portales et al., 1997) and that vagal withdrawal increased as sucking frequency increased (Porges & Lipsitt, 1993). Lappi and colleagues (2007) proposed that the hard work of nutritive sucking, which engages the ANS several times a day, contributes to infants’ psychophysiological development. While most existing work on the gustatory-vagal hypothesis has employed bottle-feeding paradigms, one study comparing vagal tone in breast- and bottle-fed healthy, full-term newborns found that breastfed infants showed higher baseline vagal tone compared with bottle-fed infants, suggesting greater capacity to regulate (DiPietro, Larson, & Porges, 1987).

**Potential Mechanisms of Vagal Stimulation by Breastfeeding in Infants and Mothers**

**Infants.** Taken together, these studies demonstrate that nutritive sucking involves dynamic modulation of cardiac function by the infant vagus, that this withdrawal and reapplication is related to sucking rate, and that breast- and bottle-fed babies may exhibit dissimilar vagal regulation. The first two findings provide a direction for further investigation of the third: If an infant’s rate of nutritive sucking modulates vagal tone, this points toward a neuromuscular mechanism for differences between breast- and bottle-fed babies—and perhaps a neuromuscular mechanism for the development of vagal regulation.

Indeed, research investigating the intraoral physiology of breast- versus bottle-feeding has revealed important differences in the physical mechanics of these two feeding methods. First, infants showed a patterned suck-swallow-breathe sequence during breastfeeding that was
not observed during bottle-feeding (Goldfield, Richardson, Lee, & Margetts, 2006). Central nervous system coordination of this sequence may explain the higher oxygenation levels in breastfeeding infants and may therefore contribute to breastfeeding’s benefits (Brown, 2007). Indeed, by two to four months of age, breastfed infants showed higher oxygenation levels, lower heart rate, longer sucking bouts separated by fewer pauses, and shorter overall feeding sessions compared with bottle-fed infants (Sakalidis et al., 2013); and exclusive breastfeeding for six months followed by some breastfeeding through 18 months of age has been linked with healthier breathing patterns later in childhood (Limeira, Aguiar, de Lima Bezerra, & Camara, 2013). Notably, research has also shown that, during feeding, bottle-fed infants sucked less frequently than breastfed infants (Moral et al., 2010). In light of empirical work linking rate of sucking and vagal withdrawal, this suggests that bottle-fed infants may correspondingly experience less vagal withdrawal during feeding than breastfed infants.

A second difference between the mechanics of breast- and bottle-feeding is infant tongue movement (Geddes, Kent, Mitoulas, & Hartmann, 2008; Miller & Kang, 2007; Sakalidis et al., 2012). While breastfeeding infants used a peristaltic motion to draw milk from the breast, bottle-feeding involved a “piston-like” sucking action. Between sucks, the tongue musculature of breastfeeding infants remained active and pressing against the breast, while bottle-feeding infants did not show this continuous muscle engagement (Weber, Woolridge, & Baum, 1986). As discussed above, the musculature involved in sucking, swallowing, and breathing is innervated primarily by the vagus (Porges, 2001, 2007), while tongue musculature is also innervated by the hypoglossal cranial nerve. Both the vagus (X) and the hypoglossal (XII) nerve originate in the nucleus ambiguus. According to the gustatory-vagal hypothesis, the Xth and XIIth cranial
nerves’ common location of source nuclei in the medulla may help to explain the soothing function of sucking and feeding in infancy (Porges & Furman, 2011; Porges & Lipsitt, 1993).

**Mothers.** Investigations of the psychosocial benefits of breastfeeding for mothers have primarily examined contributions of the hormone oxytocin. However, a small body of research has begun to examine the role of the vagal system. Uvnas-Moberg and Winberg (1989) found that infant sucking stimulates the maternal vagus, which in turn activates the endocrine system of the gastrointestinal tract in order to conserve the breastfeeding mothers’ energy. This physically adaptive function may also influence maternal social-emotional functioning by enhancing breastfeeding mothers’ capacity for vagal regulation. In fact, research shows that breastfeeding mothers demonstrated greater parasympathetic activation and attenuated sympathetic activation following a stressor relative to non-breastfeeding mothers and that feeding frequency contributed to this relationship in a dose-response manner (Mezzacappa, 2004; Mezzacappa, Kelsey, and Katkin, 2005). This research group also found psychosocial differences between breast- and bottle-feeding mothers, with breastfeeding mothers reporting less stress overall and decreased negative mood following feeding (Mezzacappa & Katkin, 2002). Together, these studies support the investigation of breastfeeding’s effects on maternal vagal regulation, particularly as it relates to responsiveness and adaptation to social contingencies in the dyad.

**Other Possible Mechanisms of Breastfeeding Effects**

In examining mechanisms by which breastfeeding may influence infant and mother development, interpretation of much existing work is limited by self-selection issues: due to recommendations by the American Academy of Pediatrics (Gartner, 1998), the World Health Organization (Horta & Victora, 2013), and UNICEF that infants under six months old be breastfed, random assignment to feeding method groups is considered unethical—and would
likely be impossible due to mother preferences and other circumstances that determine breastfeeding status. Indeed, the practice of breastfeeding is associated with a host of potential confounds including, but by no means limited to, cultural attitudes towards childrearing, availability of social supports, health conditions, and predispositions toward more or less sensitive parenting behavior (Conner et al., 2013; Ford & Labbok, 1990; Forste, Weiss, & Lippincott, 2001; Thulier & Mercer, 2009).^9^

**Maternal sensitivity.** Links between breastfeeding and social-emotional outcomes have commonly been attributed to differences in parenting behavior or relationship quality of breastfeeding versus non-breastfeeding dyads (see Jansen, de Weerth, & Riksen-Walraven, 2008 for a review). It has been proposed that more-sensitive mothers are more likely to breastfeed (Kim et al., 2011) and also that breastfeeding stimulates warm caregiving behaviors in mothers (Winberg, 2005). In either scenario, relations between breastfeeding and maternal sensitivity likely explain some variance in child outcomes while also impeding detection of other mechanisms, including physiological.

Furthermore, an earlier study on the current sample (Moore et al., 2009) showed that maternal sensitivity is related to infant and mother vagal regulation. Both infants of more-sensitive mothers and more-sensitive mothers showed vagal withdrawal from baseline levels during the reunion episode of the Face-to-Face Still-Face Paradigm (FFSFP; Tronick, Als, Adamson, Wise & Brazelton, 1978), while infants of less-sensitive mothers and less-sensitive mothers showed a return to baseline levels. The authors speculated that more-sensitive mothers and their infants showed greater vagal withdrawal to support active attempts to restore their prior levels of engagement prior to the disruption of the interaction (Moore et al., 2009).
Therefore, because breastfeeding is associated with greater maternal sensitivity (Kim et al., 2011; Winberg, 2005) and greater sensitivity is related to infants’ and mothers’ vagal tone (Moore et al., 2009), it is possible that effects of breastfeeding on vagal tone are explained by sensitivity. However, as discussed above, existing research has also shown that (a) vagal withdrawal facilitates regulation in response to social contingencies (Porges, 2007); (b) vagal stimulation during nutritive sucking may contribute to the development of vagal regulation that is later applied in social contexts (Porges & Furman, 2011); and (c) in both infants and mothers, the vagus appears to be exercised more by the neuromuscular action of breastfeeding than by that of bottle-feeding. Therefore, mother-infant mutual vagal stimulation during breastfeeding may serve as a co-regulatory process that influences the development of self-regulation independent of maternal sensitivity. In order to better understand contributions of physiological and behavioral mechanisms, therefore, the first aim of the current study was to examine whether breastfeeding was related to mothers’ and infants’ vagal tone, independent of maternal sensitivity.

**Demographic factors.** While relations between breastfeeding and infant and mother outcomes may be due to the feeding method itself and/or to associated maternal sensitivity, there are also documented associations between demographic variables and breastfeeding. In the United States, African American mothers are less likely to breastfeed and more likely to bottle-feed compared with other mothers (Forste, Weiss, & Lippincott, 2001), and mothers from low SES backgrounds are less likely to breastfeed than mothers of high SES (Bolling, Grant, Hamlyn, & Thornton, 2007; Conner et al., 2013; Matthews, Webber, McKim, Banoub-Baddour, & Laryea, 1998). Maternal age, marital status, education level, parity, and employment status are
also related to breastfeeding initiation and duration (Caulfield et al., 1998; Piper & Parks, 1996; Ryan, Zhou, & Arensberg, 2006; Thulier & Mercer, 2009).

Indeed, some studies of breastfeeding effects on later child outcomes (e.g. intelligence) have found that effects are diminished when accounting for demographic variables (Der, Batty, & Deary, 2006), while others have found that effects remain (see Horta & Victora, 2013). However, none of these studies included maternal sensitivity along with demographic variables. Notably, many of these same demographic variables have been found to be associated with maternal sensitivity, with African American, lower income, younger, unmarried, and less educated mothers—that is, those less likely to breastfeed—typically rated as less sensitive (Kaplan, Burgess, Sliter, & Moreno, 2009; NICHD Early Child Care Research Network, 2005; Propper et al., 2008).

This complex set of inter-relations among breastfeeding, maternal sensitivity, and demographic variables has thus far limited interpretation of findings linking breastfeeding to infant (and mother) outcomes and requires careful consideration. Despite these robust associations between breastfeeding status and sociocultural context, the majority of prior research has used samples in which (a) there was minimal variability in race or SES, (b) race and SES were confounded, (c) race and SES were not assessed or controlled for, or (d) maternal sensitivity was not assessed or controlled for. (See Appendices B & C.) Of six existing studies involving the gustatory-vagal hypothesis (only one of which compared breast- and bottle fed infants), four did not report racial or SES variables; one included a predominantly African American, low-SES sample; and one involved a low-SES sample but did not report race. (See Appendix A.) As discussed above, psychophysiological findings were consistent across these studies. However, the lack of racial or socioeconomic diversity within any of these samples and
the failure to examine effects of maternal sensitivity in relation to demographic factors associated with breastfeeding, has thus far prevented examination of variability in physiology due to these factors. This is particularly important in light of prior research showing that race (Moore et al., 2009; Wang et al., 2005), income (Propper, 2012), and maternal sensitivity (Moore et al., 2009) are each related to vagal tone.

In sum, due to limitations in existing work, little is known about whether apparent breastfeeding effects are in fact attributable to breastfeeding status, maternal sensitivity, demographic factors, or some combination of these factors. In addition to measuring breastfeeding and maternal sensitivity, the dataset used in the current study contained measurements of and variability in commonly cited confounds including race, income, and maternal education and age, allowing for statistical control of relevant variables and investigation of unique contributions by each. Therefore, the second aim of the current study was to examine whether breastfeeding is related to vagal regulation independent of maternal sensitivity and demographic variables that have been shown, in prior work and in the current sample, to be associated with both breastfeeding status and vagal tone.
The Current Study

The current study responds to a call for improved understanding of the mechanisms by which caregiving influences children’s developing self-regulatory skills and capacities (see Calkins, 2011) and of the development of dyadic co-regulation and its psychophysiological substrates (Feldman, 2007d).

The Face-to-Face Still Face Paradigm

The FFSFP (Tronick et al., 1978) was designed to study infants’ responses to unexpected social stimuli, disrupted social engagement, and dyadic repair. The FFSFP was selected for use in the current study because it experimentally manipulates conditions that elicit individual differences in behavioral and physiological regulation. The task is composed of three sequential episodes in which mothers are instructed to play normally with their infants (normal play), then become unresponsive to their infants while posing a neutral expression (still-face), and finally to play with or console their infants again (reunion). During the normal play episode, the infant and mother have an opportunity to co-regulate. The mother may read her infant’s level of arousal or distress and respond, while the infant may in turn draw on mother’s strategies (e.g. game playing, affectionate touch, or soothing vocalization) to maintain a calm or playful state. In the following still-face episode, however, the infant is presented with a disruption in maternal social engagement that typically elicits some distress and a need to cope (Mesman, van IJzendoorn, & Bakerman-Kranenburg, 2009). Finally, in the reunion episode, the dyad is tasked with repairing their connection in order to co-regulate once again. Therefore, the FFSFP facilitates investigation of differences in behavioral or physiological regulation between breastfeeding and non-breastfeeding infants and mothers, in episodes differentially eliciting self-regulatory or co-regulatory strategies.
Behaviorally, the FFSFP produces a robust and reliable effect in infants, characterized by increased negativity and looking away and decreased positivity during the still-face episode, followed by decreased negativity and increased positivity during the reunion episode, although typically not to prior levels (for reviews, see Adamson & Frick, 2003; Mesman et al., 2009). A growing body of research has measured infants’ physiological responses to the FFSFP (Bazhenova, Plonskaia, & Porges, 2001; Ham & Tronick, 2006; Moore & Calkins, 2004; Weinberg & Tronick, 1996). A typical physiological response in infants, which parallels the behavioral still-face effect, is marked by a decrease in vagal tone during the still-face episode, followed by an increase in vagal tone (nearing but not reaching baseline levels) during the reunion (Bazhenova, et al., 2001; Ham & Tronick, 2006; Moore & Calkins, 2004; Weinberg & Tronick, 1996). Both in infancy and later in life, vagal withdrawal in socially demanding contexts has been linked with positive behavioral regulation, including improved emotion regulation (Calkins, 1997; Porges, Doussard-Roosevelt, Portales, & Suess, 1994) and soothability (Huffman, Bryan, Del Carmen, Pedersen, Doussard-Roosevelt, & Porges, 1998; Stifter & Corey, 2001) in infancy, improved behavioral regulation in early childhood, (Doussard-Roosevelt, Porges, Scanlon, Alemi, & Scanlon, 1997), and social engagement-related coping skills in young adults (Geisler, Kubiak, Siewert, & Weber, 2013). Conversely, blunted vagal response, characterized by a lack of vagal withdrawal in response to a stressor, has been associated with less effective behavioral regulation (Geisler, Kubiak, Siewert, & Weber, 2013; Porges, 1996; Wilson & Gottman, 1996). Studies have identified atypical physiological response to the FFSFP in infants exposed to conflict in the home (Moore, 2010) and in infants who experience less dyadic synchrony (Moore & Calkins, 2004), suggesting that infants’ vagal response to the FFSFP is influenced by the early environment.
Because maternal behavior is experimentally manipulated during the FFSFP and is therefore fairly uniform across mothers, few studies have investigated individual differences in mothers’ behavior. Likewise, only a small body of work has examined mothers’ physiological responses to the FFSFP. Existing studies (Ham & Tronick, 2006; Moore, 2009; Moore et al., 2009) suggested that mothers’ vagal tone follows a pattern inverse to that of infants, with higher vagal tone in the still-face episode than in the normal play or reunion episodes. This pattern likely results from mothers’ social and co-regulatory engagement with the infant during the interactive episodes, which requires physiological mobilization to scaffold infant behavior. In one study of individual differences in mothers’ physiological responses, an earlier report using this sample found that more-sensitive mothers showed vagal withdrawal from baseline during the reunion episode, while less-sensitive mothers augmented vagal tone (Moore et al., 2009), suggesting that more-sensitive mothers may be drawing on vagal regulation to support attempts to repair the dyadic interaction.

Aims & Hypotheses

The current investigation began by examining whether breastfeeding and maternal sensitivity made independent contributions to infant and mother vagal tone (Aim 1). Then, demographic factors associated with breastfeeding and maternal sensitivity were examined to determine whether including these factors changed relations between breastfeeding and infant or mother vagal tone or between maternal sensitivity and infant or mother vagal tone (Aim 2).

H1.1: Consistent with the gustatory-vagal hypothesis that nutritive sucking stimulates vagal withdrawal and with research demonstrating neuromuscular differences between breastfeeding and bottle-feeding, breastfed infants (relative to non-breastfed infants) were expected to show greater vagal withdrawal from baseline to still-face episode (indicating
physiological mobilization in order to regulate when mother becomes unresponsive), and a
greater increase in vagal tone, though not a return to baseline levels, during the reunion episode
(in accordance with the typical physiological pattern). Non-breastfed infants were expected to
show a flatter vagal profile across the FFSFP, characterized by less vagal withdrawal in response
to the still-face episode relative to breastfed infants. Although prior work on this sample found
that infants of more-sensitive mothers showed greater vagal withdrawal in the reunion episode
than infants of less-sensitive mothers (Moore et al., 2009), breastfeeding was expected to predict
infant vagal tone independently of sensitivity in the current study.

H1.2: Because of the relative lack of research on mothers’ responses during the FFSFP,
hypotheses were exploratory. Based on studies finding that non-breastfeeding mothers reported
feeling more stress than breastfeeding mothers in general (Mezzacappa & Katkin, 2002) and that
exposing mothers to a stressor (i.e., anger) prior to the FFSFP resulted in significantly greater
vagal withdrawal in all episodes (Moore, 2009), breastfeeding mothers were expected to show
higher vagal tone throughout the FFSFP. Although prior work on this sample found that more-
sensitive mothers showed greater vagal withdrawal during the reunion episode than less-sensitive
mothers (Moore et al., 2009), and despite links between breastfeeding and sensitivity (Kim et al.,
2011), effects of breastfeeding status and sensitivity on mothers’ vagal tone were expected to
operate independently.

Analyses of the effects of demographic variables on relations between breastfeeding and
infant and mother vagal tone were exploratory. If adding demographic variables attenuated any
links between breastfeeding and vagal regulation, this would suggest that some of the variability
in vagal regulation attributed to breastfeeding may be explained by factors that are independent
of maternal sensitivity but are related to demographics and to breastfeeding status (e.g. weight, blood pressure, diet, maternal smoking).
Method

Participants

Participants \((N = 206)\) in the current study were drawn from a longitudinal study of social, emotional, and cognitive development, the Durham Child Health and Development Study (DCHDS; grant #BCS-0126475 and #BCS-0720660, PI: Martha Cox). Families were recruited using birth records and postings at birth and parenting classes. Infants (49% female) were healthy and born full-term without significant complications. The larger sample was recruited so that approximately half of African American families and approximately half of European American families were low-income (defined as having incomes below 200% of the federal poverty level) to minimize confounds between race and income. Complete feeding data were available for 205 participants; these 205 dyads were included in the current study.

Data on race, income, and other demographic variables were collected via mothers’ self-report. Each family’s income-to-needs ratio (INR) was computed from mothers’ reports of household income, adjusted for the number of household members. A crosstabulation of race, income level, and breastfeeding status is reported in Table 1. The subsample was 57% African American and 43% European American. The majority of infants (71%) were in two-parent families, 13% of mothers had no high school degree, 43% had either a high school diploma or a G.E.D., 11% had some college or vocational school, and 33% had a four-year bachelors degree or higher. Maternal age \((M = 29.5\) years, \(SD = 5.0)\) ranged from 18 to 40, and 56% of infants were first children. Approximately half (53%) of infants were breastfed (Table 1).

Measures

Feeding data were collected using the Assessment of Infant Feeding and Meals for Young Children questionnaire (Goldman & Miles, developed for DCHDS) at infant age three
and six months. Because the one existing study examining differences in breastfed and bottle-fed infants’ vagal tone detected differences as early as 17 to 56 hours postpartum (DiPietro, Larson, & Porges, 1987), suggesting that effects may occur very early in life, the three month feeding data were used to create breastfed and non-breastfed groups. Only five dyads in the current sample discontinued breastfeeding between three and six months. The questionnaire asked whether infants were being fed breast milk (yes/no), formula (yes/no), or both (yes/no) at the time of the visit; it did not gather information on frequency or amount of breastfeeding or on duration of feeding bouts. Because the current study considered effects of the physical action of breastfeeding on vagal regulation, categories were created as follows: dyads in which mothers endorsed any amount of breastfeeding at the time of the assessment were categorized as “breastfed,” and dyads in which mothers reported no breastfeeding were categorized as “non-breastfed.”

**Procedures**

**Mother-infant FFSFP.** The FFSFP was conducted at infant age six months during a laboratory visit. Consistent with established procedures, infants were placed in an infant seat and mothers sat facing them. A trained research assistant instructed mothers to play normally with their infants for two minutes. Mothers were then instructed to turn away from their infants for 15 seconds and then to face the infant and pose a still face. During the two-minute still-face episode, mothers were told to maintain a still face and refrain from engaging with their infants in any way. Mothers were assured that the procedure would be stopped if infants became too distressed. Following the still-face episode, mothers turned away again for 15 seconds and then returned to face the infant. During this final two-minute reunion episode, mothers were instructed to respond
to their infants in any way they felt was appropriate while keeping their infants in the provided seat.

The FFSFP was videorecorded using a split-screen procedure in order to observe both infant and mother behavior. Two cameras (one for infant, one for mother) were used to record the procedure, and videos were later combined using a split-screen generator and time stamped.

_Coding infants’ affective behaviors:_ To assess the effect of infant distress on vagal regulation, infant affect was coded by trained research assistants naïve to the study’s hypotheses. Facial affect (positive, neutral, or negative) was coded in one-second intervals throughout each of the three episodes of the FFSFP. If coders were unable to see an infant’s face, affect was coded as “obscured” during the seconds in question.

Coders were trained to reliability using existing videorecordings of FFSFP interactions. Then, to assess inter-observer reliability, fifteen percent of FFSFP interactions from the current study were randomly selected to be double coded. Agreement was calculated as both coders observing the same behavior within one second of each other and quantified using kappa to correct for chance agreement. Overall, coders reliably identified infant affect (\( \kappa = .89 \)).

For each infant, the percentages of time spent in positive and negative affective states were calculated in each episode as a function of total valid (i.e., not missing or obscured) time in the episode. This method of calculating affective scores has been established in previous research (Campbell, Cohn, & Meyers, 1995; Moore & Calkins, 2004; Moore et al., 2009).

_Cardiac monitoring._ At the beginning of the six-month laboratory visit, electrodes were placed on both infants’ and mothers’ chests and connected to separate preamplifiers. Outputs were transmitted to a monitor configured to collect heart interbeat intervals (IBI; Mini Logger 2000; Mini-Mitter Corp., Bend, OR). Baseline IBI was collected during a two-minute period
during which mothers were instructed not to interact with or provide toys to their infants, thus minimizing stimulation and facilitating measurement of IBI during a calm, neutral state. IBI were then collected continuously throughout the FFSFP. Electronic signals were sent manually to the monitor to mark the start and end time of each episode (baseline, normal play, still-face, and reunion).

IBI data files for the full procedure were then transferred to a computer for artifact editing. Because movement influences IBI, artifacts are common in cardiac data, particularly in infants. IBI data were edited and analyzed using MXEdit software (Delta Biometrics, Bethesda, MD). Data files that required editing of more than 10% of the data or that were incomplete due to technical problems (e.g., the infant pulled off electrodes during the procedure) were not included in analyses. This resulted in missing data for individual episodes. (See Missing Data below.)

Heart period (HP), a physiological measure of arousal, and respiratory sinus arrhythmia (RSA), a widely used index of vagal tone, were derived from edited IBI files following Porges’ (1985) method. RSA was calculated in 15-second epochs during the two-minute baseline period and each two-minute episode of the FFSFP. This epoch length has been validated by previous research with young children (Huffman et al., 1998) and is acceptable in tasks of short duration. Mean RSA values were then computed from the 15-second epochs for baseline and each episode of the FFSFP individually. These mean values were used in analyses. Measures of skewness and kurtosis showed data to be normally distributed. Larger values of RSA indicated higher vagal tone.

**Mother-infant free-play.** Maternal sensitivity was measured during a mother-infant free-play task conducted in the home at infant age six months. Mothers were provided with a standard
set of toys and instructed to play normally with their infants for 10 minutes. The task was videorecorded and later coded by trained research assistants naïve to the study’s hypotheses. The coding system, which was used by the National Institute of Child Health and Human Development Study of Early Child Care (NICHD Early Child Care Research Network, 1997), identified seven subscales of maternal behavior (sensitivity/responsiveness, intrusiveness, detachment/disengagement, positive regard, negative regard, stimulation of cognitive development, and animation). Coders were instructed to rate each quality on a scale of 1-5, indicating the degree to which the behavior characterized the interaction. Coders were trained to reliability until intraclass correlation coefficients (ICC) of .80 or greater were established and maintained with criterion coders (and for each individual pair of coders). All interactions were double coded, and final scores were agreed upon by conferencing.

An overall maternal sensitivity score was generated (guided by factor analysis) by aggregating the scores for the sensitivity/responsiveness, positive regard, stimulation of cognitive development, animation, and detachment/disengagement (reversed scored) subscales. This procedure has also been used and found to be valid in previous research (NICHD Early Child Care Research Network, 1997, 1999, 2005).

**Missing Data**

Frequencies, means, and standard deviations for complete infant and mother physiological data in each episode of the FFSFP are presented in Table 2. Frequencies are consistent with the approximately 10% attrition rate between three and six months in the larger sample and typical rates of data loss when collecting cardiac data from infants. Additional cardiac data loss in mothers was due largely to equipment malfunction.
Results

Preliminary Analyses

Preliminary analyses were conducted in IBM SPSS for Windows, Version 22.0 (SPSS Inc., 2013).

As expected, in support of Aim 1 hypotheses, breastfeeding mothers were rated as more-sensitive than non-breastfeeding mothers ($F(1,170) = 13.72, p < .001$). Breastfeeding mothers were more likely to be European American ($\chi^2(1) = 12.82, p < .001$), older ($F(1,110) = 16.79, p < .001$), married or cohabitating ($\chi^2(1) = 18.11, p < .001$), have higher INRs ($F(1,175) = 9.37, p < .01$), and have completed more years of education ($F(1,176) = 33.39, p < .001$). The number of hours that mothers reported working at the time of the lab visit, parity, and infant sex were unrelated to breastfeeding status.

Mothers rated as more highly sensitive were more likely to be European American ($F(1,170) = 17.15, p < .001$), older ($r(101) = .39, p < .001$), have higher INRs ($r(168) = .27, p < .001$), and have completed more years of education ($r(169) = .52, p < .001$).

Breastfeeding status and infant behavior. Infants showed the expected increase in negative affect from normal play to still-face episodes ($F(1,150) = 40.26, p < .001$) and continued to increase in negative affect from still-face to reunion episodes ($F(1,150) = 15.57, p < .001$). Infant positive affect decreased from normal play to still-face ($F(1,150) = 136.57, p < .001$) and then increased from still-face to reunion ($F(1,150) = 65.03, p < .001$). Because prior research has shown that breastfed infants may be fussier than non-breastfed infants (Lucas & St. James-Roberts, 1998) and because infant behavioral distress may influence vagal regulation, group differences in infant negative affect were examined. A repeated measures general linear model (GLM) was conducted with infant negative affect as the dependent variables, FFSFP
episodes as within-subjects factors, and breastfeeding status as between-subjects factor. There were no differences in frequency of infant negative affect as a function of breastfeeding status.

**Infant and mother RSA and infant behavior.** Means and standard deviations for infants’ and mothers’ RSA are presented in Table 2. Relations among infants’ and mothers’ RSA and behavior are reported in Table 3. RSA was moderately to highly stable for both mothers and infants. Positive and negative affect showed low to medium stability for infants. Infant affect was correlated with infant RSA in the normal play and reunion episodes.

**Infant and mother RSA and demographic variables.** Consistent with prior research (Moore et al., 2009; Wang et al. 2005; Bar-Haim et al., 2004), African American infants had higher RSA than European American infants throughout the FFSFP (all $p < .05$), and older infants had higher RSA in the still-face episode (Table 4). Infants of married or cohabitating mothers had lower RSA in the reunion episode than infants of single, separated, or divorced mothers ($F(1, 97) = 4.12, p < .05$). Therefore, infant age and marital status were added to main analyses of infant RSA. Infant sex and parity were unrelated to infant RSA.

First-time mothers had higher RSA at baseline ($F(1,110) = 6.03, p < .05$), normal play ($F(1,121) = 6.26, p < .05$), and reunion ($F(1,123) = 4.71, p < .05$) than non-first-time mothers. Mothers of older infants had lower RSA at baseline and in the still-face episode (Table 4), and older mothers had lower RSA in the reunion episode. Therefore, parity, infant age, and mother age were added to main analyses of mother RSA. Race, marital status, and infant sex were unrelated to mothers’ RSA.

Correlations between demographic variables and infant and mother RSA are presented in Table 4.
Demographic covariates. Because of significant inter-correlations among the several variables related to breastfeeding status (Tables 5 & 6), a binary logistic regression was conducted to determine which of these variables made independent contributions to predicting breastfeeding status. Breastfeeding status was independently predicted by race ($B = 1.76, p < .01$) and maternal education ($B = .36, p < .05$) only; therefore these were included in the analyses for infant and for mother RSA.

Because infant age and marital status were related to infant RSA (see above), these variables were added to analyses of infant RSA. And because infant age, mother age, and parity were related to mother RSA (see above) they were added to analyses of mother RSA. Although there were no differences in global amounts of infant negative affect as a function of breastfeeding status, prior research has shown that breastfed infants may be fussier than non-breastfed infants (Lucas & St. James-Roberts, 1998) and infant negative affect during the reunion episode was correlated with mothers’ RSA during the reunion (Table 3). Therefore, infant negative affect in the reunion episode was added to analyses of infant and mother RSA to control for possible effects of behavioral infant distress on infant and mother physiological regulation.

Model Specification

General mixed linear models (MLMs) were used to examine changes in infant and mother RSA across the FFSFP. Models were estimated using the PROC MIXED procedure in SAS software Version 9.4 of the SAS System for Windows (SAS Institute Inc., 2012). This data analytic method is appropriate for repeated measures designs (Little & Rubin, 1987) and dealing with missing data (Schafer & Graham, 2002). Restricted maximum likelihood (REML) was used in reporting model parameters, and degrees of freedom were estimated using the between-within
method. The dependent variable was RSA for infants or for mothers across the FFSFP (separate models were conducted for infants and mothers), and the within-subjects factor was episode (baseline, normal play, still-face, and reunion). Because change in RSA from baseline was the factor of interest, a reference cell coding was employed such that values for FFSFP episodes (normal play, still-face, reunion) represented change from baseline RSA.

Binary variables were effect coded as -1 and 1: race was coded as -1 for African Americans and 1 for European Americans, and breastfeeding status was coded as -1 for non-breastfed and 1 for breastfed.

**Initial Models.** Analyses included two models (predicting infant RSA and mother RSA) to examine effects of breastfeeding, maternal sensitivity, and related demographic variables, independently and interactively, on infant and mother RSA. Infant model included the intercept (baseline), FFSFP episode (normal play, still-face, reunion), breastfeeding status and the interactions of FFSFP episodes by breastfeeding status (terms multiplied), centered maternal sensitivity (Aiken & West, 1991) and the interactions of FFSFP episodes by maternal sensitivity (terms multiplied), the interaction of breastfeeding status and sensitivity, race, maternal education and marital status, and infant age and negative affect in the reunion episode. Mother model included the intercept (baseline), FFSFP episode (normal play, still-face, reunion), breastfeeding status and the interactions of FFSFP episodes by breastfeeding status (terms multiplied), centered maternal sensitivity (Aiken & West, 1991) and the interactions of FFSFP episodes by maternal sensitivity (terms multiplied), the interaction of breastfeeding status and sensitivity, race, maternal education, mother and infant age, parity, and infant negative affect in the reunion episode. Demographic variables were selected based on relations with breastfeeding status or with infant RSA. Although there were no differences in global amounts of infant affect
as a function of breastfeeding status, because prior research has shown that breastfed infants may be fussier than non-breastfed infants (Lucas & St. James-Roberts, 1998), infant negative affect during the reunion episode (the interactive episode with mother in which infants showed most negative affect) was included in analyses of infant and mother RSA to control for possible effects of behavioral infant distress on infant and mother physiological regulation.

**Infant RSA.** On average, all infants showed the expected decrease in RSA during the still-face episode \((B = -0.17, p < .05)\). Controlling for all covariates noted earlier, breastfed infants showed greater RSA withdrawal during the reunion episode \((B = -0.18, p < .05)\) and marginally greater withdrawal during the still-face episode \((B = -0.14, p = .10)\) than non-breastfed infants (Figures 2 & 3). Consistent with prior work on this sample (Moore et al., 2009), infants of mothers rated as more-sensitive showed greater RSA withdrawal during the reunion episode \((B = -0.05, p < .05)\) than infants of mothers rated as less-sensitive (Table 7).

**Mother RSA.** Controlling for all covariates noted earlier, breastfeeding mothers showed greater RSA augmentation in the normal play episode relative to non-breastfeeding mothers \((B = 0.28, p < .05)\) (Figure 2). More-sensitive mothers showed greater RSA withdrawal throughout the FFSFP \((B = -0.09, p < .05)\) (Table 8).

**Final Models.** As seen in Tables 7 and 8, none of the covariates included in the models for infant or mother RSA were significant predictors. Therefore, to arrive at the most parsimonious models, non-significant variables were trimmed one at a time, and the \(-2 \text{ Log Likelihood}\) fit statistics of each candidate model were compared with that of the full model by calculating \(\chi^2\) and assessing significance of the change. Removing extraneous covariates prevents overspecification of the model and is recommended in order to avoid obscuring existing effects (Meehl, 1971).
Infant RSA. Fit of the infant model improved, although not significantly, when infant age ($\chi^2 = 3.5, p = .17$), marital status ($\chi^2 = 1.20, p = .55$), race ($\chi^2 = .8, p = .67$), or marital status and race ($\chi^2 = 1.3, p = .52$) were removed. Removing infant negative affect in the reunion significantly diminished fit ($\chi^2 = 72.4, p = .00$). Removing maternal education ($\chi^2 = .7, p = .70$), maternal education and marital status ($\chi^2 = .1, p = .95$), or maternal education, marital status, and race ($\chi^2 = .8, p = .67$) did not significantly diminish fit. Removing marital status, maternal education, race, and infant age resulted in marginally diminished fit ($\chi^2 = 5.5, p = .06$). Because this difference approached significance, and due to evidence that RSA increases during the first months of life (Bar-Haim et al., 2004), infant age was retained. Furthermore, while removing race did not significantly diminish model fit, race was retained due to its relations with infant RSA in each episode of the FFSFP in preliminary analyses. The resulting model therefore included the intercept (baseline), FFSFP episode (normal play, still-face, reunion), breastfeeding status and the interactions of FFSFP episodes by breastfeeding status (terms multiplied), centered maternal sensitivity (Aiken & West, 1991) and the interactions of FFSFP episodes by maternal sensitivity (terms multiplied), the interaction of breastfeeding status and sensitivity, infant age, race, and infant negative affect in the reunion episode. Results of this final model are presented in Table 9. As in the initial model, breastfed infants showed greater RSA withdrawal in the reunion episode and marginally greater RSA withdrawal in the still-face episode (Figure 4), and infants of more-sensitive mothers showed greater RSA withdrawal in the reunion episode. A marginal race effect indicated that African American infants showed slightly greater RSA augmentation across the FFSFP than European American infants.

Mother RSA. Fit of the mother model improved, although not significantly, when removing infant age ($\chi^2 = 3.1, p = .21$), race ($\chi^2 = .7, p = .70$), or maternal education ($\chi^2 = 3.0, p$
Fit was significantly worse when mother age ($\chi^2 = 353.1, p = .00$) or infant affect ($\chi^2 = 46.9, p = .00$) were removed. Fit was not significantly diminished by removing parity ($\chi^2 = .1, p = .95$) and was improved, although not significantly, by removing parity and infant age ($\chi^2 = 3.5, p = .17$) and then parity, infant age, and race ($\chi^2 = 4.5, p = .11$). Model fit improved significantly when removing parity, infant age, race, and maternal education ($\chi^2 = 7.2, p = .03$). Therefore, the final mother model included the intercept (baseline), FFSFP episode (normal play, still-face, reunion), breastfeeding status and the interactions of FFSFP episodes by breastfeeding status (terms multiplied), centered maternal sensitivity (Aiken & West, 1991) and the interactions of FFSFP episodes by maternal sensitivity (terms multiplied), the interaction of breastfeeding status and sensitivity, mother age, and infant negative affect in the reunion episode. Results of the final model are presented in Table 10. Consistent with results of the initial model, breastfeeding mothers showed greater RSA augmentation in the normal play episode than non-breastfeeding mothers (Figure 5), and more-sensitive mothers showed greater RSA withdrawal throughout the FFSFP relative to less-sensitive mothers.

**Post hoc analyses of infant and mother heart period**

To investigate whether breastfeeding effects on RSA were explained by differences in physiological arousal between breastfed and non-breastfed infants and mothers, the PROC MIXED procedure was used to examine differences in HP. Infant and mother HP were predicted in two separate models, each using the variables included in the final (trimmed) RSA models.

*Infant HP.* On average, infants showed the expected pattern of increased physiological arousal (decreased HP), relative to baseline HP, during the still-face episode ($B = -15.73, p < .001$) and remained aroused during the reunion episode ($B = -15.62, p < .001$). No differences were found in infant HP as a function of breastfeeding status or sensitivity (Table 11).
Mother HP. On average, all mothers showed a greater increase in HP from baseline to the still-face episode ($B = 64.80, p < .001$), indicating lower arousal, relative to baseline HP. Breastfeeding mothers had increased HP (lower physiological arousal) throughout the FFSFP ($B = 36.43, p < .05$), relative to baseline. More-sensitive mothers had marginally decreased HP, relative to baseline, throughout the FFSFP compared with less-sensitive mothers ($B = -7.29, p < .10$) (Table 12).
Discussion

Although a large body of research has conceptualized breastfeeding as one in a suite of early nurturing behaviors that serve to regulate infant and mother physiological and behavioral processes (Champagne & Meaney, 2001; Feldman, 2007d; Hrdy, 1999; Winberg, 2005), facilitate warm caregiving in mothers (Winberg, 2005), and establish the infant’s first social relationship (Blass, 1994), much remains to be understood about how breastfeeding may affect infants’ social-emotional development. Existing work has largely adopted a framework in which breastfeeding effects are explained by differences in the parenting behavior of breastfeeding and non-breastfeeding mothers, which may be due to self-selection factors (Jansen et al., 2008) or to changes in mothers’ hormones (Handlin et al., 2009; Matthiesen et al., 2001; Uvnas-Moberg, 1998) or parenting behavior (Field, Hernandez-Reif, & Feijo, 2002; Kim et al., 2011; Strathearn, Mamun, Najman, & O’Callaghan, 2009; Tharner et al., 2012; Winberg, 2005) as a result of breastfeeding. Because breastfeeding status is consistently related to demographic factors such as race and socioeconomic status, some research has also considered whether breastfeeding is merely a marker for sociocultural factors that explain individual differences in children rather than a mechanism generating such differences (Horta & Victora, 2013).

However, a third possibility has thus far received almost no empirical testing: following the gustatory-vagal hypothesis, infant-mother mutual vagal stimulation during breastfeeding may be a means of co-regulating physiologically, and this frequent vagal exercise over the first months of life may contribute to the development of effective and efficient vagal regulation. Therefore, the current study aimed to take an initial step toward understanding whether and how breastfeeding is related to infants’ and mothers’ physiological regulatory development by
examining links between breastfeeding status and vagal regulation during a mild social stressor when controlling for maternal sensitivity and relevant demographic factors.

To investigate the relative contributions of these three potential contributors to individual differences in infant and mother vagal regulation, the study was guided by two aims: first, to investigate whether there were effects of breastfeeding on infant and mother vagal regulation that were independent of differences in the caregiving behavior of breastfeeding and non-breastfeeding mothers; and second, to situate breastfeeding in its complex social context in order to assess unique effects of breastfeeding on vagal tone when also controlling for demographic factors. Because there are complex inter-relations among breastfeeding, maternal sensitivity, and demographic variables, the study aimed to identify the relative and independent contributions of each.

Results were consistent with the gustatory-vagal hypothesis and with maternal sensitivity theories, finding that breastfeeding infants and mothers showed unique patterns of vagal regulation, as measured by RSA, during the FFSFP relative to non-breastfeeding infants and mothers, even when controlling for maternal sensitivity and various demographic variables. While breastfeeding status predicted infants’ patterns of RSA regulation, it did not predict physiological arousal, measured by HP, or behavioral distress, suggesting that breastfeeding may be uniquely related to infants’ vagal development. Likewise, maternal sensitivity differentially predicted both infants’ and mothers’ vagal regulation during the procedure, independent of breastfeeding status and demographic variables. The independent effects of breastfeeding and maternal sensitivity suggest that, even though breastfeeding mothers were rated as more sensitive than other mothers, breastfeeding effects were not explained by breastfeeding self-selection.
Aim 1. Even when controlling for maternal sensitivity, infant distress when mothers resumed normal interaction following the still-face disruption, and demographic variables (race, maternal education, marital status, and age), breastfed infants showed greater vagal withdrawal during the reunion episode of the FFSFP, relative to baseline, compared with non-breastfed infants. This likely reflects their marginally greater withdrawal during the still-face episode and suggests that breastfed infants continued to rely on vagal withdrawal during the reunion to support attempts at self-regulation and reparation of the dyadic exchange. Breastfed and non-breastfed infants experienced similar physiological arousal, as measured by decreased HP, during the still-face and reunion, but breastfed infants showed greater vagal reactivity when resuming social interaction. Consistent with the gustatory-vagal hypothesis, this may be a function of more flexibility or capacity of the vagal system to regulate in response to the demands of social engagement.

Consistent with prior research on this sample (Moore et al., 2009), infants of mothers rated as more-sensitive also showed greater vagal withdrawal during the reunion episode, relative to infants of mothers rated as less-sensitive, even when controlling for breastfeeding status, infant affect, and demographic factors. Importantly, however, withdrawal in the reunion episode was independently predicted by breastfeeding and sensitivity, indicating that relations between breastfeeding and infant vagal tone are not solely explained by differences in maternal behavior that may reflect self-selection factors related to breastfeeding status. Rather, these findings suggest that, as theorized by the gustatory-vagal hypothesis, breastfeeding has a direct effect on the vagal system that is independent of caregiving behaviors.

To better understand relations between breastfeeding and infant RSA and between sensitivity and infant RSA, post hoc analyses examined breastfeeding and sensitivity links with
change in infant HP, a measure of physiological arousal that is jointly determined by sympathetic and parasympathetic control of the heart. Differences in HP reactivity could have suggested that physiological arousal mediated the relationship between breastfeeding and infant RSA (or maternal sensitivity and infant RSA). However, analyses showed no differences in degree of physiological arousal between breastfed and non-breastfed infants, supporting the hypothesis that breastfeeding is uniquely related to parasympathetic regulation. Similarly, behavioral distress did not explain the differences in RSA regulation between breastfed and non-breastfed infants.

Together, these results indicated that, although all infants were similarly physiologically aroused and behaviorally distressed by the task, which is intended as a mild social stressor, breastfed infants showed greater vagal reactivity. Given Polyvagal Theory’s proposition that vagal withdrawal allows for modulation of physiological state in order to cope with the demands of social engagement, these findings suggested that the vagus is more a more active modulator of physiological state in breastfed infants than in non-breastfed infants. By withdrawing and applying the vagal brake during breastfeeding, infants may exercise the vagal system to a greater degree than non-breastfed infants, resulting in a greater capacity to engage this physiological regulatory mechanism. Findings also provide initial evidence to suggest that breastfeeding’s soothing effects may be linked specifically to vagal regulation rather than to mechanisms that directly reduce sympathetic reactivity.

Infant HP was also unrelated to maternal sensitivity. Therefore, consistent with the biopsychosocial framework, heightened regulatory support provided by more-sensitive mothers appears also to contribute specifically to infants’ vagal development in infancy. This is consistent with existing research linking vagal regulation with dyadic coordination (Moore & Calkins,
Breastfeeding mothers showed greater RSA augmentation from baseline to normal play than non-breastfeeding mothers, suggesting a calmer, more regulated state. Although there are few studies on mothers’ vagal regulation during the FFSFP, some research suggests that the typical pattern for mothers is RSA withdrawal during the interactive episodes (Moore, 2009; Moore et al., 2009), when they are expected to scaffold and support infant regulation. However, in the current study, analyses of mothers’ physiological arousal, measured by HP reactivity, confirmed that breastfeeding mothers experienced less arousal throughout the FFSFP compared with non-breastfeeding mothers, suggesting that their higher vagal tone in the normal play may have been due to a lessor need to regulate. This is consistent with existing research reporting lower physiological stress reactivity, less perceived stress, and relatively greater parasympathetic control in breastfeeding women relative to non-breastfeeding women (Altemus et al., 2001; Mezzacappa, 2004; Mezzacappa, Kelsey, & Katkin, 2005).

Conversely, mothers rated as more-sensitive experienced greater RSA withdrawal in all episodes of the FFSFP, demonstrating that breastfeeding and sensitivity exerted independent and distinct effects on mothers’ vagal responses. Post hoc analyses also showed that more-sensitive mothers were marginally more aroused throughout the task than less-sensitive mothers, perhaps explaining their greater RSA withdrawal. These effects may be explained by the dyadic nature of the task: more-sensitive mothers were marginally more aroused—perhaps in response to anticipating or witnessing their infants’ distress—and therefore showed greater withdrawal of the vagal brake in an attempt to regulate. Alternatively, they may have been more active in trying to engage or soothe their infants, and greater RSA withdrawal may have supported those social
behaviors. Of note, maternal sensitivity was measured during a separate task in the home and not during the FFSFP, where variability in maternal behavior is typically more difficult to observe due to constraints of the procedure (Mesman et al., 2009).

Relations between breastfeeding and vagal regulation in mothers, therefore, may be closely linked with other physiological systems (e.g. the SNS and endocrine systems) that modulate stress reactivity. Further research is now needed to understand the mechanisms underlying these relations—specifically, to examine whether vagal stimulation during breastfeeding mediates attenuated sympathetic, endocrine, or behavioral stress in breastfeeding women, or conversely, whether differences in breastfeeding and non-breastfeeding mothers’ vagal tone are explained by distinct patterns of stress reactivity in these two groups. For example, the growing body of research on oxytocin and breastfeeding has proposed that higher baseline oxytocin levels may explain breastfeeding mothers’ attenuated stress responses (e.g. Uvnas-Moberg, 1998). However, consistent with the current study, Altemus and colleagues (2001) reported higher vagal tone and lower sympathetic activation in breastfeeding vs. non-breastfeeding postpartum women but found no differences in oxytocin or allopregnanolone (implicated in sedation and stress reduction) between the two groups, suggesting that oxytocin levels did not explain differences in mothers’ autonomic functioning. Still, research has only begun to investigate coordination among mothers’ endocrine and autonomic systems in response to breastfeeding. Given that the nucleus ambiguus is both the origin of the myelinated vagus and an oxytocin binding site (Swain et al., 2007), and given known relations between endocrine and autonomic stress responses (Norman, Cacioppo, Morris, Malarkey, Berntson, & DeVries, 2011), these systems are likely to act in concert with respect to breastfeeding; however, further work is needed to elucidate the temporal and causal mechanisms linking these interrelated physiological
processes. In the context of this emerging literature, the current study provides additional evidence that breastfeeding women exhibit greater parasympathetic control of the heart during a social exchange with their child relative to non-breastfeeding women.

**Aim 2.** When investigating outcomes associated with breastfeeding, it is necessary to consider potential effects of sociocultural variables with known relations to feeding method. The links between these variables and maternal sensitivity and the differences in sensitivity as a function of breastfeeding status highlight the complexity of these inter-relations. Studies with inadequate assessment and control of such factors run the risk of inaccurately attributing to breastfeeding effects that are in fact due to other environmental circumstances. Therefore, the second aim of the current study was to examine effects of breastfeeding on infants’ and mothers’ RSA when controlling for variables related to breastfeeding status in the current sample and existing literature. Preliminary analyses examined relations between breastfeeding status and all demographic variables available in the current study that have been associated with breastfeeding in prior work. In the current sample, race, income, marital status, and maternal education, and age were each related to breastfeeding status; mothers’ number of hours worked per week, parity, and infant sex were not. Further analysis showed that only race and maternal education *independently* predicted breastfeeding status. The lack of unique association between income level and breastfeeding status was unexpected but suggests that apparent links between income level and breastfeeding status may be explained by mothers’ education level. This may indicate that the stratification of feeding method across socioeconomic groups is due to differences in sociocultural practices and beliefs around early feeding, such that more-educated women more frequently encounter materials extolling breastfeeding’s benefits. It may also mean that less-educated women disproportionately experience physical or psychosocial barriers to breastfeeding
(e.g. health impairments or significant stress). It is also possible that, although mothers’ number of hours worked per week did not predict breastfeeding status in the current sample, differences in the types of jobs worked by more- and less-educated mothers affect mothers’ choice or ability to breastfeed.

Strikingly, however, demographic variables did not predict infant or mother vagal regulation when also controlling for breastfeeding status, maternal sensitivity, or infant affect. The specific effects of breastfeeding and of sensitivity on infant and mother RSA remained relatively consistent whether demographic variables were included in the model or not. Furthermore, mother model fit was improved by the removal of race, maternal education, infant age, and parity; and infant model fit was unchanged by removing maternal education and marital status. Parsimonious models for both infants and mothers therefore included breastfeeding status, maternal sensitivity, race (for infants only), infant or mother age (respectively), and infant affect, suggesting that vagal regulation during mother-infant interaction is primarily influenced by proximal environmental and physiological—and, in infants, perhaps genetic (race)—factors.

In infants, these findings support theories that vagal development is the product of physiological and behavioral co-regulation during breastfeeding and other caregiving activities. Particularly in light of relations between maternal sensitivity and race, maternal education, and marital status, these findings suggest that, if demographic factors influence vagal development in early infancy, they may “get under the skin” by way of parenting behavior. As children age, however, other processes related to demographic factors may affect their physiological development to a greater degree (e.g., exercise, stress, obesity).

However, it is worth noting the following pattern, which complicates interpretation: African American mothers were rated as less-sensitive than European American mothers; infants
of less-sensitive mothers showed less vagal withdrawal in the reunion episode; and African American infants showed marginally greater RSA augmentation throughout the procedure. The finding that African American mothers were rated as less-sensitive than European American mothers may simply mean that maternal behaviors captured by this measure were culturally biased toward a European American conceptualization of sensitive parenting. Therefore, relations between maternal sensitivity and infant RSA may truly be due to differences in parenting behavior (which appears to be culturally influenced), or it may be due in part to multiply-determined factors associated with ethnicity. The finding in the current study that lower maternal sensitivity was related to less infant RSA withdrawal only in the reunion episode, while race was marginally related to RSA augmentation in all episodes, suggests that parenting behavior and ethnicity contribute uniquely to infant vagal regulation, even if one influences the other. Nevertheless, further investigation is needed to understand the potential cultural specificity of measures such as maternal sensitivity and to identify, where possible, specific maternal behaviors that influence infants’ vagal regulation. The current study suggests that breastfeeding may be one of these, as relations between vagal tone and breastfeeding were independent of demographics or sensitivity, indicating that breastfeeding gets under the skin via a separate mechanism.

The absence of demographic effects is perhaps more surprising for mothers than it is for infants, given the broader range of potential contributors to their autonomic functioning over time—and given that demographic factors such as education level and parity are likely to be salient elements of mothers’ daily lives. Further research is needed to replicate and further probe these relations. However, the fact that both maternal sensitivity and breastfeeding status were robust to the inclusion of putative salient demographic variables indicates that sensitivity and
breastfeeding—key elements of the daily lives of new mothers—may be principal contributors to mothers’ autonomic functioning, either generally or during exchanges with their infant.

Together, findings that breastfeeding status differentially predicted infants’ and mothers’ vagal regulation, albeit in specific contexts (during reunion following disruption of social engagement and in normal social play, respectively), independent of maternal sensitivity and demographic confounds, support the theory that breastfeeding may be a process by which mothers and infants co-regulate physiologically. Consistent with the biopsychosocial perspective, this co-regulation likely promotes infants’ regulatory development both directly and indirectly: while exercising of the infant vagus during breastfeeding may contribute directly to physiological self-regulatory development, stimulation of the mother’s vagal system may decrease stress reactivity and increase her own capacity for regulation. This provides a physiological basis for warm, calm caregiving that supports infants’ regulatory development indirectly. Therefore, this study provides initial findings to guide future research on the mechanisms underlying physiological co-regulation, particularly during feeding. Further investigation of these mechanisms, which explain links between early nurturing behaviors and mother-infant psychophysiology, is likely to yield new insight to the process of regulatory development.
Limitations & Future Directions

Although the current study attempted to control for factors influencing breastfeeding self-selection by including maternal sensitivity and relevant demographic variables in statistical analyses, other variables known to influence breastfeeding status (e.g., maternal health factors) and those known to affect measures of RSA (e.g., weight, smoking, hypertension) were not available for inclusion. Maternal health and weight, in particular, have known relations with both breastfeeding status and physiology (Donath & Amir, 2000; Berntson, Quigley, & Lozano, 2007) and should be included in future research where possible. Because random assignment to feeding group is considered unethical, statistical control for demographic, behavioral, and health-related variables is likely the best option for isolating true feeding effects.

Future studies should also include measurements of the frequency and duration of breastfeeding, neither of which were available in the current study, in order to investigate possible dose-response relationships between breastfeeding and vagal tone.

Finally, the current study did not measure mutual vagal stimulation during breastfeeding but used breastfeeding status to capture the theoretical mechanism of effects of breastfeeding on vagal regulation during a social stressor. Future work is necessary to investigate mothers’ and infants’ vagal activity during breast- and bottle-feeding.

Other important areas of future inquiry include examining associations between parasympathetic and neuroendocrine function in the context of breastfeeding, particularly in mothers; and exploring whether feeding differences in vagal regulation early in life contribute to later differences in behavioral regulation and other social-emotional outcomes.
Conclusions

Findings of the current study support the theory that mutual vagal stimulation during breastfeeding is a mechanism of physiological co-regulation that contributes to self-regulatory development. Relations between breastfeeding and infant and mother vagal regulation were independent of maternal sensitivity; and demographic variables did not predict infant or mother vagal tone. Further, while breastfed infants showed greater vagal withdrawal from baseline during the reunion episode of the FFSFP relative to non-breastfed infants, the two groups did not differ in behavioral distress or physiological arousal, indicating unique relations between breastfeeding and vagal regulation. Further research is now needed to examine infants’ and mothers’ vagal tone during breast- and bottle-feeding to better understand whether mutual vagal stimulation during breastfeeding is a co-regulatory process.
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Breastfeeding as one in a suite of nurturing behaviors

In postpartum settings, feeding and tactile stimulation often go hand-in-hand, one generating the other: skin-to-skin contact immediately following birth regulates infants’ temperature, energy expenditure, and acid-base balance (Christensson et al., 1992) and initiates infant putative innate nursing behavior, facilitating breastfeeding (Varendi, Porter, & Winberg, 1994). However, due to the grouping of nurturing behaviors in existing research, we do not yet understand to what extent the unique sensory inputs provided by each of these behaviors stimulates common or different physiological processes. According to these studies, breastfeeding and tactile stimulation excite the infant vagus, which in turn activates hormone production in the enteric nervous system (gut) (Uvnas-Moberg, Widstrom, Marchini, & Winberg, 1987). This vagal engagement may serve to regulate the stress of birth, which excites the SNS (Christensson et al., 1992). Such a regulatory effect would be consistent with the finding that early contact inhibits infant crying (Christensson, Cabrera, Christensson, Uvnas-Moberg, & Winberg, 1995; Michaelsson, Christensson, Rothganger, & Winberg, 1996). While studying these nurturing behaviors as a group is ecologically valid, it does not allow for differential identification of the contributions of specific behaviors (e.g. breastfeeding versus skin-to-skin contact) to a developmental process.

For example, Klaus and colleagues (Klaus et al., 1972; Klaus & Kennell, 1976) found that mothers who experienced at least 18 hours of physical contact with their infant in the three days following birth were more likely to attend to their infants affectionately later in infancy. However, research also shows that increasing the time that mothers and infants spent in skin-to-skin contact increased the likelihood of exclusive breastfeeding during the hospital stay.
(Bramson, 2008). This relationship may be due to physiological processes that stimulate lactation in postpartum mothers (discussed in more detail above), or it may be explained by the fact that mothers who intend to exclusively breastfeed are more likely to engage in prolonged skin-to-skin contact (Bramson, 2008). After all, one of the best predictors of breastfeeding status across studies is mothers intention to breastfeed—a decision commonly made early in pregnancy or prior to conception (DiGirolamo, Thompson, Martorell, Fein, & Grummer-Strawn, 2005; Thulier & Mercer, 2009; Lawson & Tulloch, 1995). This intention is informed by a host of social, cultural, economic, and physical factors (Arora, McJunkin, Wehrer, & Kuhn, 2000; Balcazar, Trier, & Cobas, 1995; Forste, Weiss, & Lippincott, 2001; Piper & Parks, 1996; Ryan, Zhou, & Arensberg, 2006; Scott, Binns, Oddy, & Graham, 2005; Taylor, Risica, Geller, Kirtania, & Gabral, 2006; Thulier & Mercer, 2009). While the current study did not experimentally manipulate specific nurturing behaviors (e.g. breastfeeding or bottle-feeding with or without skin-to-skin contact) and therefore cannot isolate their unique effects, it was able to control for maternal sensitivity, which likely influences mothers’ use of other nurturing behaviors.

Benefits of breastfeeding

Breastfeeding’s ability to soothe in the moment, together with its associated physical and psychological outcomes, has inspired researchers from across disciplines to consider what it is about this behavior that confers benefits in such a wide range of developmental domains. The resulting studies have primarily investigated nutritional (Anderson, Johnstone, & Remley, 1999; Horta & Victora, 2013; Michaelson, Lauritzen, & Mortensen, 2009), hormonal (Jansen, de Weerth, & Riksen-Walraven, 2008; Stuebe et al., 2013; Sullivan et al., 2011; Uvnas-Moberg, 1997; Uvnas-Moberg et al., 1987), and attachment-related (Britton et al., 2006; Jansen, de Weerth, & Riksen-Walraven, 2008; Kim et al., 2011) mechanisms—the third category yielding
inconclusive findings (Jansen, de Weerth, & Riksen-Walraven, 2008). While nutritional- and hormonal-mediated models show theoretical promise, conclusions of these studies have often been limited by racially and socioeconomically homogeneous samples and by research designs that focus on a single mechanism rather than situating that mechanism among other variables operating at different levels of analysis. As a result, despite widespread enthusiasm in both the scientific and popular discourses over breastfeeding’s outcomes (Horta & Victora, 2013; Jansen, de Weerth, & Riksen-Walraven, 2008), little is yet understood of the processes by which breastfeeding influences psychophysiological development.

Despite the development of alternative feeding methods, breastfeeding is recommended for children under six months (Gartner, 1998; Horta & Victora, 2013). In addition to well-documented physical and medical benefits (Eglash, Montgomery, & Wood, 2008; Horta & Victora, 2013), studies show that breastfeeding is associated with enhanced cognitive capacity (Anderson, Johnstone, & Remley, 1999; Hoefer & Hardy, 1929; Michaelson, Lauritzen, & Mortensen, 2009) and improved psychosocial outcomes (Jansen, de Weerth, & Riksen-Walraven, 2008; Taylor & Wadsworth, 1985) later in childhood, as well as heightened positive parenting behaviors in mothers (Strathearn, Mamun, Najman, & O’Callaghan, 2009; Winberg, 2005).

Regarding physical health, breastfeeding has been found to reduce infants’ risk of infection, allergies, obesity, and some chronic illnesses, and to lower infant mortality rates (Horta & Victora, 2013). With respect to cognitive capacity, studies have consistently found that breastfed children have higher intelligence quotient (IQ) scores than formula-fed children even when controlling for commonly included covariates (e.g. maternal IQ and birth weight). (However, meta-analyses of prior research on breastfeeding and IQ note that the influence of
other potentially confounding variables has not been adequately assessed.) Researchers have primarily proposed nutritional explanations for these differences in cognitive outcome, citing the importance of long-chain polyunsaturated fatty acids (LCPUFAs) contained in breast milk for early brain development (Anderson, Johnstone, & Remley, 1999; Horta & Victora, 2013; Michaelson, Lauritzen, & Mortensen, 2009).

Psychosocially, breastfeeding has been linked with lower perception of (Mezzacappa & Katkin, 2002) and physiological response to (Altemus et al., 2001) stress in mothers, lower rates of maternal depression (Eglash, Montgomery, & Wood, 2008), decreased risk for abuse and neglect (Strathearn, Mamun, Najman, & O’Callaghan, 2009), improved attachment formation (Britton, Britton, & Gronwaldt, 2006), and increased maternal sensitivity (Kim et al., 2011; Tharner et al., 2012). Furthermore, breastfeeding may act as a protective factor for infants of depressed mothers (Aaron Jones, McFall, & Diego, 2004), and has been associated with fewer behavior problems later in childhood (Taylor & Wadsworth, 1984). Indeed, breastfeeding’s perceived relational benefits are often cited by mothers as key incentives for breastfeeding their children (Arora, McJunkin, Wehrer, & Kuhn, 2000).

Studies have also compared the sleep patterns, frequency of crying, and temperamental traits of breast- versus bottle-fed infants. Research on sleep is inconclusive, with one study asserting that breastfed babies sleep more than bottle-fed babies (Lee, 2000) and another finding that they sleep less (Lucas & St. James-Roberts, 1998). This discrepancy is likely due to the different time points at which the two studies measured sleep: while Lucas & St. James-Roberts assessed sleep patterns at two and six weeks, Lee did so between 11 and 122 days (roughly 1.5 to 17.5 weeks). This latter time frame may be too wide to detect an effect, particularly because research investigating breastfeeding’s association with related domains suggests that
breastfeeding may influence the course of development. For example, Lucas and St. James-Roberts (1998) found that breast- and formula-fed infants reach peak crying frequency at different points, with formula-fed infants decreasing in crying frequency from two to six weeks and breastfed infants increasing in crying from two to six weeks. This is consistent with findings that, relative to bottle-feeding infants, breastfeeding infants are rated as more difficult on multiple temperamental dimensions in early infancy, including higher negative reactivity and lower soothability (DiPietro, Larson, & Porges, 1987; de Lauzon-Guillain et al., 2012; Niegel, Ystrom, Hagtvet, & Vollrath, 2008) but that the relationship between breastfeeding status and difficult temperament falls away after the first year of life (Niegel, Ystrom, Hagtvet, & Vollrath, 2008). Together, these findings suggest that breastfeeding and bottle-feeding infants may mature at different rates both physiologically and socio-emotionally. This is in keeping with the conceptual framework laid out herein, which proposes that the hard work of breastfeeding stimulates the infant vagus, contributing over time to organization of the infant’s psychophysiological regulatory systems.

3 Behavioral co-regulation

The process of call and response between infant and caregiver has been conceptualized as mutual or co-regulation because of the bi-directional influence that each member of the dyad has on the other: while caregiver response modifies infant behavior, so, too, does infant behavior differentially elicit caregiver response (Cohn & Tronick, 1988; Feldman, 2007). Over time, caregivers and infants tend to become increasingly attuned to each other’s cues (Cohn & Tronick, 1987; Feldman, 2007), ideally allowing for faster, better fitted, and more effective responses. The development of this dyadic attunement results in patterns of interaction that may contribute to or constrain co-regulation, which in turn contributes to or constrains the child’s
development of self-regulation. According to Tronick’s Dyadic Expansion hypothesis, the infant is able to navigate challenges that exceed his own regulatory capacities by drawing on the resources of the caregiver and dyad. Through the dyad, the infant is able to expand beyond the boundaries of his own competence to face new and increasing demands, thereby growing his self-regulatory capacity (Tronick, 1998).

In this way, the quality of co-regulatory (external) interactions provides a framework for self-regulatory (internal) competence. Therefore, in an effort to understand the composition of more- and less-successful dyadic transactions, researchers have investigated the microbehavioral and physiological patterns that make up dyadic exchanges (Moore et al., 2013). One construct identified by this body of research is dyadic synchrony (Feldman, 2003; 2007c; 2007d; Moore et al., 2013; Porter, 2003), which Feldman has defined as “the temporal coordination of micro-level social behavior” (Feldman, 2007d, p. 340). Research suggests that both infant vagal tone (Feldman, 2006; Moore & Calkins, 2004) and maternal sensitivity (Moore et al., 2009) are related to dyadic synchrony, which in turn contributes to the child’s ability to regulate physiologically and behaviorally (Feldman, 2003; 2007c; 2007d). Behavioral synchrony has been linked with a variety of developmental outcomes including cognitive functioning (Feldman, 2003; Feldman & Eidelman, 2003; Feldman, Greenbaum, Yirmiya, & Mayes, 1996) and prosocial behavior (Harrist & Waugh, 2002).

Phylogenetic Organization of the Autonomic Nervous System

The phylogenetically oldest component of the autonomic nervous system is made up of the unmyelinated branch of the tenth cranial (vagus) nerve, which originates in the dorsal motor nucleus of the medulla. The unmyelinated vagus is associated with the freezing or feigning death response to threat and is common to primitive vertebrates, amphibians, reptiles, and mammals.
When activated, the unmyelinated vagus exerts a powerful inhibitory effect on the cardiac pacemaker, slowing heart rate and facilitating the behavioral freeze response (Porges, 2001, 2007).

The second-oldest branch of the autonomic nervous system is the sympathetic nervous system (SNS). The SNS is common to amphibians, reptiles, and mammals and is associated with mobilization, better known as the fight or flight response. Activation of the SNS exerts an excitatory effect on the heart and sweat glands while down-regulating metabolism in order to conserve energy (Porges, 2001, 2007).

The phylogenetically youngest branch of the ANS is the myelinated vagus. (Discussed in more detail in text.)

5 Dynamic Regulation in the Polyvagal System

According to Porges (2001, 2007), when faced with a social demand, a mammal may sequentially engage each of the three hierarchically integrated branches of the polyvagal system, beginning with the phylogenetically youngest (the myelinated vagus). If this parasympathetic regulation proves insufficient to face the demand or cannot be maintained, the SNS will activate to mobilize the organism for action. This has the effect of speeding heart rate while slowing digestive function, which conserves energy. Finally, once the other two systems have been exhausted, the organism reverts to the phylogenetically oldest branch of the system, the unmyelinated vagus. This branch’s powerful inhibitory effect on the heart, however, may induce bradycardia, which can be dangerous and even lethal to humans (Porges, 2001). This hierarchically contingent system allows for modulated processing of and response to nuanced social information—processes critical to the survival and wellbeing of social species. Indeed, Porges posits that the third branch of the autonomic nervous system evolved to allow mammals

6 Development of the Vagal System

In typically developing infants, the corresponding growth in behavioral and physiological systems manifests in an increase in baseline vagal tone over the first years of life (Bar-Haim, Marshall, & Fox, 2004; Bornstein & Suess, 2000; Patriquin, Lorenzi, Scarpa, & Bell, 2013), which indicates a capacity for physiological regulation via the parasympathetic nervous system (Calkins, 2011; Porges & Furman, 2011). Vagal regulation in response to disruption of mother-infant co-regulation has been observed in infants as early as three months of age (Moore & Calkins, 2004).

7 Physical Mechanics of Breast- vs. Bottle-Feeding

Goldfield and colleagues (2006) examined suck-swallow-breathe patterns in infants who were exclusively breastfed for four to six weeks and then fed breast milk using a combination of breast- and bottle-feeding. Infants were observed in the lab in both breastfeeding and bottle-feeding episodes. This study found that infants showed a patterned suck-swallow-breathe sequence during breastfeeding that they did not show during bottle-feeding. Furthermore, infants had lower oxygen levels during the bottle-feeding episode. Based on these results, the authors theorized that during breastfeeding, the infant’s sequencing of sucking, swallowing, and
breathing is organized to create space for patterned breathing (Goldfield, Richardson, Lee, & Margetts, 2006). A separate review agreed with this interpretation, proposing that the central nervous system’s coordination of unique suck-swallow-breathe patterns during breastfeeding likely explains the higher oxygenation levels in breastfeeding infants and may therefore contribute to breastfeeding’s benefits (Brown, 2007).

A longitudinal study of suck-swallow-breathe organization during breastfeeding (Sakalidis et al., 2013) found that, while breastfeeding infants are already able to coordinate these patterns in the first month of life, by two to four months postpartum they show increased efficiency during feeding, marked by longer bouts of sucking, shorter pauses between bouts, and shorter overall feeding sessions. By two to four months of age, infants also showed higher oxygen levels and lower heart rate during feeding than they had in the first month. In keeping with findings that breastfeeding infants have higher oxygenation than bottle-feeding infants and that oxygenation levels during breastfeeding improve over time, a study by Limeira and colleagues (2013) found that exclusive breastfeeding for the first six months of life, followed by some amount of breastfeeding during the next 18 months, was associated with healthier breathing patterns later in childhood (Limeira, Aguiar, de Lima Bezerra, & Camara, 2013).

Finally, Moral and colleagues (2010) investigated suck-pause patterns in exclusively breast- or bottle-fed three- to four-week-old infants during feeding. The researchers found that bottle-fed infants paused for longer periods of time during feeding and sucked less frequently than infants who were breastfed. Following empirical work on the gustatory-vagal hypothesis that has demonstrated a positive correlation between rate of sucking and vagal withdrawal, the finding that bottle-fed infants suck less frequently than breastfed infants suggests that bottle-fed
infants may correspondingly experience less vagal withdrawal during feeding than breastfed infants.

Finally, using ultrasound technology, Weber and colleagues (1986) identified two types of tongue movements during feeding—one characteristic of breastfed and the other of bottle-fed infants in the first week of life. While breastfeeding infants exhibited a peristaltic undulation of the tongue, bottle-fed infants used a “piston-like” movement to suck. The former movement, required to squeeze milk from the breast, involves the dynamic and continuous engagement of tongue musculature. Even between sucks, breastfeeding infants’ tongue musculature remained active, pressing against the breast. This continuous muscle activation did not occur in bottle-feeding infants (Weber, Woolridge, & Baum, 1986).

8 Oxytocin and Breastfeeding

At the beginning of a feeding session, infant suckling at the breast generates oxytocin production in the mother, which in turn stimulates lactation (Matthiesen, Ransjo-Arvidson, Nissen, & Uvnas-Moberg, 2001). Oxytocin has also been tied to sensitive parenting behaviors in mothers (Feldman, Weller, Zagoory-Sharon, & Levine, 2007). Given oxytocin’s dual biological (lactation) and psychological (bonding) functions, researchers have speculated that the oxytocin produced following suckling also promotes nurturing behaviors in mothers. In fact, one study found that mothers whose infants suckle shortly after birth go on to show increased attention to—and proximity-seeking behavior towards—their infants (Widstrom et al., 1990).

While few studies comparing breastfeeding and bottle-feeding mothers have considered relations between neuroendocrine and autonomic responses, existing evidence suggests that these two systems work in concert with one-another in the context of affiliative behavior. The nucleus
ambiguous, which contains the source nuclei of the vagus, has also been identified as an oxytocin binding site (Swain, Lorberbaum, Kose, & Strathearn, 2007). This may help to explain the finding that administration of intranasal oxytocin led to increased vagal tone (Norman et al., 2011). With respect to breastfeeding, however, one study showed that oxytocin levels and vagal regulation are not necessarily correlated: Altemus and colleagues (2001) found that, while breastfeeding mothers showed greater vagal control of cardiac function and lower sympathetic reactivity following a social stressor than did bottle-feeding mothers, the two groups did not differ in oxytocin level either at baseline or following the lab procedure. These findings suggest that (a) further research is needed to disentangle relations among breastfeeding, the neuroendocrine system, and the autonomic nervous system, and (b) investigation of breastfeeding’s effects on the maternal vagal system may help to explain differences observed in the emotions and social behaviors of breast- and bottle-feeding mothers.

9 Confounds

Relationships between breastfeeding and cultural, racial, or socioeconomic factors have remained stable over time, with studies conducted on datasets from the 1970s reporting associations that are still found in current research (Conner et al., 2013; Ford & Labbok, 1990; Forste, Weiss, & Lippincott, 2001; Thulier & Mercer, 2009). Research has also identified proximal factors that may explain some of the association between demographics and breastfeeding status. These include maternal self-efficacy (Blyth et al., 2002); accessibility of social supports (Alexy & Martin, 1994); family and friend attitudes towards breastfeeding (Arora, McJunkin, Wehrer, & Kuhn, 2000; DiGirolamo, Thompson, Martorell, Fein, & Grummer-Strawn, 2005); and pre-birth intention to breastfeed (DiGirolamo, Thompson,
Martorell, Fein, & Grummer-Strawn, 2005; Lawson & Tulloch, 1995; Piper & Parks, 1996). This final variable highlights an important point: Mothers’ intention to breastfeed is likely informed by cultural attitudes and beliefs as well as exposure to particular types of education and socialization. According to Jansen and colleagues (2008), the decision to breastfeed (barring medical or logistical barriers) is often based on the perceived socioemotional—specifically, attachment-related—benefits of the practice. Therefore, it is likely that the same maternal traits that contribute to a decision to breastfeed may also manifest in sensitive parenting behaviors. If this is the case, then benefits attributed to breastfeeding may actually be due to self-selection: sensitive mothers choose to breastfeed, and sensitive mothers exhibit other positive parenting behaviors that benefit their children’s development.

The few studies that have attempted to control for common confounds when examining outcomes associated with breastfeeding have yielded inconclusive findings; and those involving large-scale or nationally representative samples have largely focused on factors influencing breastfeeding initiation and duration (e.g. DiGirolamo, Thompson, Martorell, Fein, & Grummer-Strawn, 2005; Ford & Labbok, 1990; Piper & Parks, 1996; Taylor, Risica, Geller, Kirtania, & Cabral, 2006) or on health and cognitive benefits associated with breastfeeding (Anderson, Johnstone, & Remley, 1999; Horta & Victora, 2013; Horwood & Fergusson, 1998; Michaelsen, Lauritzen, & Mortensen, 2009) and therefore cannot shed light on relations between breastfeeding and regulatory development.

However, when controlling for SES and other confounds (e.g. stimulation at home, maternal IQ, and variables related to physical health), Horta and Victora (2013) found that the
difference in IQ scores between breast- and bottle-fed children shrunk from 4.69 points (SE = 0.38) to 0.52 points (SE = 0.36). However, another meta-analysis reported a difference of 3.16 points (95% CI: 2.35, 3.98) when controlling for common covariates, which included SES in 17 out of 20 studies in the analysis (Anderson, Johnstone, & Remley, 1999).

11 Does HP mediate relations between breastfeeding or maternal sensitivity and mother RSA?

Follow-up analyses probed mediation models of breastfeeding status, mother RSA, and mother HP and of maternal sensitivity, mother RSA and mother HP, following Barron and Kenny’s (1986) steps. Although breastfeeding status predicted mother RSA (Table 10) and mother HP (Table 12), and mother HP predicted mother RSA ($B = .01, p < .001$), mother HP did not mediate the relationship between breastfeeding status and mothers’ RSA, as relations remained when adding HP to the mother RSA model ($B = .24, p = .02$). Therefore, while breastfeeding mothers showed lower physiological arousal throughout the FFSFP and greater vagal regulation during the normal play episode, arousal did not explain links between breastfeeding and mothers’ vagal tone.

Heart period partially mediated the relationship between maternal sensitivity and RSA ($B = -.06, p = .06$), indicating that more-sensitive mothers’ lower vagal tone throughout the FFSFP was partly explained by greater physiological arousal during the task.

12 Does maternal education mediate the relationship between income and breastfeeding status?

Follow-up analysis probed a mediation model of INR, maternal education level, and breastfeeding status, again following Barron and Kenny’s (1986) steps. INR predicted breastfeeding status ($B = .21, p < .01$) and maternal education level ($B = 12.44, p < .001$).
Maternal education also predicted breastfeeding status ($B = .34, p < .001$). In a model predicting breastfeeding status from INR and maternal education, maternal education continues to predict feeding ($B = .38, p < .001$) but INR does not ($B = -.06, p = .49$), indicating that maternal education level mediates the relationship between income and breastfeeding.

13 **Do demographic variables “get under the skin” by way of parenting behavior?**

Collectively, race, maternal education, and marital status did not predict infant RSA in the FFSFP ($ps$ ranging from .07 to .76). As expected, when race was the sole predictor, it was significantly related to infant RSA ($B = -.18, p = .02$) such that European American infants had lower RSA across the FFSFP. Also as expected, given that links between race and vagal tone are theorized to be genetic (Wang et al., 2005), the relationship between race and RSA was not mediated by sensitivity ($B = -.17, p = .03$). However, neither maternal education nor marital status predicted infant RSA. Therefore, mediation models were not tested.
Appendices

Appendix A:

Tables and Figures

Table 1.

*Crosstab of Breastfeeding status by Race and Income Level*

<table>
<thead>
<tr>
<th></th>
<th>Low-Income</th>
<th>Higher Income</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BF</td>
<td>nBF</td>
<td>BF</td>
</tr>
<tr>
<td>African</td>
<td>15</td>
<td>40</td>
<td>23</td>
</tr>
<tr>
<td>American</td>
<td>38 (40%)*</td>
<td>56 (60%)**</td>
<td></td>
</tr>
<tr>
<td>European</td>
<td>16</td>
<td>9</td>
<td>41</td>
</tr>
<tr>
<td>American</td>
<td>57 (69%)**</td>
<td>26 (31%)**</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31 (39%)*</td>
<td>49 (61%)*</td>
<td>64 (66%)*</td>
</tr>
</tbody>
</table>

* Breastfed infants are more likely to be from high-income families, \( p < 0.05 \)
** Breastfed infants are more likely to be European American, \( p < 0.01 \)
Table 2.

*Means and Standard Deviations of Infant and Mother RSA, HP, and Behavior*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>Normal Play</th>
<th>Still-Face</th>
<th>Reunion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M (SD)</td>
<td>N</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Infant RSA</td>
<td>97</td>
<td>3.68 (0.89)</td>
<td>111</td>
<td>3.58 (0.98)</td>
</tr>
<tr>
<td>Mother RSA</td>
<td>112</td>
<td>5.63 (1.23)</td>
<td>123</td>
<td>5.82 (1.15)</td>
</tr>
<tr>
<td>Infant HP</td>
<td>97</td>
<td>445.54 (50.79)</td>
<td>111</td>
<td>441.89 (49.32)</td>
</tr>
<tr>
<td>Mother HP</td>
<td>112</td>
<td>740.65 (120.46)</td>
<td>123</td>
<td>730.98 (110.56)</td>
</tr>
<tr>
<td>Infant Positive</td>
<td>-</td>
<td>-</td>
<td>164</td>
<td>.22 (.20)</td>
</tr>
<tr>
<td>Infant Negative</td>
<td>-</td>
<td>-</td>
<td>164</td>
<td>.06 (.14)</td>
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Table 3.  
**Correlations among Infant and Mother Physiology and Behavior**

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*p < .05  
**p < .01
Table 4.

*Continuous Variables Associated with Infant and Mother RSA*

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Table 5.

*Correlations Among Demographic Variables*

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Table 6.

*Relations among Demographic Variables: Oneway ANOVAs*

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<th>Maternal Education $M$ (SD)</th>
<th>Maternal Age $F$</th>
<th>Hours Worked $M$ (SD)</th>
<th>Sensitivity $F$</th>
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<td>18.94 (19.19)</td>
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<td>12.72**</td>
<td>24.18**</td>
<td>21.55**</td>
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<td>15.39 (2.44)</td>
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<td>14.83 (17.60)</td>
<td>11.84 (3.67)</td>
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<td></td>
<td></td>
<td>28.58**</td>
<td>48.72**</td>
<td>15.39 (18.28)</td>
<td>7.63 (3.24)</td>
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<td><strong>Single, divorced, or separated</strong></td>
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<td>12.44 (2.03)</td>
<td>26.34 (5.74)</td>
<td>15.39 (18.28)</td>
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<td></td>
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<td>28.58**</td>
<td>48.72**</td>
<td>17.36**</td>
<td>4415**</td>
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<tr>
<td><strong>Married or cohabitating</strong></td>
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<td>18.20 (19.33)</td>
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Table 7.

*Initial Model: Change in RSA in Infants as a Function of the FFSFP, Breastfeeding, Maternal Sensitivity, and Demographic Variables*

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Table 9.

**Final Model: Change in RSA in Infants as a Function of the FFSFP, Breastfeeding, Maternal Sensitivity, Infant Affect, and Infant Age**

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Table 10.

**Final Model: Change in RSA in Mothers as a Function of the FFSFP, Breastfeeding, Maternal Sensitivity, Infant Affect, and Mother Age**

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Table 11.
Change in HP in Infants as a Function of the FFSFP, Breastfeeding, Maternal Sensitivity, Infant Affect, and Infant Age

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Table 12.

*Change in HP in Mothers as a Function of the FFSFP, Breastfeeding, Maternal Sensitivity, Infant Affect, and Mother Age*

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**Figure 2.** Infants’ and Mothers’ RSA across the FFSFP by Breastfeeding Status
Figure 3. Breastfeeding Status Moderates Change in Infants’ RSA From Baseline to Reunion
Figure 4. Infants’ RSA Reactivity across the FFSFP as a Function of Breastfeeding Status, Controlling for Maternal Sensitivity, Infant Age, Race, and Infant Distress in the Reunion Episode.
Figure 5. Mothers’ RSA Reactivity across the FFSFP as a Function of Breastfeeding Status, Controlling for Maternal Sensitivity, Maternal Age, and Infant Distress in the Reunion Episode.
Appendix B:

*Studies of the gustatory-vagal hypothesis*

<table>
<thead>
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<th>Authors (Year)</th>
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<th>Findings</th>
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<tr>
<td>DiPietro, Larson, &amp; Porges (1987)</td>
<td>100 healthy newborns at a hospital in the mid-west. No racial or SES variables reported.</td>
<td>Breastfed infants showed higher baseline vagal tone than bottle-fed infants. Breastfed infants showed more negative affect and less soothability than bottle-fed infants.</td>
</tr>
<tr>
<td>Lappi et al. (2007)</td>
<td>23 infants born at Kuopio University Hospital, Finland. No racial or SES variables reported.</td>
<td>Nutritive sucking resulted in an increase in heart rate and a decrease in vagal tone across the first 6 months of life.</td>
</tr>
<tr>
<td>Porges &amp; Lipsitt (1993)</td>
<td>13 healthy newborns at a hospital in Rhode Island. No racial or SES variables reported.</td>
<td>Higher frequencies of sucking were associated with decreases in vagal tone.</td>
</tr>
<tr>
<td>Suess et al. (2000)</td>
<td>32 preterm neonates at hospitals around Baltimore. No racial or SES variables reported.</td>
<td>Vagal tone decreased during bolus feeding in preterm infants.</td>
</tr>
<tr>
<td>Zeskind, Marshall, &amp; Goff (1992)</td>
<td>28 infants at a small, urban hospital. All infants were from low-SES households receiving federally subsidized prenatal care.</td>
<td>Breastfeeding infants had lower heart rate and more reliable heart rate cycles than bottle-fed infants, suggesting more efficient psychophysiological organization.</td>
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Appendix C:

**Recent studies on breastfeeding’s associated psychological outcomes in infants**

<table>
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<th>Authors (Year)</th>
<th>Findings</th>
<th>Sample</th>
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</thead>
<tbody>
<tr>
<td>Aaron Jones, McFall, &amp; Diego (2004)</td>
<td>Maternal depression x feeding method interaction: Breastfed infants of depressed mothers less likely to have reactive temperament than formula-fed infants of depressed mothers.</td>
<td>78 dyads: 71 White, 4 African American, 2 Hispanic, 1 Asian; middle- to upper-class</td>
</tr>
<tr>
<td>Anderson, Johnstone, &amp; Remley (1999)</td>
<td>Breastfed children demonstrated better cognitive functioning than bottle-fed children</td>
<td>Meta-analysis: 20 studies: 3 assessed variability due to race; 17 assessed variability due to SES</td>
</tr>
<tr>
<td>Drane &amp; Logemann (2000)</td>
<td>Reviewed research investigating links between breastfeeding and cognitive development. Concluded that few studies employed sufficiently rigorous design and adequate control of confounds to determine whether breastfeeding influences cognitive development.</td>
<td>Review: 24 studies: 15 controlled for important confounds that frequently included SES; no discussion of race</td>
</tr>
<tr>
<td>Horta &amp; Victora (2013)</td>
<td>Breastfed children scored higher on intelligence tests during childhood and adolescents than did bottle-fed children even when controlling for common confounds, including SES and maternal IQ.</td>
<td>Meta-analysis: 13 studies: racially and ethnically diverse samples from developed and developing countries</td>
</tr>
<tr>
<td>Horwood &amp; Fergusson (1998)</td>
<td>Longer duration of breastfeeding was related to higher IQ at age 8-9, better reading and math performance age 10-14, better academic performance by graduation.</td>
<td>&gt; 1000 children in New Zealand</td>
</tr>
<tr>
<td>Kramer et al. (2008)</td>
<td>Infants whose mothers were assigned to a breastfeeding promotion intervention had significantly higher full-scale IQ scores (as measured by the WISC) and higher teacher ratings at age 6.5.</td>
<td>13,889 children recruited from Belarussian maternity hospitals</td>
</tr>
<tr>
<td>de Lauzon, et al. (2012)</td>
<td>Breastfeeding mothers rated their infants as having more difficult temperaments.</td>
<td>316 infants in Cambridge, UK: race not reported; scores on the Index of Multiple Deprivation (2007) were relatively low (mean = 9.59), indicating higher SES</td>
</tr>
<tr>
<td>Lucas &amp; St. James-Roberts (1998)</td>
<td>Breastfed infants reach peak crying later than formula fed infants.</td>
<td>97 mothers: feeding method confounded with social class and maternal education level (Review article.)</td>
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<tr>
<td>Michaelsen, Lauritzen, &amp; Mortensen (2009)</td>
<td>Breastfeeding appears to be associated with higher IQ scores later in childhood even when controlling for SES and maternal IQ.</td>
<td></td>
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<tr>
<td>Taylor &amp; Wadsworth (1984)</td>
<td>At age 5, breastfed children showed better cognitive functioning and a trend</td>
<td>13,135 children in the United Kingdom</td>
</tr>
</tbody>
</table>
Worobey (1992) Breastfed infants smiled earlier and had better physical health than bottle-fed infants. Bottle-fed infants were toilet trained earlier than breastfed infants.

Worobey (1998) Breastfed infants were more active than bottle-fed infants. No differences in temperament across groups.

Nationally representative sample of 2,700 infants

80 infants:
Appendix D:

**Recent studies on breastfeeding’s associated psychological outcomes in mothers & dyads**

<table>
<thead>
<tr>
<th>Authors (Year)</th>
<th>Findings</th>
<th>Sample</th>
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</thead>
<tbody>
<tr>
<td>Altemus et al. (2001)</td>
<td>Breastfeeding women show greater vagal regulation of cardiac function during the Trier Social Stress Test.</td>
<td>51 women: race/ethnicity and income level not reported</td>
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<tr>
<td>Else-Quest, Hyde, &amp; Clark (2003)</td>
<td>Breastfeeding mothers report stronger attachment to their infants than bottle-fed infants at 4 months but not at 12 months.</td>
<td>570 women: 93% non-Hispanic white; income levels assessed but not reported</td>
</tr>
<tr>
<td>Handlin et al. (2009)</td>
<td>Mothers showed lower levels of cortisol and ACTH following breastfeeding.</td>
<td>63 mothers in Stockholm, Sweden: race/ethnicity and income level not reported</td>
</tr>
<tr>
<td>Kim et al. (2011)</td>
<td>Breastfeeding mothers showed heightened BOLD response to own infant cry relative to formula-feeding mothers in brain regions later associated with maternal sensitivity.</td>
<td>17 mothers: all Caucasian; income level not reported</td>
</tr>
<tr>
<td>Mezzacappa &amp; Katkin (2002)</td>
<td>Breastfeeding mothers experienced less negative mood and perceived stress than bottle-feeding mothers.</td>
<td>55 women: 82% White, 7% African American, 2% Latina, 7% Asian, 2% blended ethnicity</td>
</tr>
<tr>
<td>Mezzacappa, Kelsey, &amp; Katkin (2005)</td>
<td>Exclusively breastfeeding mothers showed greater vagal regulation in response to a laboratory stressor.</td>
<td>28 mothers: 12/14 exclusive breastfeeding mothers were White, 2/14 were Asian. 12/14 nonexclusive breastfeeding mothers were White, 1 was Latina, 1 was Asian</td>
</tr>
<tr>
<td>Strathearn, Mamun, Najman, &amp; O’Callaghan (2009)</td>
<td>Breastfeeding duration was negatively associated with maltreatment by mother.</td>
<td>6621 Australian dyads: 6056 non-aboriginal, 367 aboriginal; income level not reported; predominantly married and completed high school.</td>
</tr>
<tr>
<td>Tharner et al. (2012)</td>
<td>Breastfeeding duration weakly associated with maternal sensitive responsiveness.</td>
<td>675 mother-infant dyads: all white Dutch; income level not reported; sample was generally highly educated</td>
</tr>
<tr>
<td>Tu, Lupien, &amp; Walker (2006)</td>
<td>Multiparous breastfeeding mothers experienced reduced cortisol response to the Trier Social Stress Test and an emotional film clip than non-breastfeeding and primiparous breastfeeding mothers.</td>
<td>66 women: race and income level not reported; some variability in income level</td>
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