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The current study examined the way in which regulatory processes of the central and parasympathetic nervous system are associated with one another, and linked to behavioral regulation, during both mild and moderate frustration. To gain a more comprehensive understanding of emotion regulation and the process through which it develops, the current study also examined the associations between maternal sensitivity and infants' physiological and behavioral regulation, in addition to assessing the influence of maternal sensitivity on the development of infants' physiological and behavioral regulation across early infancy. Finally, the current study assessed whether physiological regulation was a mediating mechanism through which maternal sensitivity was associated with infant's behavioral regulation.

Results demonstrated that vagal withdrawal and EEG activation were only associated at 10 months during mild frustration; as vagal withdrawal increased EEG activation also increased indicating more active processing in the right hemisphere. This positive association suggests that by 10 months of age, when infants encounter a frustrating situation that is at least moderate in intensity, cortical and autonomic processes respond in similar ways. At 5 months, there was a negative association between vagal withdrawal and observed distraction during mild frustration and a positive association during moderate frustration. This inconsistent pattern suggests that the mildly frustrating task may have been more interesting than frustrating for 5 month-old infants.

EEG activation at 5 months was not associated with any observed regulatory behaviors during mild or moderate frustration, but was associated positively with mother reported infant regulation; this positive association conveys that infants who increased in active right frontal processing from baseline to task were also likely to be reported by their mothers as better able to recover from peak distress, excitement, or general arousal. During moderate frustration at 10 months, EEG activation and vagal withdrawal were associated positively with infant’s mother orientation behaviors and associated negatively with infant’s distraction behaviors; this suggests that 10 month-old infants thought to be better physiologically regulated may use more co-regulatory strategies when engaging in an novel and intense frustration task rather than employing more independent self-regulatory strategies. Maternal sensitivity at 5 months was associated with increases in vagal withdrawal during moderate frustration from 5 to 10 months but was not associated with increases in EEG activation or behavioral regulation from 5 to 10 months. It is possible maternal sensitivity at 5 months may help infants’ manage physiological arousal in a way that facilitates greater myelination of vagal fibers and subsequently greater vagal regulation from 5 to 10 months. No indirect effects were found for maternal sensitivity on behavioral regulation via infant’s physiological regulation.

MATERNAL SENSITIVITY AND PHYSIOLOGICAL PROCESSES AS PREDICTORS OF INFANT EMOTION REGULATION

by

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To my husband, Wil. Thank you for keeping me balanced, making me smile, and being my biggest fan throughout this journey. I could not have done it without your love, support, and encouragement.

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

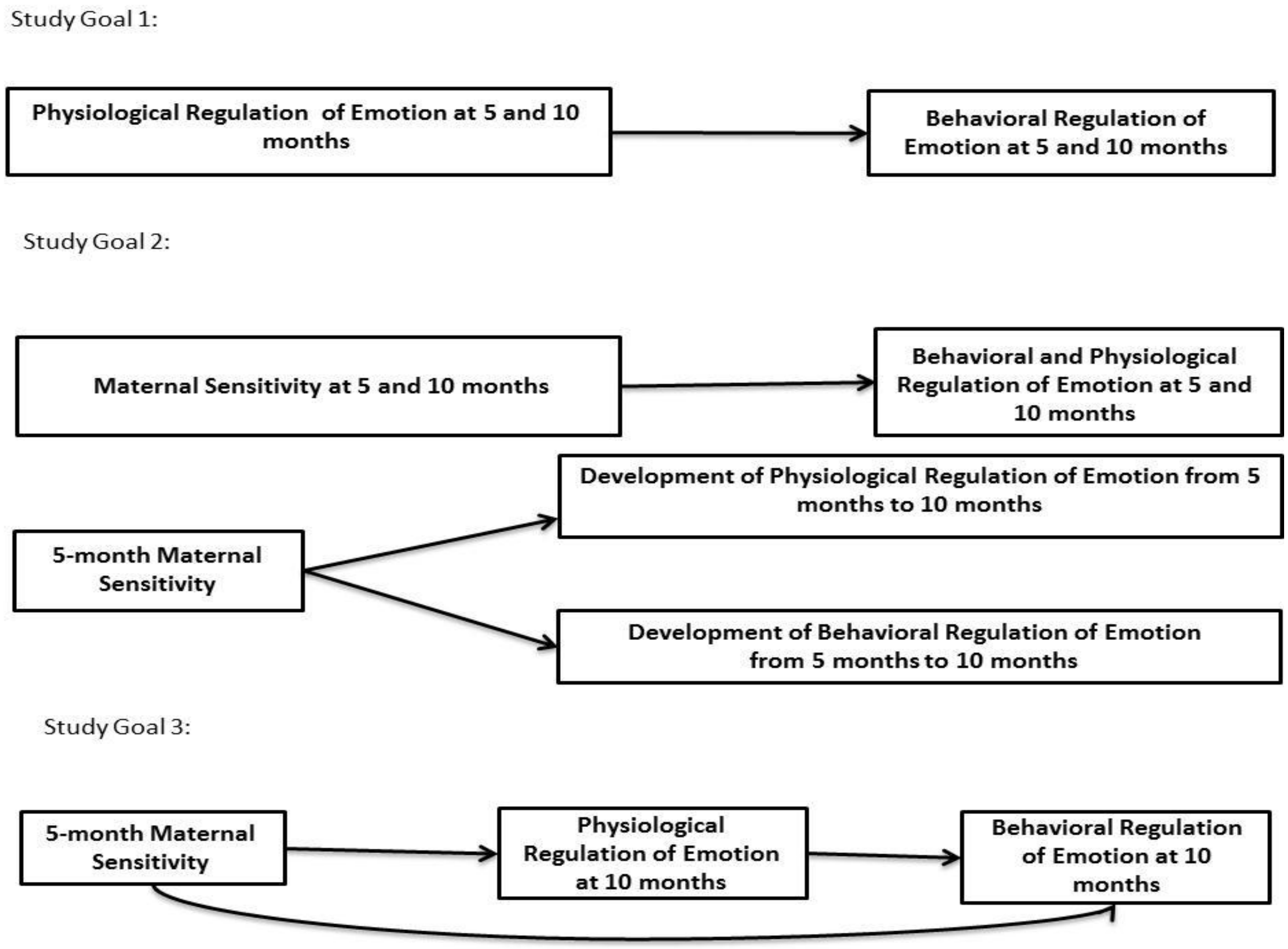
Researchers have identified self-regulation as an aspect of temperament that is comprised of a set of processes that function at both a behavioral and biological level. Broadly, regulation has been defined as the ability to modulate physiological arousal, attention, emotion, and behavior in adaptive ways (Calkins, 2011; Vohs & Baumeister, 2010; Rothbart,1981). The ability to regulate during emotional situations emerges in infancy and has implications for multiple areas of development, such as later social competence (Spinrad et al., 2006), school readiness (Denham, 2006), and psychological adjustment (Calkins, 1994; Hill, Degnan, Calkins, & Keane, 2006). Thus, one of the most fundamental skills for infants to acquire is the ability to modulate, inhibit, or enhance emotional expression and experiences (Calkins & Hill, 2007; Stifter, 2002).

The hierarchical nature of self-regulation is informed from research in developmental neuroscience. Specifically, researchers have identified prefrontal cortical and limbic system processes as playing a role in the deployment of attention and regulation of emotion and behavior (Posner & Rothbart, 2000). Thus, given that emotional responding is dependent on the biological maturation of pre-frontal and limbic connections, self-regulatory processes are thought to stem from early biological regulation to later effortful regulation of behavior and emotion (Beauregard, Levesque, & Paquette, 2004; Ochsner & Gross, 2004, Calkins, 2011). Because of the hierarchical nature of these mechanisms, understanding individual differences in early psychophysiological regulation of emotion is imperative for the understanding of the development and deployment of subsequent behavioral regulatory processes throughout childhood. That is, the basic underlying physiological regulatory capabilities of the central and autonomic nervous system need to be examined in order to better understand individual differences in children's behavioral regulation of emotion across development.

Previous empirical work has implicated both the parasympathetic (a subsystem of the autonomic nervous system) and the central nervous system in the development of behavioral regulation of emotion (e.g., Brooker & Buss, 2009; Diaz & Bell, 2012). More recently however, Thayer and Lane (2000; 2009) have proposed a model of neuroviscerel integration that asserts a connection between the brain and the heart in processes involved in behavioral self-regulation. Although parasympathetic and central nervous system processes have been theoretically linked and implicated in the development of emotion regulation, and both systems have been associated with differences in emotional behavior, little empirical work has examined them in the same context within the same individuals. When individuals encounter emotional situations that require the regulation of emotional expression, physiological processes from both the central and parasympathetic nervous system respond simultaneously. Thus, to broaden our understanding of physiological regulation of emotion it is important to move beyond studying a single physiological mechanism and begin to focus on the way in which multiple biological systems predict regulatory behavior. Therefore, the first goal of the current study was to examine whether an index of parasympathetic nervous system functioning at 5 and 10 months, as measured by cardiac vagal withdrawal, and an index of central nervous system functioning at 5 & 10 months, as measured by electroencephalography (EEG) activation, serve as predictors of infant behavioral regulation of frustration at 5 and 10 months. Assessing both of these physiological processes simultaneously allowed the current study to address similarities and differences in the physiological regulation of both central and parasympathetic nervous system responding during heightened negative emotional arousal, and investigate the way in which these physiological regulatory abilities may be related to observed regulatory behavior.

In addition to having a biological foundation, the developmental process of self-regulation has come to be viewed as transactional between the child and his or her environment (Calkins, Graziano, Berdan, Keane, & Degnan, 2008; Gunnar, 2000; Propper & Moore, 2006). Given infants' limited capacity at regulating their own emotions, it has been theoretically proposed and empirically supported that individual differences in regulating heightened emotional arousal stem from both individual child factors (i.e., behavioral and physiological capabilities), as well as environmental factors such as caregiving (Posner & Rothbart, 2000; Calkins & Howse, 2004; Moore & Calkins, 2004). Although not extensive, some empirical work has found caregiver behaviors to predict individual differences in infant regulatory behavior, as well as parasympathetic and central nervous system functioning (e.g., Moore et al, 2009; Diego et al., 2004). However, far fewer studies have examined the influence of caregiver behavior on the development of these physiological systems and regulatory behaviors over time. Further, little work has examined the influence of caregiving behavior on the development of physiological regulatory capabilities during early infancy, a time when infants' physiological systems are rapidly maturing (Porges & Furman, 2011). Given that caregiver behaviors are likely to have the strongest impact on the development of biological systems during a time of rapid biological maturation, it is imperative these associations be studied very early in development. Therefore, the second goal of the current study was to extend the current literature by examining whether maternal sensitivity at 5 and 10 months predicts concurrent physiological and behavioral regulation. In addition, the current study tested whether maternal sensitivity at 5 months predicts developmental changes in behavioral and physiological regulation of emotion (i.e., vagal withdrawal and EEG activation) from 5 months of age to 10 months of age. Finally, given the theoretical and empirical support for the association between physiological regulation and behavioral regulation, as well as between maternal sensitivity and both physiological and behavioral regulation, a third goal of the current study was to test whether there are indirect effects of maternal sensitivity on behavioral emotion regulation via physiological regulation. A model underlying the goals of the current study can be found in Figure 1.

Figure 1. Models Depicting Study Goals



Behavioral Regulation of Emotion.

Emotion regulation is largely theorized to arise out of interactions with primary caregivers over the first years of life, and is often defined as the ability to modify the intensity and duration of physiological arousal, attention, and affective states in order to modulate positive and negative expression (Sroufe, Egeland, Carlson, & Collins, 2005). Emotion regulation is often thought of as indicative of adaptive functioning or the lack thereof (i.e., dysregulation) (Cole, Martin, & Dennis, 2004). However, strategies and behaviors that infants develop to regulate affective states may be maladaptive in situations when infants are not able to respond flexibly or appropriately to changes in their environment (Bridges, Denham, & Ganiban, 2004). For example, a toddler might reduce his frustration with another child by hitting that child; however, hitting another child would not be considered an appropriate way to modify arousal. Thus, more regulation is not always better or adaptive regulation, and it may mean different things for different children. An infant may be struggling because he or she is using many ineffective or inefficient regulatory strategies, or it may mean that an infant is appropriately handling emotional arousal and using all of their regulatory abilities to do so. Therefore, adaptive emotion regulation involves initiation and maintenance of emotion states, as well as the ability to reduce heightened levels of arousal in ways that allow individuals to meet regulatory goals and maintain positive social interactions with the environment (Bridges et al., 2004). The investigation of the regulation of negative emotional arousal is particularly important because the task of coping with negative affect is more developmentally difficult than coping with positive affect (Ramsden &

Hubbard, 2002). Further, the inability to regulate negative emotional arousal in contexts that prove to be emotionally challenging is likely more detrimental to the maintenance and formation of social interactions than regulating positive emotional arousal.

Specific infant regulatory behaviors that have been the primary focus of empirical work assessing infants in negative emotionally arousing situations include disengagement of attention or distraction, mother orientation, and attempts to self-comfort (Rothbart et al., 1992). When infants use distraction as a regulatory strategy, they disengage their attention from the source of negative arousal and avert their gaze to other objects in their environment (Johnson, Posner, & Rothbart, 1991). Indeed, much research, including contingency studies, has demonstrated that infants who avert their gaze or distract away from a distressing stimulus (i.e., frustrating or fearful) show reduced negative affect in the moment, and less anxious behavior over time (Crockenberg & Leerkes, 2004; Crockenberg & Leerkes, 2006; Stifter & Spinrad, 2002; Mangelsdorf, Shapiro, & Marzoff, 1995). During infancy, infants are just learning independent regulatory strategies and are often engaged in co-regulatory processes to calm distress; therefore, orienting toward the mother is adaptive in that it attempts to facilitate co-regulation between the infant and the mother in an attempt to reduce arousal. Finally, empirical research has found self-comforting behaviors to reduce negative arousal (Crockenberg & Leerkes, 2004; Crockenberg & Leerkes, 2006). Self-comforting behaviors calm the infant and often include sucking on the fingers or gums, or engaging in repetitive gentle rubbing.

Physiological Regulation.

Central and parasympathetic physiological aspects of emotion regulation have primarily been assessed through the measurement of cardiac vagal functioning and electroencephalography activity. Each physiological system is described in detail in the following section.

Cardiac vagal functioning. The autonomic nervous system (ANS) is comprised of the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The primary job of the ANS is to maintain the body's homeostasis; therefore, the two subsystems work in conjunction to increase or decrease cardiac activity. The SNS promotes metabolic output to deal with environmental challenges and is responsible for accelerated heart beats and dilated pupils, while the PNS works to conserve the body's energy, rest vital organs, constrict pupils, and slow the heart (Porges, 1995). Porges (1995) introduced the Polyvagal Theory and identified an index of the functional status of the parasympathetic nervous system, vagal tone, which reflects the vagal control of the heart, as a measurable organismic variable that accounts for differences in emotional expression and regulation. Porges (1995) developed a method that measures the amplitude and period of the oscillations associated with inhalation and exhalation; this measure refers to the variability in heart rate which occurs at the frequency of breathing (respiratory sinus arrhythmia, RSA) and is thought to reflect the parasympathetic influence on heart rate via the vagus nerve.

Developmental studies using RSA measures have primarily examined vagal withdrawal (decreases in RSA from a baseline task to a frustration task) in response to challenging environmental contexts. Research on the study of self-regulation has been particularly focused on the measure of vagal regulation of the heart during emotionally charged situations. Vagal regulation is thought to be indexed by a decrease in RSA or vagal tone (vagal withdrawal) during situations where coping or emotional regulation is necessary. Specifically, the vagus nerve sends input to the heart and causes changes in cardiac activity that allows the body to transition between the PNS function of sustaining metabolic processes and the SNS function of generating responses to the environment (Porges, 2007). In essence, the vagus nerve serves as a brake that can inhibit or disinhibit vagal influence and quickly mobilize or calm an individual. During situations that do not present environmental challenge, the vagus nerve inhibits the sympathetic nervous system's influence on cardiac activity through increased parasympathetic influence; thus, producing a relaxed and restorative state (Porges, 1995). However, during times of social, emotional, or cognitive challenge, the vagal brake is withdrawn to support an increase in heart rate and active coping. In this way, measures of heart rate variability may be usefully studied as physiological indicators of physiological regulation.

Electroencephalography activity. In addition to cardiac processes of the parasympathetic nervous system, cerebral processes of the central nervous system have also been used to measure children's regulation of emotion. The majority of research measuring electrical brain activity and neurophysiology has used electroencephalogram (EEG) methodology. Specifically, individual nerves in the brain give off small amounts of electricity when they work. Therefore, EEG is able to measure brain electrical activity of specific brain regions by assessing the activity of a large number of neurons firing simultaneously in that location.

Developmental studies using EEG asymmetry have measured frontal EEG asymmetry during baseline and task procedures, and computed the change in asymmetry in response to stimuli (i.e., EEG activation). Frontal EEG asymmetry during a baseline procedure reflects baseline recordings of cortical processes and is computed by subtracting right hemisphere activity from left hemisphere activity (Allen & Kline, 2004). The product of equation is the relative activity of the right and left hemisphere where negative values are indicative of greater right frontal asymmetry and positive values are indicative of greater left frontal asymmetry. In addition to measuring baseline asymmetry, researchers can also measure EEG asymmetry during an emotional task and compute EEG activation. EEG activation is computed by subtracting task asymmetry from baseline asymmetry, and is thought to reflect state-related changes in asymmetry as a function of state changes in emotion (Coan & Allen, 2004). As a result, EEG activation can be thought of as a neurophysiological indicator of emotional regulation during an emotionally arousing task.

CHAPTER II

THEORY

Researchers have studied the influence of parasympathetic and central processes on infant behavioral regulation of emotion separately. However, no study has simultaneously studied both physiological systems in the same context and as they relate to infant behavioral regulation of emotion. Further, although developmental theorists assert that caregiver behavior and the parent-child relationship are crucial for the development of infants' behavioral regulation, a somewhat small amount of research investigates the way in which caregiving influences the development of infant behavioral regulation and vagal withdrawal. Moreover, no research has examined caregiving influences on EEG activation. Thus, to support the importance of empirically investigating these gaps in the literature, the following chapter 1) describes the process through which physiological regulation is thought to underlie infant behavioral regulation 2) reviews the model of neurovisceral integration proposed by Thayer and Lane (2000; 2009) to support the theoretical relation between autonomic and central nervous system functioning as it relates to emotion and emotional behavior in infancy and 3) discusses the processes through which caregiving is thought to influence developing physiological systems and behavioral regulation in early infancy.

Physiological Underpinnings of Behavioral Emotion Regulation.

Emotion regulation processes have been found to be fundamentally linked to central physiological processes in infancy (Thompson, Lewis, & Calkins, 2008) such that individual differences in the degree of physiological arousal have been posited to play a role in the display and development of specific emotion regulation behaviors (Calkins & Hill, 2007). Emotion regulation theories that integrate biological and physiological aspects of regulation assume that adaptive emotion regulation behaviors result from the maturation of different biological systems across childhood (Calkins and Hill, 2007). To examine the physiological underpinnings of behavioral regulation in emotional contexts, researchers have primarily assessed indices of the parasympathetic and central nervous system. The following two sections describe the theoretical underpinnings for the way in which these physiological processes are thought to underlie behavior. Empirical work to support these associations will be reviewed in Chapter III.

Vagal withdrawal and infant behavior. According to Porges' (2007) theory, physiological states are associated with different classes of behavior including social engagement and appropriation of emotion. That is, a physiological state characterized by vagal withdrawal would support coping behaviors, and a physiological state characterized by increased vagal influence would support relaxed social engagement (Porges, 2007). The vagus nerve serves as a vagal brake that can inhibit or disinhibit vagal tone and quickly mobilize or calm an individual. During an environmentally challenging situation that calls for active coping, the vagal brake is withdrawn to support an increase in heart rate and increased attention to the environment. This increased attention, as a result of vagal withdrawal, may facilitate the use of regulatory behaviors that function to reduce distress.

EEG activation and regulatory behaviors. Davidson (1993) asserted that the prefrontal lobes of the right and left hemisphere are specialized for approach versus avoidant behavioral responses and differences in frontal lobe activation are associated with behaviors that individuals engage in when emotionally and behaviorally aroused. Specifically, left frontal baseline asymmetry has been associated with approach behaviors such as fine motor behavior, language, and the expression of emotion; whereas right frontal baseline asymmetry has been associated with withdrawal behaviors from stressful stimuli such as gross motor movement and the expression of negative affect (Fox & Davidson, 1987). Davidson (1994, 1995) has speculated that the left prefrontal cortex underlies approach behavior because it facilitates representation of desired goals, thus guiding behavior toward the attainment of these goals. Therefore, individuals with more active left prefrontal regions at rest may be more likely to organize limited resources in a way that supports goal-directed behaviors. In turn, this leads them to experience positive affect more frequently and intensely than those individuals with less active left prefrontal regions (Wheeler et al., 1993). In contrast, the right prefrontal cortex may underlie behavioral withdrawal and negative affect because it supports focused attention (see Posner, 1995, for a review). Therefore, individuals with active right prefrontal regions during a resting state may be predisposed to become alert for threat-related stimuli, thus inhibiting behavior and organizing resources for behavioral withdrawal.

Much less is known regarding the way in which EEG activation (i.e., the shift in EEG asymmetry from baseline to task) underlies behavior. By definition, EEG activation reflects state-related changes in asymmetry as a function of changes in emotion (Coan & Allen, 2004). Therefore, a shift in EEG asymmetry (i.e., EEG activation) toward the right or left hemisphere during an emotionally challenging context may underlie a predisposition for specific behavioral responses associated with each region. For example, if the right prefrontal region is predisposed for behavioral withdrawal, a greater shift toward the right hemisphere may allow for the withdrawal from negative stimuli and subsequently elicit more adaptive regulatory behaviors.

The Heart and Brain Connection for Behavioral Regulation of Emotion.

Heart rate and heart rate variability are determined by intrinsic cardiac mechanisms and the joint activity of the sympathetic and parasympathetic (vagus) nerves at the sinoatrial node (i.e., impulse-generating tissue located in the right atrium of the heart that is responsible for generating normal sinus rhythm). In normally functioning systems, both subsystems of the autonomic nervous system are active with sympathetic activity associated with increased heart rate and parasympathetic activity associated with decreased heart rate. The vagus nerve serves to modulate the influence of parasympathetic and sympathetic activity on the heart and thus plays a role in the acceleration and deceleration of heart rate. There is evidence that cortical activity modulates cardiovascular functioning such that there are direct and indirect pathways linking the prefrontal cortex to autonomic circuits responsible for both the sympathetic (excitatory) and parasympathetic (inhibitory) effects on the heart (Balaban and Thayer, 2001). Given these individual links between autonomic and central nervous system functioning in emotion regulatory processes, Thayer and Lane (2000; 2009) have proposed a theoretical model of neurovisceral integration which asserts a specific connection between the brain and the heart in processes involved in behavioral self-regulation.

According to the model of neurovisceral integration (Thayer & Lane, 2000; 2009), the prefrontal cortex modulates cardiovascular functioning through the amygdala, a key brain region for the processing of emotional reactions. In contexts characterized by low emotional arousal, the prefrontal cortex inhibits amygdala activity via GABAergic (inhibitory) neurons. However, during times of heightened emotional arousal or threat, it has been proposed that the prefrontal cortex becomes less active in order to let autonomic processes regulate behavior (Thayer & Lane, 2009). That is, areas of the prefrontal cortex become hypoactive and this hypoactive state is associated with activation of the amygdala and in turn sympathetic activity necessary for mobilization and coping. This selective prefrontal inactivation is thought to be adaptive in that during times of threat, it allows for the facilitation of non-volitional behaviors associated with the amygdala to organize responses without influences from the more effortful and consciously influenced prefrontal cortex (Thayer & Lane, 2009).

When an individual encounters a situation that elicits heightened emotional arousal, the primary response is increased heart rate (i.e., sympathetic activity) to support what is commonly referred to as the fight or flight response needed for survival and adaptation. The central nucleus of the amygdala is a major efferent source of cardiac control and autonomic responses such that activation of the amygdala leads to increased heart rate and decreased heart rate variability. Specifically, activation of the central nucleus of the amygdala inhibits neurons in the nucleus solitary tract (structures in the brainstem that carry and receive visceral sensation from the facial, glossopharyngeal, and vagus cranial nerves), which in turns leads to the inhibition of the nucleus ambiguous and the dorsal vagal neurons, resulting in a decrease in parasympathetic activity and an increase in sympathetic activity (Thayer and Lane, 2000). Thus, amygdala activity is context specific (with a bias toward negative information) and is important in the association between the prefrontal cortex and cardiovascular functioning needed during emotionally charged situations.

In sum, pathways from the prefrontal cortex to the amygdala control heart rate and heart rate variability; when the inhibitory control of the amygdala by the frontal cortex is reduced, an increase in heart rate, and a decrease in heart rate variability, is produced through decreased inhibition of neurons associated with sympathetic activity and increased inhibition of vagal outputs. These multiple cortical processes allow for intricate regulation of cardiac activity in response to changing environmental demands. Given that the neurovisceral integration model asserts a specific connection between the brain and the heart in processes involved in behavioral self-regulation, it is useful to examine these physiological systems simultaneously in the same individuals to better understand their relation to one another as well as their association with regulatory behaviors.

Effect of Maternal Sensitivity on Emotion Regulation.

Caregiver support and flexible responding is critical in the development of infants' emotion regulation because infants are not able to regulate their own emotional states without caregiver assistance (Calkins and Fox, 2002; Sroufe, 2000). Specifically, over the first few years of life there is a fundamental shift from dyadic to self-regulation that is characterized by a gradual transition from almost sole reliance on a caregiver to the ability to independently regulate emotional arousal in varying contexts (Sameroff, 2010).

According to Bowlby (1973) an infants' behavioral, psychological, and biological capacities cannot be understood outside the parent–infant dyad. Bowlby asserted that in the presence of sensitive and responsive caregiving, an infant forms a strong bond of emotional communication with their mother in which they gain socioemotional competencies that get internalized into the capacity to appropriately regulate, generate, and maintain states of emotional security. The most common definition of sensitivity encompasses correctly interpreting infants' cues and responding promptly and appropriately according to the developmental needs of the child and the context of the situation (Ainsworth, Bell, & Stayton, 1971; Ainsworth, Blehar, Waters, & Wall, 1978). Therefore, sensitive caregiving is characterized by identifying children's emotional states and parenting based on their specific emotional and physical needs. For example, continuing to engage an infant with strong positive affect when an infant shows clear signs of being emotionally over-aroused would not be considered sensitive; however, a caregiver would be reacting sensitively if they were to display the same behavior when an infant is showing signs of enjoyment and engagement.

Infants display a range of behaviors, including crying, looking, and clinging, that signal to the caregiver their need for external support during times of heightened emotional arousal (Calkins, 2004). Bowlby asserts that sensitive and supportive caregiver responses increase the child's expectations regarding his or her own ability to respond, in addition to increasing the expectations that his or her caregiver will be available to intervene, and be successful at reducing arousal should he or she require assistance; that is, sensitive interactions can create increased child trust in themselves and the caregiver, that can be utilized as a secure base during exploration. As a result of increased child exploration and confidence in one's own abilities to handle the environment and the arousal associated with novel environments, a shift from dyadic to self-regulation occurs, resulting in increased self-regulatory capabilities (Thompson, 1994). Caregivers learn to read infant signals and are able to control the amount of stress and arousal an infant experiences by responding in a way that not only teaches children appropriate expression of emotion but reduces arousal and builds infants' trust. As a result, caregivers can slowly increase the exposure to emotionally charged situations in a positive way that encourages and teaches particular regulatory behavioral strategies and facilitates the development of biological regulatory systems that may be useful for the expression of emotion and the reduction of emotional arousal (Sroufe, 1996; Calkins & Hill, 2007; Propper & Moore, 2006).

Maternal Sensitivity and Behavioral Regulation of Emotion. Caregivers who are more sensitive and responsive to their infants' negative emotions may influence their infants' experience of negative emotions and create a context in which the infants associate their behaviors and the caregiver's behaviors with their accompanying changes in arousal (Gianino & Tronick, 1988; Kopp, 1989). For example, an infant crying in distress elicits responsive caregiver assistance for reducing that arousal. The caregiver may introduce new arousal reducing behavioral self-comforting strategies, such as sucking or gentle rubbing, thus teaching the infant that these behaviors are associated with a reduction in negative arousal (Stifter & Spinrad, 2002). Similarly, caregivers who engage in facial and vocal cues that distract infants when they are distressed foster the redirection of infant attention as an emotion regulation strategy. Through distraction, caregivers give infants opportunities to engage with something else, and to experience decreases in negative affect that coincide with shifts in attention (Spinrad & Stifter, 2002). Engaging in these sensitive behaviors that help and teach infants to manage their arousal may influence the development of increased behavioral regulatory abilities. That is, through learning, it would be expected that infants who repeatedly experience reduced negative affect through these interactions, would develop and repeat similar behaviors when confronting emotionally charged situations independently.

Maternal Sensitivity and Physiological Regulation. Early in development children have rudimentary physiological abilities in place and are therefore reliant on external sources to achieve and maintain a regulated physiological state (Spangler & Grossman, 1993). It has been proposed, and empirically supported, that warm, supportive, responsive, and sensitive parenting may facilitate the organization and development of physiological systems to achieve regulation and reduce negative affect (e.g., Moore et al., 2009; Moore & Calkins, 2004).

Parasympathetic Cardiac Activity. The specific process through which caregiving affects physiology has been somewhat abstract in the recent literature. Recently, Porges and Furman (2011) illustrated one possible way in which caregiving affects the biological development of the vagal system. The Polyvagal Theory articulates a shift in neural regulation of the autonomic nervous system in three global stages, each associated with specific behaviors (Porges, 2001). According to Porges (2001), the first stage is associated with immobilization behaviors (e.g., behavioral and physiological shut-down) and is characterized by a primitive un-myelinated vagus nerve that facilitates digestion and responds to threat by depressing metabolic activity. Stage two is characterized by sympathetic nervous system functioning capable of increasing metabolic output and inhibiting the vagus nerve in order to facilitate mobilization behaviors necessary for 'fight or flight' responses (e.g., tantrums or behavioral meltdowns). The third stage is characterized by a myelinated vagus nerve that quickly regulates cardiac output to facilitate engagement and disengagement with the environment (e.g., vocalization, facial expression, or listening). The product of the development of these stages is a nervous system characterized by three circuits that regulate physiological reactions to heightened emotional challenge (Porges, 2001). In this three-circuit organized hierarchy, the newest circuit associated with social communication is employed first during emotionally arousing situations to provide safety. If this circuit fails then older survival-oriented circuits are called upon (Porges, 2011). Because the circuit associated with social communication is the newest, and is only partially developed at birth, it is most vulnerable to environmental input postpartum and becomes a biobehavioral pathway though which social interactions between and infant and his or her caregiver can calm an infant's internal state (Porges & Furman, 2011). Given that the third social communication stage is characterized by the myelination of vagal fibers, and the vagus nerve continues to myelinate after birth (Sachis, Armstrong, Becker, & Bryan, 1982), early sensitive caregiving characterized by the modulation of infants' internal states, may influence the myelination of the vagus nerve and therefore facilitate or impede the developmental trajectory of the vagal system; thus, leading to less efficient vagal regulation (as indexed by decreased vagal withdrawal during an emotional challenge) (Porges & Furman, 2011).

Processes of the Central Nervous System. The organization of the developing brain is established in the context of a relationship with the primary caregiver such that the primary caregiver acts as an internal physiological regulator of the growth of an infant's central nervous system during the first 2 years of life (Schore, 1996). It has been posited that affective transactions within the mother-infant dyad facilitate the inter-coordination of affective brain states (Trevarthen & Aitken, 2001). Specifically, an infant's brain is not only affected by these transactions with caregivers, participation in a sensitive and positive affective relationship with the caregiver is required for the development of cerebral circuits. Thus, the prefrontal cortex is thought to be impacted by early social experiences and activated during heightened emotional states. That is, infants are thought to use their mother's behaviors (i.e., resulting from their own emotion-regulating prefrontal cortex) as the foundation for which they develop cerebral circuits in their own cortex, which will eventually underlie many affective behaviors (Dawson, 1994).

Together, the Polyvagal Theory, biological theories of the maturation of the central nervous system, and theories of emotion regulation, provide a framework for understanding how caregiving impacts the development of regulation at multiple levels. With this theoretical framework, researchers are better able to understand the specific ways in which maternal sensitivity impacts the development of biological and behavioral regulation and the importance of these processes for adaptive social and emotional functioning. In addition, the model of neurovisceral integration provides theoretical support for the integration of central and parasympathetic nervous system functioning when understanding regulatory behaviors, therefore underscoring the need to consider both physiological systems when attempting to understand the development of infants' physiological regulation.

In the following chapter, research examining the relations between maternal sensitivity, infant regulatory behavior, and infant biological regulation (as indexed by vagal withdrawal and EEG activation) is reviewed, highlighting some well-established links between caregiving and infant regulation as well as areas in which more research is needed. Moreover, empirical work supporting the link between parasympathetic and central nervous system regulatory processes is presented.

CHAPTER III

LITERATURE REVIEW

Infant Physiology and Infant Regulatory Behavior.

Biological processes have been identified as the framework from which behavioral regulation is built such that individual differences in infants' physiological arousal are thought to influence the display of emotion and the ability to regulate. Empirical work in the area of emotion regulation has often assessed parasympathetic influences on the heart by measuring vagal withdrawal (i.e., decreases in RSA from baseline to task), as well as EEG activation (i.e., a shift in EEG asymmetry from baseline to task), as physiological predictors of regulatory behavior. Thus, the current section reviews empirical support for the association between physiological indices of regulation and regulation behavior.

Vagal withdrawal. Although limited, research has supported the association between infant cardiac vagal withdrawal and infant regulatory behaviors. Most studies assessing this link examine vagal withdrawal within the still-face paradigm, a task designed to elicit distress by removing social and emotional communication with the mother through maternal depressed affect (Wienberg & Tronik, 1996). As previously highlighted, under conditions of stress, vagal withdrawal, or a decrease in RSA relative to baseline, is thought to support behaviors indicative of active coping (Porges, 1991, 1996; Wilson & Gottman, 1996); therefore, infants are expected to vagally withdrawal during the still-face task (exhibit a decrease in RSA from baseline to the still-face episode, indicative of active coping). Indeed, many researchers have demonstrated this pattern (Bazhenova, Plonskaia, & Porges, 2001; Moore & Calkins, 2004; Weinberg & Tronick, 1996). Coinciding with this physiological pattern, researchers have found infants and children with greater withdrawal show greater soothability, attentional control (Huffman et al., 1998), behavioral distraction (Calkins, 1997), and fewer socially withdrawn, depressed, and aggressive behavior problems (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). Although most research within this small body of literature supports the association between greater vagal withdrawal and adaptive infant regulatory behavior, Conradt and Ablow (2010) examined specific behavioral strategies (i.e., attention and resistance) and did not find this association. Therefore, the current study aimed to gain greater clarification regarding link between vagal withdrawal and infant reported and observed emotion regulation behaviors.

EEG activation. EEG activation, or the shift in EEG asymmetry from a baseline measure to a task measure, has not been studied in infants or children, and has only been assessed in one study examining its link to maternal behavior and psychopathology. Specifically, Killeen and Teti (2012) examined the links between mothers' frontal EEG asymmetry at rest and during videos of their 5- to 8-month-old infants expressing three emotional states. Results indicated that a greater relative right frontal activity at rest was associated with greater maternal anxiety; however, a shift toward greater relative right frontal activation in response to infant emotional stimuli was associated with lower maternal anxiety, greater mother–infant emotional availability, and mothers' experience of sadness, concern, and the absence of joy in response to seeing their own infant in distress. These findings suggest that although resting right frontal asymmetry may be maladaptive, a shift toward right frontal activation in response to a distressful context may allow for increased maternal regulation and subsequently appropriate and sensitive parental behaviors. It is possible that this process works similarly in children. Resting right frontal asymmetry has been found to be associated with a more social inhibition and lower social competency in young children (Fox et al., 1995), however, a shift toward right frontal asymmetry during an emotionally arousing context may allow infants to appropriately react to negative stimuli and employ adaptive regulatory behaviors.

Coan, Allen, and McKnight (2006) have referred to the changes in asymmetry in response to specific environmental events as an index of one’s capacity to respond given situational demands, and thus a potential index of emotion regulation. Although the comparison from EEG baseline asymmetry to task asymmetry was not directly studied, Fox and Davidson (1987) found that 10-month-old infants who cried in response to maternal separation showed a large increase in relative right-frontal asymmetry during this condition compared with a previous less stressful condition, and those infants who did not cry in response to this stressor showed a decrease of the right-frontal region. Thus, it was suggested that the degree to which infants increased right frontal asymmetry may be associated with individual differences in negative affective responses. Therefore the current study aimed to extend this literature and better understand the relation between EEG activation scores and emotion regulation by examining the extent to which the shift in EEG asymmetry from a baseline task to an emotionally challenging task is predictive of behavioral regulation of negative arousal.

Empirical Links between Central and Parasympathetic Nervous System Functioning.

The neurovisceral model (Thayer & Lane, 2000; 2009) laid the theoretical foundation for the link between the heart and the brain as it relates to behavioral regulation. However, some empirical work has supported this link as well. For example, Ahern and colleagues (2001) showed that cortical activity inhibits vagally influenced cardiac pathways as indexed by an increase in heart rate and a decrease in heart rate variability during pharmacological inactivation of either cerebral hemisphere. Specifically, heart rate and heart rate variability were assessed before and after a central nervous system depressant was administered to each hemisphere of the frontal cortex. Results indicated that during inactivations of each hemisphere, heart rate increased and then gradually decreased supporting the notion that cortical activity inhibits cardioacceleratory outputs from the amygdala. Interestingly, different hemispheric effects appeared such that vagally mediated heart rate variability decreases were greater in the right hemisphere; thus, these findings support that right hemisphere autonomic inputs to the heart are associated with greater autonomic control.

Although there are theoretical and empirical links between the central and autonomic nervous system during emotional arousal, developmentalists have not yet empirically examined the way in which these two systems simultaneously relate to infant or child regulation behaviors. It may be that a physiological pattern comprised of frontal

EEG activation and vagal withdrawal underlies infant behavioral regulation during challenging or emotionally arousing contexts. Because the right prefrontal hemisphere has greater autonomic control, and therefore greater sympathetic influence on the heart, right frontal asymmetry may be associated with withdrawal behaviors due to the increased sympathetic influence known to be related to fight or flight responses. During contexts that do not contain emotionally challenging properties, this pattern may be maladaptive. However, during emotionally challenging or threatening contexts, a shift toward right frontal asymmetry, and subsequently greater sympathetic influence on their heart (as indexed by greater vagal withdrawal), may be adaptive and serve the goal of reducing arousal. Therefore, infants who display greater shifts toward right frontal EEG asymmetry and show increased vagal withdrawal, may also be infants who display more regulatory behaviors. Thus, the current study aimed to address this gap in the literature and investigated these links by examining the way in which EEG activation and vagal withdrawal relate to each other and to infants' behavioral regulation of emotion.

Caregiving and Behavioral Regulation of Emotion.

It is thought that sensitive caregiving, particularly to negative emotional displays, may impact infants' experience of negative emotions and create a context in which infants come to associate their behaviors and caregiver behaviors with changes in arousal. In cross-sectional studies, Calkins and Johnson (1998) found that when mothers used more positive guidance, their 18-month-old infants engaged in more distraction and gaze aversion strategies during frustrating events. Researchers have also found that mothers and fathers who were more sensitive had 4-month-old infants who used more parent orientation during the still face paradigm (Braungart-Rieker, Garwood, Powers, & Notaro, 1998). Further, infants who spend more time engaged in collaborative joint attention during a parent-involved delay task have been found to avert their attention away from a delay object, providing support for the suggestion that parents who establish shared attention on objects during interaction may facilitate the development of children's ability to use their own attention to reduce distress (Morales, Mundy, Crowson, Neal, & Delgado, 2005). Finally, it has been argued that contingent responsiveness may be particularly important for the development of infant regulation, and adaptive regulation has been contingently linked with prior sensitivity behaviors (Gunnar, 2000). Specifically, in dyads in which mothers responded contingently to their looking away, infants were less distressed than infants whose mothers did not respond contingently (Crockenberg & Leerkes, 2004); thus identifying contingent maternal responsiveness as a key predictor of emotion regulation behaviors in infancy.

Longitudinal studies have also established this association. For example, Glöggler and Pauli-Pott (2008) reported that low maternal depression and high sensitivity at 4, 8, and 12 months predicted subsequent withdrawing and self-comforting behaviors in 30-month-old children during a fear task. Moreover, in a controlled intervention study designed to improve mother's ability to monitor infant signals attentively, and respond appropriately and contingently to infants from 6 to 9 months of age, van den Boom (1994) reported that intervention group mothers were significantly more responsive, stimulating, visually attentive, and controlling of their 9-month-old infant's behavior than control group mothers, and it was found that intervention mother's infants scored higher than control infants on sociability, self-comforting, and exploration at 9 months. Importantly, these effects lasted into the 2nd and 3rd year of life as evidenced by an increased display of cooperation, orientation, and fewer behavior problems (van den Boom, 1995).

These studies illustrate the significance of sensitive caregiving for the development of infant behavioral regulation of affect. However, there is not an extensive amount of work that has examined the development of behavioral regulation of emotion during early infancy and outside of the still-face procedure. The still face procedure is characterized by cutting off affective communication with the primary caregiver and therefore may be qualitatively different distress than frustration due to blocked goals; therefore, the current study aimed to add to the current literature by investigating the association between maternal sensitivity and behavioral regulation, in addition to examining the effect of maternal sensitivity on the development of specific behavioral regulatory strategies during frustration across early infancy.

Caregiving and Physiological Regulation.

Although the exact process through which sensitive caregiving influences infants' physiology is not known, several hypotheses have been posited. The following section reviews empirical work that that supports the influence of caregiving on children's parasympathetic and central nervous system processes.

Vagal withdrawal. Porges and Furman (2011) suggested one way in which caregivers may aid infants in physiological homeostasis is by facilitating greater myelination of the vagus nerve, allowing for greater physiological control. Research has in fact demonstrated a relation between caregiving behavior and vagal withdrawal. For example, infants who engaged in less synchronous interactions with caregivers showed a less adaptive pattern of vagal regulation as evidenced by higher vagal withdrawal during a normal play episode, less vagal withdrawal during a situation meant to elicit distress, and more difficulty returning to previous levels baseline RSA following distress (Moore & Calkins, 2004). Further, Calkins and colleagues (2008) found that maternal–child relationship quality predicted the degree of children’s vagal regulation at 5-years-old even after controlling for behavior problems and vagal regulation at age 2, such that children with poorer early maternal–child relationships displayed significantly poorer vagal regulation at the later age. In a similar study assessing the effects of maternal emotional support on the trajectory of physiological regulation, children of mothers with higher emotional support were found to have greater levels of vagal withdrawal at age 3 and age 4 when compared to children of mothers displaying lower emotional support (Perry et al., in Press). Further, infants of sensitive mothers showed greater vagal withdrawal during the still-face procedure compared to infants of less sensitive mothers (Moore et al., 2009), and maternal positive touch was found to reduce infants’ physiological reactivity to stress (Feldman, Singer, & Zagoory, 2010). Finally, in a study examining the gene–environment contributions to the development of vagal regulation, Propper et al. (2008) found that infants who were at genetic risk for poor physiological regulation had vagal withdrawal similar to those not at genetic risk by 12 months of age when they were exposed to sensitive parenting during infancy.

In sum, these findings suggest that sensitive caregiving may promote the development of effective physiological regulation of the parasympathetic nervous system in young children. It may be that sensitive caregiving behaviors facilitate greater myelination of the vagus nerve in infancy, thus improving children's physiological regulatory abilities and in turn leading to more adaptive cognitive, emotional, and behavioral regulation strategies later in development. To support this literature, the current study assessed the way in which sensitive caregiving is associated with concurrent vagal withdrawal and examined whether maternal sensitivity predicts developmental changes in vagal withdrawal during an emotionally frustrating context across early infancy.

EEG activation. Because EEG activation, or the shift in EEG asymmetry from a baseline measure to a task measure, has not been studied in infants or children, the effect of maternal sensitivity on this activation has not been examined. Thus, the current study aimed to address this gap in the literature by assessing the effect of maternal sensitivity on the development of EEG activation.

The indirect effect of Maternal Sensitivity. Given the theoretical and empirical association between maternal sensitivity and infant physiological and behavioral regulation, and the association between physiological regulation and behavioral regulation, it may be that one way in which maternal sensitivity influences behavioral regulation is though the facilitation of infants' physiological development. To date, no study has assessed these indirect pathways. Therefore, the current study aimed to assess the possible indirect effect of maternal sensitivity on behavioral regulation of emotion during frustration via infants' physiological regulation during frustration.

Current Study Hypotheses.

Seven research questions and hypotheses are presented for the current study: 1) are physiological processes of the central and parasympathetic nervous system, as indexed by EEG activation and vagal withdrawal, associated with one another during frustration at 5 and 10 months 2) do physiological indices of regulation in the central and parasympathetic nervous system at 5 and 10 months, as indexed by EEG activation and vagal withdrawal, underlie infant regulation behavior during frustration at 5 and 10 months 3) does maternal sensitivity at 5 and 10 months influence infants' behavioral and physiological regulation at 5 and 10 months 4) does maternal sensitivity at 5 months influence developmental changes in infants' physiological regulation during frustration from 5 months to 10 months 5) does maternal sensitivity at 5 months influence developmental changes in infants' observed and reported behavioral regulation to frustration from 5 months to 10 months 6) is maternal sensitivity at 5 months an indirect predictor of behavioral regulation at 10 months via children's physiological regulation at 10 months and 7) do the associations between physiological regulation and behavioral regulation, as well as between maternal sensitivity and the development of physiological and behavioral regulation, vary depending on whether the frustration task is mild or moderate in intensity?

1). Are physiological processes of the central and parasympathetic nervous system, as indexed by EEG activation and vagal withdrawal, associated with one another during frustration at 5 and 10 months?

Because greater vagal withdrawal has been theoretically and empirically associated with an increased ability to cope with negative or emotionally stressful situations, and a shift toward right frontal EEG asymmetry (i.e., EEG activation) has been thought to allow for increased regulation of negative affect, it is hypothesized that vagal withdrawal and EEG activation will be associated such that an increase in one physiological process will coincide with an increase in the other during at 5 and 10 months.

2). Do physiological indices of regulation in the central and parasympathetic nervous system at 5 and 10 months, as indexed by EEG activation and vagal withdrawal, underlie infant regulation behavior during frustration at 5 and 10 months?

It is anticipated that physiological indices of emotion regulation in the central and parasympathetic nervous system at 5 and 10 months will predict concurrent reported and observed behavioral regulation of emotion. Because vagal withdrawal supports increased attention to the environment, and increased attention may facilitate the use of regulatory behaviors that function to reduce distress, it is hypothesized that vagal withdrawal during emotional frustration will be associated with greater infant displays of emotion regulation strategies during frustration, and mother report of infant behavioral regulation at both 5 and 10 months. In contrast, because distress to limitations can be thought of as a difficulty to regulate effectively, distress was hypothesized to be associated negatively with vagal withdrawal at 5 and 10 months. No previous study has assessed the relation between EEG activation and infant regulatory behaviors; thus, the hypothesis regarding this association is exploratory. However, because EEG activation is thought to reflect state-related changes in asymmetry and active processing as a function of changes in emotion, and it has been speculated that a shift toward right frontal activation and an increase in right processing in response to a distressful context may allow for adaptive responding, it is hypothesized that infants who shift toward more right frontal asymmetry during frustration will display more regulatory behaviors and be reported by their mothers to be better regulated and less distressed.

3). Does maternal sensitivity at 5 and 10 months influence infants' behavioral and physiological regulation at 5 and 10 months?

It is anticipated based on prior research that maternal sensitivity at 5 and 10 months will predict infants' concurrent physiological and behavioral regulation. Because sensitive parenting is thought to reduce emotional arousal and in turn help infants regulate their physiological state, it is hypothesized maternal sensitivity will be associated positively with infant vagal withdrawal and a shift toward right EEG activation. Further, because sensitive parenting is thought to indirectly teach infants self-regulatory strategies, it is hypothesized that maternal sensitivity will be associated positively with infants' reported and observed regulatory behaviors. Because distress to limitations can be thought of as a difficulty to regulate, distress was hypothesized to be associated negatively with maternal sensitivity.

4). Does maternal sensitivity at 5 months influence developmental changes in infants' physiological regulation during frustration from 5 months to 10 months?

Because early in development children have rudimentary physiological abilities in place and are therefore reliant on external sources to achieve and maintain a regulated physiological state (Spangler & Grossman, 1993), and both theoretical and empirical work have supported the idea that warm and sensitive parenting to infant distress may be a biobehavioral pathway though which social interactions between infants and their caregivers can calm infants' internal states (Porges & Furman, 2011), it is hypothesized that maternal sensitivity at 5 months will be associated with increasess in infants' physiological regulation, as indexed by changes in vagal withdrawal and EEG activation, from 5 to 10 months. Specifically, the Polyvagal Theory has theorized a possible association between caregiving and myelination of the vagus nerve, and greater myelination of the vagus nerve is thought to be indicative of greater cardiac regulation. Therefore, it is hypothesized that maternal sensitivity at 5 months will be associated positively with infant vagal withdrawal at 10 months after controlling for prior vagal withdrawal at 5 months. No previous study has explored the relation between EEG activation and maternal sensitivity. Therefore, the hypothesis regarding this association is exploratory. However, because positive EEG activation values are indicative of a shift toward right frontal asymmetry, and right frontal asymmetry during stress may be adaptive in order to cope with stressful stimuli, it is hypothesized that maternal sensitivity at 5 months will be positively associated with changes in EEG activation during frustration at 10 months after controlling for prior EEG activation at 5 months.

5). Does maternal sensitivity at 5 months influence developmental changes in infants' observed and reported behavioral regulation to frustration from 5 months to 10 months?

It is anticipated based on prior research that early maternal sensitivity will predict increases in mother's reports of infants' emotion regulation, as well as infants' observed emotion regulation strategies during frustration from 5 months to 10 months. Because repeated and consistent sensitive parenting is thought to reduce emotional arousal and in turn facilitate the development of infant self-regulation behaviors, it is hypothesized that maternal sensitivity at 5 months will be associated positively with increases in infants' use of emotion regulation strategies and mother reported emotion regulation from 5 to 10 months, and associated negatively with infant distress from 5 to 10 months.

6). *Is maternal sensitivity at 5 months an indirect predictor of behavioral regulation at 10 months via children's physiological regulation at 10 months?*

Given the theoretical and empirical association between maternal sensitivity and infant physiological and behavioral regulation, and the association between physiological regulation and behavioral regulation, it is hypothesized that maternal sensitivity at 5 months will be directly associated with behavioral regulation at 10 months, as well as indirectly associated with behavioral regulation at 10 months via infants' physiological regulation at 10 months.

7). Do the associations between physiological regulation and behavioral regulation, as well as between maternal sensitivity and the development of physiological and behavioral regulation, vary depending on whether the frustration task is mild or moderate in intensity?

Because a frustration task of moderate intensity may elicit stronger physiological and behavioral regulatory responses, it is hypothesized that associations between primary study constructs will be stronger when analyzed in the moderately frustrating context, and weaker when analyzed in the mildly frustrating context.

CHAPTER IV

METHODS

Sample.

As part of a longitudinal study examining the relations between cognition, affect, and psychophysiology across early development, 283 healthy full-term infants (144 girls, 139 boys; 212 Caucasian, 45 African American, 22 other, four not reported) were recruited at two research locations (Blacksburg, Virginia, and Greensboro, North Carolina) to participate in a laboratory visit when infants were 5-months-old. A total of 276 mothers reported educational information. Of those mothers, 97% of mothers graduated from high school, 3% had a technical degree, 42% had a bachelor's degree, and 21% had a graduate degree. Mothers were, on average, 29 years old (*SD*=6years) when the infants were born. Infants were recruited via commercial mailing lists, newspaper birth announcements, and word of mouth.

Infants were brought into the laboratory again when they were 10-months-old. Of the 283 participants that participated at 5-months, 253 returned for the 10-month visit. There were no significant differences between infants that did and did not return for the 10-month visit by child gender; however, infants who did not return were more likely to be ethnic minority (χ^2 [1, N=253] = 8.57, $p < .01$) and have mothers with less education ($t(253) = 3.29$, $p < .01$). All infants were born within 28 days of their calculated due dates and were healthy at the time of testing. Infants' mean ages (in days) were 162 (*SD* = 8) and 314 (*SD* = 11) at 5 and 10 months, respectively. Parents were paid for each laboratory visit.

At each laboratory visit infants participated in a mild and a moderate frustration task. If at any time during the visit the infant became very upset, they did not participate in the subsequent frustration task. That is, if an infant became highly upset before the first mild frustration task was administered, the infant did not participate in the mild frustration task or the moderate frustration task. Similarly, if the infant became very upset during the mild frustration task, the infant did not participate in the subsequent moderate frustration task. Thus, the current study utilized two sub-samples of children. The first sub-sample included infants who participated in the mildly frustrating toy-removal task (N= 236 at 5-months; N=216 at 10-months). These children did not differ from the full sample at 5-months or 10-months in terms of maternal sensitivity, maternal reported regulation, or negative reactivity. The second sub-sample included infants who participated in the moderately frustrating arm-restraint task (N= 135 at 5-months; N=95 at 10-months). These children did not differ from the full sample at 5 or 10-months in terms of maternal sensitivity. However, children who did participate were reported by their mothers to be better regulated at 5-months, ($t(272) = -2.16$, $p < .05$), and have lower negative affectivity at 10-months, ($t(248) = 2.34$, $p < .05$).

Procedure.

Participating families reported demographic information, completed questionnaires regarding infant behavior, and participated in behavioral tasks during a laboratory visit when infants were approximately 5 and 10-months-old. Specifically, mothers reported on infants’ regulatory behaviors and participated in two mother-child interaction tasks. Infants were observed in emotionally frustrating tasks that were mild and moderate in intensity during which infant behavioral regulation was assessed. Moreover, physiological indices of regulation were collected during both frustration tasks.

Table 1. Summary of Study Measures.

Construct	Measure	Wave	Type
Maternal Sensitivity	Structured interactions	5 & 10 months	Observational
Physiological Regulation	EEG activation	5 & 10 months	Physiological
	Vagal withdrawal	5 & 10 months	Physiological
Behavioral Emotion Regulation	Mother orientation	5 & 10 months	Observational
	Self-comforting	5 & 10 months	Observational
	Distraction	5 & 10 months	Observational
	Falling Reactivity subscale of the Infant Behavior Questionnaire-Revised	5 & 10 months	Mother reported
	Distress to Limitations subscale of the Infant Behavior Questionnaire-Revised	5 & 10 months	Mother reported

Physiological Measures.

EEG activation. EEG was recorded during baseline and during the mild and moderate frustration task at 5 and 10 months of age. The baseline procedure was one minute in duration and consisted of a research assistant manipulating a toy containing colored balls in front of the infant while the infant was seated on his or her mother's lap. Recordings were made from 16 left and right scalp sites: frontal pole (Fp1, Fp2), medial frontal (F3, F4), lateral frontal (F7, F8), central (C3, C4), temporal (T7, T8), medial parietal (P3, P4), lateral parietal (P7, P8), and occipital (O1, O2). All electrode sites were referenced to Cz during recording. EEG was recorded using a stretch cap (Electro-Cap, Eaton, OH) with electrodes in the 10/20 system pattern (Jasper, 1958; Pizzagalli, 2007). After the cap was placed on the infant's head, recommended procedures regarding EEG data collection with infants were followed (Fox, Schmidt, Henderson, & Marshall, 2007). Specifically, a small amount of abrasive was placed into each recording site and the scalp was gently rubbed. Afterward, conductive gel was placed in each site. Electrode impedances were measured and accepted if they were below 10K ohms. The electrical activity from each lead was amplified using separate SA Instrumentation Bioamps (San Diego, CA) and bandpassed from 0.1 to 100 Hz. Activity for each lead was displayed on the monitor of an acquisition computer. The EEG signal was digitized online at 512 samples per second for each channel so that the data were not affected by aliasing. The acquisition software was Snapshot-Snapstream (2003) and the raw data were stored for later analyses.

EEG data were examined and analyzed using EEG Analysis System software developed by the James Long Company (Long, 2011a). First, the data were re-referenced via software to an average reference configuration (Lehmann, 1987). Average referencing, in effect, weighted all the electrode sites equally and eliminated the need for a non-cephalic reference. Active (F3, F4, etc.) to reference (Cz) electrode distances vary across the scalp. Without the re-referencing, power values at each active site may reflect inter-electrode distance as much as they reflect electrical potential. The average reference configuration requires that a sufficient number of electrodes be sampled and that these electrodes be evenly distributed across the scalp. Currently, there is no agreement concerning the appropriate number of electrodes (Hagemann, Naumann, & Thayer, 2001), although the 10/20 configuration used does satisfy the requirement of even scalp distribution.

The re-referenced EEG data were artifact scored for eyeblinks using Fp1 and Fp2 (Myslobodsky et al., 1989) and for gross motor movements; these artifact-scored epochs were eliminated from all subsequent analyses. The data then were analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap. Power was computed for the 6- to 9-Hz frequency band. The power was expressed as mean square microvolts and the data were transformed using the natural log (ln) to normalize the distribution. Coherence between medial frontal and all other electrode sites within each hemisphere was computed for the 6- to 9-Hz band using an algorithm by Saltzberg, Burton, Burch, Fletcher, and Michaels (1986). For the current study, only the medial frontal pairing (i.e., F3 & F4) was examined because of the well-established role of the frontal cortex during emotional contexts (Coan & Allen, 2004).

The primary EEG measure used in the current study was EEG activation. EEG activation can be thought of as a shift in EEG asymmetry towards the right or left hemisphere in response to the frustration task. A shift toward right frontal asymmetry in response to the frustration task would be indicative of an increase in active processing in the right hemisphere as compared to EEG asymmetry at baseline. Similarly, a shift toward left frontal asymmetry in response to the frustration task would be indicative of an increase in active processing in the left hemisphere as compared to baseline. EEG activation (i.e., a shift in EEG from a baseline asymmetry measure to a task asymmetry measure) was computed by subtracting the frustration task asymmetry score from the baseline asymmetry score so that positive scores were indicative of a shift to the right and negative scores were indicative of a shift toward the left.

Vagal withdrawal. Electrocardiography (ECG) was recorded at 5 and 10 months during a baseline procedure and during the mild and moderate frustration tasks from two neonatal disposable electrodes using modified lead II (right collarbone and lower left rib; Stern, Ray, & Quigley, 2001), grounded at the scalp near electrode site Fz. The cardiac electrical activity was amplified using a SA Instrumentation Bioamp, and the QRS complex was displayed on the acquisition computer monitor along with the EEG data. The cardiac signal was digitized at 512 samples per second. The acquisition software was Snapshot-Snapstream (2003) and the raw data were stored for later analyses. Data were examined and analyzed using IBI Analysis System software developed by the James

Long Company (Long, 2011b). First, R waves were detected and movement artifact, designated by the absence of at least three consecutive R waves, was scored. These artifact-scored epochs were eliminated from all cardiac calculations.

Estimates of RSA were calculated using Porges' (1985) method of analyzing IBI data. This method applies an algorithm to the sequential heart period data. The algorithm uses a moving 21-point polynomial to detrend periodicities in heart period (HP) slower than RSA. A band-pass filter then extracts the variance of HP within the frequency band of spontaneous respiration (.24–1.04 Hz) in young children; research with young children has consistently examined this band and identified associations with child functioning (Huffman et al.,1998; Stifter & Fox, 1990). RSA was calculated every 16 seconds for the baseline period and every 16 seconds for the frustration task. These epoch durations were used to maximize the use of available data from each task and are typical for studies of short-duration tasks with a developmental population (Marcovitch et al., 2010; Calkins and Keane, 2004; Doussard-Roosevelt et al., 2003; Calkins & Dedmon, 2000 Huffman et al., 1998). The primary cardiac measure used in the current study was vagal withdrawal. Vagal withdrawal was calculated by subtracting task RSA from baseline RSA so that positive values are indicative of greater withdrawal.

Infant Behavioral Regulation.

Mildly Frustrating Toy-Removal. At 5 and 10 months, observed emotion regulation behaviors were assessed through a mildly frustrating *Toy-Removal task.* Mothers were asked to play with their infant with a Busybox toy while talking and laughing as they normally would. After 30 seconds, mothers were asked to stop playing and talking, hold the toy against their chest, and look at the baby with no response for a full two minutes. If very intense frustration occurred for several seconds, the task was stopped and the infant was soothed.

Moderately Frustrating Arm-restraint. Observed emotion regulation behaviors were also assessed through a moderately frustrating *Arm-Restraint Procedure* (Provost & Gouin-Decarie, 1979) at the 5 and 10-month visit. During this 2-minute task, infants were placed in a highchair and mothers were seated to the left of the infant and asked to gently but firmly hold down the infants' arms against the infants' sides in order to restrict their movement. Mothers were asked to maintain a blank neutral face and not to speak or respond to the infant's distress. If very intense frustration occurred for several seconds, the task was stopped and the infant was soothed.

*Regulation Scoring***.** Both frustration tasks were videotaped and coded for distraction, mother orientation, and self-comforting behaviors. These behaviors are thought to be adaptive in that they reduce infant distress to arousal. The distraction score measured the extent to which the infant distracted themselves away from the frustrating event. Examples include attending to the wall, or various objects around the room. The self-comforting score measured the extent to which the child used auto-manipulative behaviors to comfort themselves during the frustrating task. Examples include rubbing their face on their shoulder or hand, and sucking on their hands, arm, or their mother. In addition, videos were coded for mother orientation. The mother orientation score measured the extent to which infants oriented to their mother and away from the frustration task. Because infants are not fully capable of self-regulation and often look to their caregiver to help them regulate their internal states (Evans & Porter, 2009), greater scores on mother orientation were thought to be adaptive.

The videos were coded in 10-second epochs for the presence of any distraction, self-comforting, and mother orienting behavior. The number of epochs during which the child displayed these behaviors were summed and divided by the total number of task epochs to obtain an overall proportion score for each behavior. That is, the total proportion score for each regulatory behavior is the number of epochs the child distracted away from the task divided by the total amount of epochs during which the child participated. To establish reliability, approximately 24% of the videotapes were coded by two coders. For the Virgina cohort, the intraclass correlations between the two rater's codes for the distraction, self-comforting, and mother orientation score during the arm-restraint task were .99, .99, and .99 at 5 months, and .96, .99, and .92 at 10 months; the Virginia cohort's intraclass correlations between the two rater's codes for the distraction, self-comforting, and mother orientation score during the toy-removal task were .98, .98, and .96 at 5 months, and .95, .99, and .96 at 10 months. For the North Carolina cohort, the intraclass correlations between the two rater's codes for the distraction, self-comforting, and mother orientation score during the arm-restraint task were .95, .72, and .91 at 5 months, and .90, .99, and .98 at 10 months; the North Carolina cohort's intraclass correlations between the two rater's codes for the distraction, self-comforting, and mother orientation score during the toy-removal task were .70, .65, and .92 at 5 months, and .97, .92, and .98 at 10 months.

Infant Behavior Questionnaire-Revised. At the 5 and 10-month visit mothers reported on infant behavior in commonly occurring situations using the revised version of Rothbart's Infant Behavior Questionnaire (IBQ–R; Gartstein & Rothbart, 2003). A 7-point Likert scale ranging from *never* (1) to *always* (7) was used to rate the frequency with which the child had exhibited behaviors in the past 2 weeks. For the current study, the Falling Reactivity/Recovery from Distress (13 items; α =.86 at 5 months, α =.82 at 10 months) and the Distress to limitations (16 items; α =.80 at 5 months, α =.77 at 10 months) subscales were used. The Falling Reactivity/Recovery from Distress subscale measured the rate of recovery from peak distress, excitement, or general arousal and is used as an index of the infant's ability to regulate his or her own state (Gartstein & Rothbart, 2003). The Distress to Limitations Subscale measured the infant's fussing, crying, or showing distress while in a confining place or position, involved in caretaking activities, or when they were unable to perform a desired action. Item values were averaged to produce a score the subscale at each time point.

Maternal Sensitivity.

*Observed Sensitivity Tasks***.** At 5 and 10 months, mothers and their infants participated in two 2-minute mother-child interaction tasks. In the first task, mothers were given 2 simple toys and asked to play with their infants as they normally would at home. They were instructed that it was okay to talk, laugh, and have a good time together. In the second task, mothers and their infants played Peekaboo. Mothers were instructed to only use their hands and not to cover the infant's face so that the infant's reactions could be seen as they played. The toys and Peekaboo task were coded for maternal sensitivity.

Examples of sensitivity observed include responsiveness, being aware of the infant's emotional state, giving the infant a chance to explore, showing warmth, sharing positive affect with the infant, and adjusting to the infant's interest or lack of interest in the toys or game.

The videos were coded in 30-second epochs for the level of maternal sensitivity. For each task, during each epoch, sensitivity was rated on a 4-point Likert scale ranging from 1 (no evidence of sensitivity) to 4 (high level, intense, prolonged, repeated behavior). The total sensitivity score for each task is the mean of the sensitivity scores for each epoch. To establish reliability, approximately 20% of the videotapes were coded by an additional coder. The intraclass correlation between the two rater's codes for sensitivity in the toy task and Peekaboo task were .93 and .87 at 5 months and .76 and .75 at 10 months for the Virgina cohort. The intraclass correlation between the two rater's codes for sensitivity in the toy task and Peekaboo task were .87 and .81 at 5 months and .79 and .74 at 10 months for the North Carolina cohort. A global maternal sensitivity score was calculated by averaging across the two task score

CHAPTER V

RESULTS

Preliminary Analyses.

Preliminary analyses were conducted to examine the descriptive properties and frequencies of each study variable. These descriptive properties are presented in Table 2. Relations between study variables were also examined. Correlations between infants' physiology and infants' behavioral regulation in both frustration tasks were investigated, as were correlations between maternal sensitivity, infant physiology, and infant behavioral regulation. Because separate analyses addressing each research question were conducted for the mild and moderate frustration task, correlations among study variables are presented separately for each task. Correlations among variables included in analyses involving the mildly frustrating toy-removal task are presented in Table 3, and correlations among variables included in analyses involving the moderately frustrating arm-restraint task are presented in Table 4.

Correlations across task for physiological and behavioral indices of regulation were also examined for each year. EEG activation scores during the toy-removal and arm-restraint task were correlated at 5 months (r =.61, p <.01) and 10 months (r =.38, p <.01), indicating moderate to high stability across task. Vagal withdrawal scores during the toy-removal and arm-restraint task were also correlated at 5-months (r =.46, p <.01) and 10-months (r =.46, p <.01), indicating moderate stability across task. Observed distraction during the toy-removal and arm-restraint task were not correlated at 5-months (*r* =.09, *p* >.05) but were correlated at10-months (*r* =.16, *p* <.05), indicating low stability across task. Observed mother orientation during the toy-removal and arm-restraint task were correlated at 5-months (*r* =.36, *p* <.01) and 10-months (*r* =.25, *p* <.01), indicating moderate stability across task. Due to task design there was not sufficient variability in the self-comforting measure during the arm-restraint task; thus, this variable was not used in any analyses assessing associations among variables during moderate frustration.

Although baseline measures of RSA and EEG asymmetry were not primary variables of interest, correlations between both baseline measures at 5 and 10 months and primary study variables were analyzed. Baseline RSA at 5 months was correlated with distress at 5 months (*r* =.13, *p* <.05), baseline RSA at 10 months (*r* =.29, *p* <.01), vagal withdrawal during toy-removal at 5 months (*r* =.61, *p* <.01), and vagal withdrawal during arm-restraint at 5 months (*r* =.39, *p* <.01). Baseline RSA at 10 months was correlated with vagal withdrawal during toy-removal at 10 months (*r* =.56, *p* <.01), and vagal withdrawal during arm-restraint at 10 months (*r* =.44, *p* <.01). Baseline asymmetry at 5 months was correlated with baseline asymmetry at 10 months (*r* =-.13, *p* <.05), distress at 5 months (*r* =-.13, *p* <.05), EEG activation during toy-removal at 5 months (*r* =.57, *p* <.01), EEG activation during arm-restraint at 5 months (*r* =.36, *p* <.01), and mother orientation during arm-restraint at 5 months (*r* =-.16, *p* <.05). Baseline asymmetry at 10 months was correlated with EEG activation during toy-removal at 10 months (*r* =.50, *p* <.01), EEG activation during arm-restraint at 10 months (*r* =.44, *p* <.01), and distraction behaviors during arm-restraint at 5 months (*r* =-.19, *p* <.05).

The toy-removal and the arm-restraint task were compared to examine whether the arm-restraint task was indeed more frustrating than the toy-removal task. Due to the nature of the different samples, it is difficult to determine whether one task elicited more frustration than the other. Thus, in an attempt to best address this concern, the sample was paired and only the means of overall negative affect of the children who participated in both the toy-removal and arm-restraint task were compared. Paired t-tests indicated that the mean of overall negative affect elicited by the toy-removal task at 5 months (M = .56) was significantly smaller than the mean of overall negative affect elicited by the arm-restraint task at 5 months (M = 2.11) ($t(132) = -13.91$, $p < .001$). Similarly, the mean of overall negative affect elicited by the toy-removal task at 10 months (M = .84) was significantly smaller than the mean of overall negative affect elicited by the arm-restraint task (M = 2.53) ($t(91) = -12.00$, $p < .001$). Therefore, although the samples are different for each task, and the ability to best compare the intensity of the frustration is hindered, there is evidence the arm-restraint task was more frustrating.

To test whether there were significant developmental changes from 5 to 10 months within these physiological systems, t-tests were analyzed to compare overall mean differences. There was no significant difference between vagal withdrawal at 5 months and vagal withdrawal at 10 months ($t(51) = 1.3$, $p =.24$) during the arm-restraint task. However there was a significant difference between vagal withdrawal at 5 months and vagal withdrawal at 10 months ($t(183) = -2.17$, $p =.03$) during the toy-removal task. EEG activation was not significantly different during arm-restraint ($t(60) = 1.28$, $p =.20$), or toy-removal task ($t(175) = 1.3$, $p =..20$), from 5 months to 10 months.

Missing Data.

Full information maximum likelihood (FIML), a modeling method that estimates parameters based on available and implied values without actually imputing missing data (Schlomer, Bauman, & Card, 2010) was used in all path analyses. FIML estimation utilizes all available information to account for missing data; however, cases are dropped when data are missing from exogenous variables.

Analyses Addressing Research Questions.

Path analyses were conducted to examine all of the associations between primary study variables utilizing Mplus Version 7 (Muthen & Muthen, 2012). Separate analyses were conducted to address each research question and separate path models were examined for the mildly frustrating toy-removal task and the moderately frustrating arm-restraint task. Infant sex, race, and age in days were included as covariates in all models. In addition, for models containing vagal withdrawal and EEG activation, baseline asymmetry and baseline RSA were added as covariates, and for all models containing maternal sensitivity, mother age and education were added as covariates.

Are physiological processes of the central and parasympathetic nervous system, as indexed by EEG activation and vagal withdrawal, associated with one another during frustration at 5 and 10 months?

It was hypothesized that that vagal withdrawal and EEG activation would be associated such that an increase in one physiological process would coincide with an increase in the other during both mild and moderate frustration at 5 and 10 months. As hypothesized, vagal withdrawal and EEG activation were correlated at 10 months during the moderately frustrating arm-restraint task (r =.28, p <.05). However, contrary to hypotheses, EEG activation were uncorrelated at 5 months during the mild (r =-.06, p >.05) and moderate (r =-.05, p >.05) frustration tasks, and at 10 months during the mild frustration tasks *(*r =.07*,* p >.05).

Do physiological indices of regulation in the central and parasympathetic nervous system at 5 and 10 months, as indexed by EEG activation and vagal withdrawal, underlie infant regulation behavior during frustration at 5 and 10 months?

Vagal withdrawal.

Because vagal withdrawal was calculated by subtracting RSA during the frustration tasks from baseline RSA, positive values are indicative of greater withdrawal (i.e., greater physiological regulation of the parasympathetic nervous system). It was hypothesized that 5 and 10-month vagal withdrawal during frustration would be associated positively with concurrent infant displays of emotion regulation behaviors during frustration, and mother report of infants' falling reactivity. In contrast, because distress to limitations can be thought of as a difficulty to regulate, distress was hypothesized to be associated negatively with vagal withdrawal. To test this hypothesis, path analyses examining the associations between infant vagal withdrawal, infant observed distraction, infant mother orientation, infant self-comforting, mother reported falling reactivity, and mother reported distress, were conducted.

5-month vagal withdrawal and 5-month infant regulation behaviors. The model for the mildly frustrating toy-removal task at 5 months fit well, χ^2 (10, N = 263) = 9.49, p = .49, CFI = 1.00, RMSEA = .00 [CI = .00, .06]. The direct path from vagal withdrawal during toy-removal to observed distraction (β = -.15, p = .03) was significant, and the path from vagal withdrawal to mothers' reports of their infants' distress was marginally significant (β = .11, p = .08). However, the paths from vagal withdrawal to observed mother orientation (β = .01, p = .97), observed self-comforting (β = .02, p = .72), and reported falling reactivity (β = -.06, p = .33), were not significant (see Figure 2). These findings suggest that infants with greater vagal withdrawal were less likely to engage in distraction behaviors during mild frustration and were somewhat more likely to be reported by their mothers to be higher on distress at 5 months.

The model for the moderately frustrating arm-restraint task at 5-months also fit well, χ^2 (8, N = 263) = 10.99, p = .20, CFI = .94, RMSEA = .04 [CI = .00, .09]. Similar to the mildly frustrating toy-removal task, the direct path from vagal withdrawal at 5-months to observed distraction (β = .21, p = .04) task was significant. However, in the moderately frustrating task infants who displayed greater vagal withdrawal were more likely to engage in distraction behaviors. The direct paths from vagal withdrawal to observed mother orientation (β = -.11, p = .29), reported falling reactivity (β = -.04, p = .64), and mother reported distress (β = .12, p = .13) were not significant (see Figure 2). These findings suggest that at 5 months infant vagal withdrawal is not related to distraction behaviors in the same way across the mild and moderate frustration tasks. Infants with greater vagal withdrawal were less likely to engage in distraction behaviors during mild frustration but more likely to engage in distraction behaviors during moderate frustration.

10-month vagal withdrawal and 10-month infant regulation behaviors. The model for the mildly frustrating toy-removal task at 10 months fit well, χ^2 (10, N = 242) = 3.54, p = .97, CFI = 1.00, RMSEA = .00 [CI = .00, .00]. However, contrary to hypotheses, the direct paths from vagal withdrawal at 10 months to observed distraction (β = -.07, p = .37), observed mother orientation (β = .01, p = .90), observed self-comforting (β = .03, p = .69), reported falling reactivity (β = .02, p = .80), and reported distress (β = .01, p = .92) were not significant (see Figure 3).

The model for the moderately frustrating arm-restraint task at 10-months also fit well, χ^2 (8, N = 242) = 8.48, p = .38, CFI = 1.00, RMSEA = .02 [CI = .00, .08]. In contrast to the non-significant direct paths in the mildly frustrating toy-removal task, the direct paths from vagal withdrawal to observed distraction (β = -.20, p = .04) and observed mother orientation (β = .22, p = .03) were significant. However, the direct paths from vagal withdrawal to reported falling reactivity (β = -.01, p = .95) and mother reported infant distress (β = .11, p = .22) were not significant (see Figure 3). These findings suggest that infants with greater vagal withdrawal at 10 months were less likely to engage in distraction behaviors but were more likely to orient to their mother during the moderately frustrating arm-restraint task.

EEG Activation.

Because EEG activation was calculated by subtracting asymmetry during the frustration tasks from asymmetry during the baseline tasks, positive values are indicative of a greater shift toward right frontal asymmetry (i.e., greater proposed physiological regulation of the central nervous system). It was hypothesized that 5 and 10-month EEG activation during frustration would be associated positively with concurrent infant displays of emotion regulation behaviors during frustration, and mother report of falling reactivity, and associated negatively with reported infant distress. To test this hypothesis, path analyses examining the associations between infant EEG activation, infant observed distraction, mother orientation, infant self-comforting, mother reported falling reactivity, and mother reported distress, were conducted.

5-month EEG activation and 5-month infant regulation behaviors. The model for the mildly frustrating toy-removal task fit well, χ^2 (10, *N* = 258) = 8.72, *p* = .56, CFI = 1.00, RMSEA = .00 [CI = .00, .06]. Contrary to hypotheses, the direct paths from EEG activation to observed distraction (β = -.05, *p* = .50), observed mother orientation (β = .06, *p* = .39), observed self-comforting (β = -.06, *p* = .41), and reported distress to limitations (β = -.08, *p* = .24) were not significant. However, EEG activation was associated positively with reported falling reactivity (β = .14, *p* = .03) (see Figure 2) in the hypothesized way suggesting that infants that shifted toward greater right frontal asymmetry during mild frustration were also more likely to show greater recovery from peak distress and general arousal.

The model for the moderately frustrating arm-restraint task fit the data well, χ^2 (8, *N* = 258) = 9.40, *p* = .31, CFI = .97, RMSEA = .03 [CI = .00, .08]. However, the direct paths from EEG activation to observed distraction (β = -.06, *p* = .60), observed mother orientation (β = .11, *p* = .29), reported falling reactivity (β = .02, *p* = .82), and reported distress (β = -.11, *p* = .16), were not significant (see Figure 2).

10-month EEG activation and 10- month infant regulation behaviors. The model for the mildly frustrating toy-removal task fit well, χ^2 (12, *N* = 237) = 3.81, *p* = .99, CFI = 1.00, RMSEA = .00 [CI = .00, .00]. The direct path from EEG activation to observed distraction was significant (*β* = .14, *p* = .04). However, the direct paths from EEG activation to observed mother orientation (*β* = .11, *p* = .11), observed self-comforting (*β* = -.06, *p* = .42), reported falling reactivity (*β* = .01, *p* = .94), and reported distress (*β* = .03, *p* = .68), were not significant (see Figure 3). These findings suggest infants who shifted more toward right frontal asymmetry were also more likely to show distraction behaviors in the mildly frustrating toy-removal task.

The model for the moderately frustrating arm-restraint task also fit well, χ^2 (8, *N* = 237) = 8.02, *p* = .43, CFI = 1.00, RMSEA = .01 [CI = .00, .07]. Similar to results found with vagal withdrawal, when assessing the direct paths between EEG activation during the moderately frustrating arm-restraint task and infant regulation behaviors, significant pathways emerged. Specifically, infant EEG activation during arm-restraint at 10 months was negatively associated with infant observed distraction (*β* = -.17, *p* = .05), and positively associated with infant mother-orientation (*β* = .30, *p* = .001). These findings suggest that infants that shifted toward right frontal EEG asymmetry during the arm-restraint task were more likely to orient to their mother and less likely to display distraction behaviors. The direct paths from EEG activation at 10 months to reported falling reactivity (*β* = .04, *p* = .64), and reported distress (*β* = .02, *p* = .79) were not significant (see Figure 3).

Does maternal sensitivity at 5 and 10 months influence infants' behavioral and physiological regulation at 5 and 10 months?

Path analyses were conducted examining the concurrent associations between maternal sensitivity and infants' behavioral and physiological regulation at 5 and 10 months. At both 5 and 10 months, it was hypothesized that maternal sensitivity would be associated positively with infants' observed distraction, observed self-comforting, observed mother orientation, and reported falling reactivity. In contrast, maternal sensitivity was hypothesized to be negatively correlated with mothers' reports of infant distress.

5-month maternal sensitivity and 5-month behavioral regulation. The model for the mildly frustrating toy-removal task fit adequate, χ^2 (11, N = 273) = 19.37, p = .06, CFI = .85, RMSEA = .05 [CI = .00, .09]. The direct paths from maternal sensitivity to observed distraction (β = -.09, p = .18), observed mother orientation (β = .08, p = .20), observed self-comforting (β = .00, p = .98), and reported falling reactivity (β = -.02, p = .75), were not significant. However, as hypothesized, the path from maternal sensitivity to reported distress (β = -.12, p = .05) was significant and suggested that infants with more sensitive mothers were reported to have lower distress (see Figure 4).

The model for the moderately frustrating arm-restraint task also fit adequate, χ^2 (9, N = 273) = 16.55, p = .06, CFI = .89, RMSEA = .05 [CI = .00, .09]. Similar to the associations described above, in the moderate frustration task the direct paths from maternal sensitivity to observed distraction (β = .00, p = .99), observed mother orientation (β = .14, p = .08), and reported falling reactivity (β = -.02, p = .75), were not significant. However, it should be noted that there was a trend level positive association between maternal sensitivity and infant mother orientation suggesting that infants with mothers who were observed to be more sensitive also tended to orient to their mothers more. Finally, and as expected, the path from maternal sensitivity to reported distress (β = -.12, p = .05) was significant and again suggested that infants with more sensitive mothers were reported to have lower distress (see Figure 4).

5-month maternal sensitivity and 5-month physiological regulation. The model for the mildly frustrating toy-removal task fit well, χ^2 (9, N = 244) = 15.71, p = .08, CFI = .97, RMSEA = .05 [CI = .00, .09]. However, maternal sensitivity at 5 months did not predict vagal withdrawal at 5 months (β = .03, p = .61) or EEG activation at 5 months (β = .01, p = .97). Similarly, the model for the moderately frustrating toy-removal task fit well, χ^2 (9, N = 241) = 10.24, p = .08, CFI = .97, RMSEA = .02 [CI = .00, .08] but maternal sensitivity at 5 months did not predict vagal withdrawal at 5 months (β = .11, p = .21) or EEG activation at 5 months (β = .08, p = .30).

10-month maternal sensitivity and 10-month behavioral regulation. The model for the mildly frustrating toy-removal task fit well, χ^2 (11, N = 248) = 11.03, p = .44, CFI = 1.00, RMSEA = .00 [CI = .00, .07]. However, the direct paths from maternal sensitivity to observed distraction (β = -.02, p = .76), observed mother orientation (β = .05, p = .72), observed self-comforting (β = .01, p = .80), reported falling reactivity (β = .02, p = .72), and reported distress (β = -.12, p = .07), were not significant. Similar to association at 5 months, the path from maternal sensitivity to reported distress approached significance and suggested that infants with more sensitive mothers were reported to have lower distress at 10 months (see Figure 4).

The model for the moderately frustrating arm-restraint task also fit well, χ^2 (9, N = 248) = 16.55, p = .40, CFI = 1.00, RMSEA = .01 [CI = .00, .07]. In contrast to the association between maternal sensitivity and observed regulation in the mildly frustrating task, maternal sensitivity was negatively associated with infants' observed distraction (β = -.17, p = .03) in the moderately frustrating task suggesting that infants with more sensitive mothers distracted less during the arm-restraint task (see Figure 4). However, the direct paths from maternal sensitivity to observed mother orientation (β = -.05, p = .50), reported distress (β = -.11, p = .07), and reported falling reactivity (β = .03, p = .70), were not significant. Again, there was a trend level negative association between maternal sensitivity and reported distress suggesting that infants with more sensitive mothers were reported to have lower distress at 10 months.

10-month maternal sensitivity and 10-month physiological regulation. The model for the mildly frustrating toy-removal task fit well, χ^2 (9, N = 224) = 2.67, p = .97, CFI = 1.00, RMSEA = .00 [CI = .00, .00]. However, maternal sensitivity at 10 months did not predict vagal withdrawal at 10 months (β = .04, p = .56) or EEG activation at 10 months (β = .00, p = .99) (see Figure 5). Similarly, the model for the moderately frustrating toy-removal task fit well, χ^2 (9, N = 224) = 4.74, p = .85, CFI = 1.00, RMSEA = .00 [CI = .00, .04] but maternal sensitivity at 10 months did not predict vagal withdrawal at 10 months (β = .14, p = .12) or EEG activation at 10 months (β = -.04, p = .70).

In sum, maternal sensitivity at 5 months was associated negatively with mother's reports of infant distress and showed a trend level positive association with observed mother orientation during the moderate frustration task. Similar to 5 months, 10-month maternal sensitivity showed a marginal negative association mother reported distress and a significant negative association with infant observed distraction during moderate frustration.

Does maternal sensitivity at 5 months influence developmental changes in infants' physiological regulation during frustration from 5 months to 10 months?

Although maternal sensitivity did not predict concurrent vagal withdrawal or EEG activation at 5 or 10 months, it was hypothesized that maternal sensitivity may predict developmental changes in these physiological systems from 5 months to 10 months. Path analyses were conducted examining the association between maternal sensitivity at 5 months and vagal withdrawal and EEG activation at 10 months. In order to assess change in these physiological indices of regulation from 5 months to 10 months, vagal withdrawal and EEG activation at 5 months were entered as covariates.

Maternal sensitivity and vagal withdrawal. It was hypothesized that maternal sensitivity at 5 months would be associated positively with infant vagal withdrawal at 10 months after controlling for prior vagal withdrawal at 5 months. The model for the mildly frustrating toy-removal task fit well, χ^2 (15, *N* = 226) = 20.62, *p* = .15, CFI = .97, RMSEA = .04 [CI = .00, .08]. However, maternal sensitivity did not predict the change in vagal withdrawal in the toy-removal task from 5 months to 10 months (β = -.03, *p* = .64) (see Figure 5). The model for the moderately frustrating arm-restraint task also fit the data moderately well, χ^2 (15, N = 219) = 24.8, p = .06, CFI = .90, RMSEA = .05 [CI = .00, .09]. In contrast to the toy-removal task, maternal sensitivity at 5 months did predict increases in vagal withdrawal from 5 months to 10 months (β = .18, p = .03) during the moderately frustrating arm-restraint task (see Figure 5).

Maternal sensitivity and EEG activation. Although exploratory, maternal sensitivity at 5 months was predicted to be positively associated with changes in EEG activation (a shift toward right frontal) during frustration at 10 months after controlling for prior EEG activation at 5 months. The model for the mildly frustrating toy-removal task fit well, χ^2 (15, N = 218) = 9.3, p = .86, CFI = 1.00, RMSEA = .00 [CI = .00, .00]. However, maternal sensitivity did not predict the change in EEG activation in the toy-removal task from 5 months to 10 months (β = -.02, p = .55) (see Figure 6). Similarly, model fit was good for the moderately frustrating arm-restraint task, χ^2 (15, N = 211) = 16.99, p = .31, CFI = .95, RMSEA = .03 [CI = .00, .07], but maternal sensitivity did not predict changes in EEG activation in the arm-restraint task from 5 months to 10 months (β = .00, p = .97) (see Figure6).

In sum, maternal sensitivity did predict changes in vagal withdrawal from 5 months to 10 months in the moderately frustrating arm-restraint task but was not associated with changes in vagal withdrawal from 5 months to 10 months in the mildly frustrating toy-removal task. Unexpectedly, maternal sensitivity was not associated with changes in EEG shift from 5 months to 10 months in the mildly frustrating toy-removal task or the moderately frustrating arm-restraint task.

Does maternal sensitivity at 5 months influence the change in infants' observed and reported behavioral regulation to frustration from 5 months to 10 months?

It was hypothesized that maternal sensitivity at 5 months would be associated positively with increases in infants' use of emotion regulation strategies from 5 to 10 months and mother reported falling reactivity from 5 to 10 months. It was also hypothesized that maternal sensitivity at 5 months would be associated negatively with increases in infants' reported distress. Path analyses were conducted examining the association between maternal sensitivity at 5 months and infants' observed and reported behavioral regulation at 10 months. In order to examine change in these behavioral indices of regulation from 5 months to 10 months, observed and reported regulation behaviors at 5 months were entered as covariates.

The model examining the association between maternal sensitivity at 5 months and the change in regulation behaviors during the mildly frustrating toy-removal task fit the data well, , χ^2 (40, N = 273) = 39.17, p = .51, CFI = 1.00, RMSEA = .00 [CI = .00, .04]. However, maternal sensitivity at 5 months was not associated with changes in observed distraction (β = -.00, p = .90), observed mother orientation (β = -.01, p = .80), or observed self-comforting (β = -.00, p = .81) during toy-removal.

The model examining the association between maternal sensitivity at 5 months and the change in regulation behaviors during the moderately frustrating arm-restraint task did not fit the data well , χ^2 (27, N = 270) = 45.06, p = .01, CFI = .60, RMSEA = .05 [CI = .00, .07]. Thus, path analyses should be interpreted with caution. Similar to the toy-removal task, maternal sensitivity at 5 months was not associated with changes in observed distraction (*β* = -.15, *p* = .07) or observed mother orientation (*β* = .08, *p* = .33) during arm-restraint. Maternal sensitivity was also not associated with changes in reported regulation (*β* = .02, *p* = .82). In sum, maternal sensitivity was not directly associated with the change in observed or reported regulatory behaviors from 5 months to 10 months during the mildly frustrating toy-removal task or the moderately frustrating arm-restraint task.

Is maternal sensitivity at 5 months an indirect predictor of behavioral regulation at 10 months via children's physiological regulation at 10 months?

Although maternal sensitivity is only directly related to observed distraction at 10 months during moderate frustration, maternal sensitivity may influence observed behavioral regulation through vagal withdrawal and EEG activation at 10 months. That is, maternal sensitivity at 5 months may influence how well infants physiologically regulate at 10 months, which then may influence the behavioral regulation strategies infants employ. In order for this indirect effect to be present, maternal sensitivity at 5 months needed to be associated positively with physiological regulation at 10 months, and physiological regulation at 10 months needed to be associated positively with observed behavioral regulation at 10 months.

Path analyses indicated that maternal sensitivity at 5-months was significantly associated with vagal withdrawal at 10-months during the moderately frustrating arm-restraint task (*β* = .18, *p* = .03). However, it was unrelated to vagal withdrawal (*β* = -.02, *p* = .67) and EEG activation (*β* =-.05, *p* = .43) during the mildly frustrating toy-removal task, and EEG activation (*β* = .00, *p* = .92) during the moderately frustrating arm-restraint task. Moreover, and as previously stated, vagal withdrawal at 10 months during moderate frustration was associated negatively with observed distraction (β = -.20, p = .04) and associated positively with observed mother orientation (β = .22, p = .03) (see Figure 3). Therefore, because maternal sensitivity was only associated with vagal withdrawal at 10 months during the arm-restraint task, and vagal withdrawal during the arm-restraint task was only associated with observed distraction and mother orientation, the only possible indirect effect was from maternal sensitivity at 5 months to 10-month observed distraction and mother orientation during arm-restraint.

Path analyses testing these indirect effects were run. The model fit the data well, χ^2 (12, N = 227) = 15.31, p = .22, CFI = .64, RMSEA = .03 [CI = .00, .08]. The direct effects described above remained such that maternal sensitivity at 5 months predicted vagal withdrawal at 10 months (β = .19, p = .03), and vagal withdrawal at 10 months predicated observed distraction (β = -.19, p = .05) and observed mother orientation (β = .22 p = .03). However, the indirect effects of maternal sensitivity at 5 months on observed distraction (β = -.03, p = .17) and mother orientation (β = .04, p = .12) at 10 months were not significant.

CHAPTER VI

DISCUSSION

Physiological Underpinnings of Infant Regulation Behavior.

Behavioral regulation in emotionally charged situations is a fundamental skill that has implications for multiple areas of development (Vohs & Baumeister, 2010). The ability to regulate is rooted in the biological maturation of physiological systems over time, and regulation continues to function at both a biological and behavioral level throughout life (Calkins & Fox, 2002). Researchers have primarily focused on a single physiological mechanism and its relation to regulatory strategies; however, when individuals encounter a situation that requires the regulation of affect, multiple biological processes underlying regulatory behavior function simultaneously, and take place across multiple physiological systems. It has been theorized that both central and parasympathetic nervous system processes are associated with differences in regulatory abilities (Thayer & Lane, 2009). To date, no study has investigated the way in which these processes relate to each other and behavioral regulation in the same child within the same context. Therefore, a primary goal of the current study was to better understand the connection between central and parasympathetic regulatory processes, as well as to identify the way in which these processes influence the regulation of behavior during mild and moderate frustration. It was hypothesized that higher levels of vagal withdrawal and greater shifts toward right frontal EEG asymmetry during frustration would be associated positively, and predict greater infant displays of emotion regulation strategies during frustration. In addition, it was hypothesized that both physiological processes would be associated positively with mother report of infant behavioral regulation at both 5 and 10 months.

Unexpectedly, infants’ EEG activation and vagal withdrawal at 5 months were not correlated in the mild or moderate frustration task, suggesting a lack of association between these two physiological processes. Scientists have suggested that brainstem reflexes of the autonomic nervous system do not become fully coordinated with cortical processes until around 6 months of age (Porges & Furman, 2011). Therefore, it was anticipated that 5 months may be a time when we begin to see the emergence of these associations, and subsequently similar patterns in parasympathetic and central nervous system regulation during heightened emotional arousal. However, the lack of association in the current study suggests that 5 months may be too early to begin to examine the complex relations between behavioral regulation and processes of the central and parasympathetic nervous system. Assessing these relations after 6 months may provide more insight into the coordination of these regulatory mechanisms.

Given the lack of association between vagal withdrawal and EEG activation at 5 months, it is not surprising that these processes were related to regulation behaviors differently. As predicted, vagal withdrawal at 5 months was associated with increased distraction behaviors during the moderately frustrating arm-restraint task, suggesting that infants who had greater vagal withdrawal were also more likely to distract their attention to other objects in the room and away from the source of their distress. Interestingly, 5-

month vagal withdrawal during the mildly frustrating task was associated with less distraction. A core component of vagal regulation (i.e., increased vagal withdrawal) is control of attentional processes. Therefore, during a frustration task, increased vagal withdrawal, and subsequently increased attentional control, should allow for an infant to adaptively redirect their attention to an object or behavior that effectively reduces arousal. However, in a task that is interesting as opposed to frustrating, increased vagal withdrawal may allow for greater attention to the object of interest. For example, Pizur-Barnekow, Kraemer, and Winters (2008), found that increased vagal withdrawal was greater in asynchronous slideshows of auditory and visual stimuli than during synchronous slideshows. The authors suggested that the increase in vagal withdrawal was likely due to the increased attention the infants pay to asynchronous events that defy their expectations. It may be that for many 5-month-old infants, the toy-removal task elicited more interest than frustration. Indeed, on a 5-point Likert scale, the mean of negative affect elicited in the toy-removal task at 5 months was 1.55, suggesting a somewhat low occurrence of responses high in negative affectivity. The task was designed such that after a brief period of engagement with a toy, the toy was removed and held beyond the infant’s reach. Young infants see size, color, and brightness, and pay closest attention to areas in their field of vision that are highest in information, such as objects that directly contrast with the rest of their environment (Feldman, 2007). Thus, it could be that because the task still allowed the infants to see the brightly colored and visually stimulating toy, infants who increased in vagal withdrawal attended more to the object and subsequently showed significantly less distraction behaviors.

As predicted, a shift toward right frontal EEG asymmetry at 5 months was associated positively with mothers' reports of infants' falling reactivity. This suggests that infants who increased in active right frontal processing from baseline to task were also likely to be reported as better able to recover from peak distress, excitement, or general arousal. However, this association was only evident during the mildly frustrating toy-removal task. The falling reactivity subscale is generally used as an index of an infants' ability to regulate his or her own general state. Therefore, it may be that EEG activation during the toy-removal task was more closely aligned with general day-to-day situations that infants' mothers reported on, rather than behaviors most commonly utilized for coping with more uniquely stressful situations.

EEG activation at 5 months was not related to observed regulatory behaviors during the mild or moderate frustration task. As previously stated, autonomic and cortical processes do not become coordinated until around 6 months of age (Porges and Furman, 2011), and unlike the development of the autonomic nervous system, neurobiological research indicates that the complex regulatory structures within the frontal cortex are formed postnatally and do not undergo major maturational changes until 10 to 12 months. Thus, it could be that EEG activation at 5 months is not related to specific regulatory behaviors because these processes are not yet mature or fully connected to more primal nervous system responses.

As hypothesized, vagal withdrawal and EEG activation were positively correlated during the moderately frustrating arm-restraint task at 10 months. Specifically, as infants increased in vagal withdrawal they also displayed a greater shift toward right frontal asymmetry and relative increases in right frontal processing. Greater vagal withdrawal has been theoretically and empirically associated with an increased ability to cope with negative or stressful situations. Similarly, although somewhat exploratory, a shift toward right frontal asymmetry has been hypothesized to allow for increased regulation of negative affect. This positive association suggests that by 10 months of age, cortical and autonomic processes are coordinated, and when infants encounter a frustrating situation that is at least moderate in intensity, regulatory processes from each system respond in similar ways. It is unclear why vagal withdrawal and EEG activation were not associated in the 10-month toy-removal task. It is possible that in mildly frustrating contexts, physiological regulation within the central and parasympathetic nervous system are not as synchronous.

Given that vagal withdrawal and EEG activation were positively correlated during the 10-month arm-restraint task, and are believed to serve similar functions, it is not surprising that they are also related to observed regulatory behaviors during moderate frustration in similar ways. Because distraction and mother orientation behaviors are thought to be adaptive strategies used to reduce distress, it was hypothesized that both would be positively associated with EEG activation and vagal withdrawal. However, during moderate frustration, vagal withdrawal and EEG activation were associated negatively with distraction behaviors and associated positively with infants’ mother orientation behaviors. That is, as vagal withdrawal and shifts toward right frontal asymmetry increased, infants displayed less distraction behaviors and more mother orientation. It is likely that infants utilize their mother in a co-regulatory way when experiencing a more emotionally challenging context than they encounter on a daily basis. Infancy is a developmental time period during which infants' self-regulatory abilities are built from within the caregiver-infant dyad (Propper & Moore, 2006). Over time, infants begin to trust that their caregiver will assist them if they fail to reduce their own distress; in turn, this trust serves as a safety net that eventually allows infants to explore new situations, and their own abilities, more freely (Sroufe, 1996). From this perspective, it is highly adaptive for 10 month-old infants to make bids to their mother for assistance in reducing moderately intense negative arousal, rather than attempting to employ an independent self-regulatory strategy such as distraction. It is interesting this same pattern did not emerge during the arm-restraint task at 5 months. It is possible that 5 month-old infants have not experienced many emotionally distressing situations outside the caregiver-infant dyad and therefore have not yet fully realized the caregiver's utility for reducing arousal.

Contrary to hypotheses, 10-month vagal withdrawal during mild frustration was not associated with any observed regulatory behaviors, and EEG activation was only associated with increased distraction. Given that by 10 months these physiological systems are believed to be somewhat coordinated, it is unclear why these physiological processes would be associated to behavior similarly during moderate but not mild frustration. Because the autonomic nervous system is associated with primal fight and flight responses to negative arousal, and vagal withdrawal is an index of regulation within the autonomic nervous system, it is possible that the mild frustration task did not elicit enough distress for this association to emerge. However, EEG activation at 10 months was associated with increased distraction behaviors in the hypothesized way; greater shifts toward right frontal EEG asymmetry were associated with more observed distraction behaviors. This positive association is in direct contrast with the negative association found between physiological regulation and distraction in the moderate frustration task. Thus, it is possible that 10-month-old infants feel as though they can handle their own arousal during mild frustration by employing self-regulatory distraction behaviors, and do not need to elicit caregiver assistance. Finally, vagal withdrawal and EEG activation during the mild or moderate frustration task was not associated with maternal report of infants' regulatory behavior. One reason for this unexpected finding could be that physiological regulation during these uniquely stressful situations does not accurately reflect the way in which infants handle general arousal during their day-to-day lives. Thus, a better indicator may be physiological regulation during every-day caregiving tasks.

Maternal Sensitivity and Physiological and Behavioral Regulation.

Processes of emotion regulation that function at the biological and behavioral level are thought to develop within the parent-child dyad (Gunnar, 2000). Caregivers play a crucial role in helping children develop and manage their physiological state, and teach children appropriate strategies for the regulation of heightened emotion (Sroufe,1996). However, only a small body of research has examined the relations between parenting and both physiological and behavioral regulation. Moreover, the work examining the relation between parenting and physiological regulation has focused primarily on aspects of the parasympathetic nervous system. Finally, little work has examined the way in which parenting influences developmental changes in behavioral and physiological regulation across early infancy; a developmental time period of rapid biological maturation. Thus, the second primary goal of the current study was to improve our understanding of the way in which maternal sensitivity influences multiple aspects of infants' physiological and behavioral regulation of emotion during mild and moderate frustration. Specifically, the study addressed whether maternal sensitivity at 5 and 10 months influenced infants' concurrent behavioral and physiological regulation. In addition, the study also examined whether maternal sensitivity at 5 months influenced developmental changes in infants' physiological and behavioral regulation during frustration from 5 months to 10 months. It was hypothesized that maternal sensitivity would be associated positively with both indices of physiological regulation (i.e., vagal withdrawal and EEG activation) and infants' reported and observed regulatory behaviors, and associated negatively with mother's reports of infant distress. It was also hypothesized that maternal sensitivity at 5 months would be associated with increases in infants' physiological and behavioral regulation from 5 to 10 months.

As predicted, observed maternal sensitivity at 5 months was negatively associated with mother reported distress, suggesting that infants of more sensitive mothers were reported to be less distressed during caregiving tasks and in response to blocked goals. This same pattern appeared at 10 months, although it was marginal in nature. Contrary to hypotheses, maternal sensitivity at 5 and 10 months did not predict observed regulatory behaviors during the mildly frustrating toy-removal task. It is thought that sensitive interactions with caregivers during heightened emotional arousal teach children that the use of particular strategies is useful in reducing arousal; thus making it unclear why maternal sensitivity didn’t predict these behaviors during mild frustration. Caregiving facilitates the development of children’s regulatory abilities; it is not solely responsible. Thus, regardless of maternal sensitivity, all children develop and employ some regulatory abilities that they use to reduce arousal. It is possible that because most children show some degree of competency at managing arousal, maternal sensitivity is less influential to infants’ regulatory abilities during mild frustration than it is to infants’ abilities during moderate frustration. That is, most infants may be able to cope with mild frustration, but infants with sensitive mothers may be more likely to utilize effective regulatory strategies in contexts that are more emotionally challenging.

Indeed, maternal sensitivity showed a marginal positive association with infant mother orientation at 5 months, and a negative association with observed distraction at 10 months, during the moderately frustrating arm-restraint task. Although it was hypothesized that maternal sensitivity would be positively instead of negatively associated with observed distraction, it may be less appropriate for 10 month-old infants to employ self-regulatory strategies such as distraction, and more appropriate to display co-regulatory strategies such as mother orientation behaviors, during a situation that elicits high negative arousal. It is possible that less sensitive mothers have children who utilize more distraction behaviors because they do not have a history of their mother effectively aiding them in reduction of arousal.

Unexpectedly, 5-month maternal sensitivity did not predict an increase in the use of self-regulatory strategies from 5 to 10 months in the mild or moderate frustration task.

It is theorized that repeated interactions with caregivers over time teach these regulatory behaviors. Thus, the time span from 0 to 5 months may not have been long enough, or provided enough opportunities, for mothers to consistently teach these strategies in a way that facilitates their development; thus, highlighting concurrent maternal sensitivity as a better predictor of regulation behaviors during early infancy.

Maternal sensitivity at 5 months did predict the change in infants' vagal withdrawal during moderate frustration from 5 to 10 months as hypothesized. This finding supports the myelination hypothesis presented by Porges and Furman (2011). Early infancy is a developmental time period during which there is a rapid biological maturation of the vagus system (Sachis, Armstrong, Becker, & Bryan, 1982). Thus, maternal sensitivity at 5 months may help the infant manage physiological arousal in a way that facilitates greater myelination of vagal fibers and subsequently greater vagal regulation from 5 to 10 months. In contrast, maternal sensitivity did not predict the change in vagal withdrawal from 5 months to 10 months during the mildly frustrating toy-removal task. This finding may be similar to the relation between maternal sensitivity and observed behavioral regulation such that maternal sensitivity may be more influential to infants' ability to vagally withdrawal during frustrating contexts that tax the infant's physiological resources to a greater extent.

Interestingly, maternal sensitivity at 5 months was not associated with the change in EEG activation from 5 months to 10 months in the mild or moderate frustration task. Maturation of the prefrontal cortex begins substantially later relative to the vagal system. Moreover, the time period of rapid maturation extends well into the second year, much later than that of vagal maturation (Schore, 1996; Porges and Furman, 2011). Therefore, assessing maternal sensitivity at 5 months may be too early to examine its influence on the developing frontal lobes. Although maternal sensitivity is stable throughout infancy, it was only moderately stable in current sample. Therefore, maternal sensitivity at 10 months may be a better predictor of change in EEG activation throughout the first and second year.

Indirect Effect of Maternal Sensitivity.

Given that maternal sensitivity has been theoretically and empirically related to physiological regulation of the parasympathetic and central nervous system, and to infant regulation behaviors, it was hypothesized that physiological regulation may be a mechanism through which maternal sensitivity influenced observed regulation behaviors. Specifically, maternal sensitivity at 5 months was hypothesized to be directly associated with behavioral regulation at 10 months, as well as indirectly associated with behavioral regulation at 10 months via infants' 10- month physiological regulation.

Unexpectedly, this hypothesis was not supported. In the current study, maternal sensitivity and observed regulation were not strongly related; thus, the weak association made testing indirect effects difficult. Maternal sensitivity was only associated with observed distraction during the moderately frustrating arm-restraint task at 10 months and marginally associated with observed mother orientation during arm-restraint at 5 months. Although researchers have linked maternal sensitivity with observed regulatory behavior, the majority of empirical work has found this association with infants much older than 10 months (Morales, Mundy, Crowson, Neal, & Delgado, 2005; Glöggler & Pauli-Pott, 2008). Repeated and consistent interactions with caregivers during times of distress are thought to aid infants in learning how to behaviorally regulate in a way that allows them to associate specific strategies the caregiver helps them to employ with reduced arousal. Infants at 10 months of age may just be beginning to make these paired associations. Thus, it is possible that assessing infant regulatory behaviors later in infancy would provide greater insight into whether physiological regulation is mechanism though which sensitivity relates to infant behavior.

Effects of Mild and Moderate Frustration.

Because a frustration task of moderate intensity may elicit stronger physiological and behavioral regulatory responses, the current study examined whether the associations between physiological regulation and behavioral regulation, as well as between maternal sensitivity and the development of physiological and behavioral regulation, varied depending on whether the frustration task was mild or moderate in intensity. It was hypothesized that associations between primary study constructs would be stronger when analyzed in the moderately frustrating context and weaker when analyzed in the mildly frustrating context.

Generally, the current study supported the hypothesis that the proposed relations between physiology and behavior, sensitivity and behavior, and sensitivity and physiology, would be stronger in the moderately frustrating arm-restraint task. Physiological and behavioral regulation enable children to cope with increasingly stressful and emotionally charged situations. The vagal system in particular is evolutionarily adapted to respond to environmental contexts that threaten safety and survival. The integral balance between the parasympathetic and sympathetic branches of the autonomic nervous system allow for variation in physiological response to a variety of contexts. It would be maladaptive and developmentally inappropriate for infants to have the same physiological response, or utilize the same amount of behavioral resources, for all degrees of frustration. Further, because most infants are capable of regulating in some way or another to everyday contexts, it is not surprising that maternal sensitivity is more strongly related to infants' behavioral and physiological regulation during particularly stressful or emotionally challenging situations. That is, more sensitive mothers may facilitate the development of more sophisticated physiological systems, and teach adaptive, effective, and specific regulatory techniques that equip children to better regulate in highly emotionally charged contexts.

Strengths, Limitations, and Future Directions.

The current study had a number of noteworthy strengths. First, rather than assessing one physiological system hypothesized to be important for behavioral regulation, two physiological mechanisms were examined. Assessing two aspects of physiological regulation in the same infants allowed for a deeper understanding of the way in which these indices of physiological regulation relate to behavior and to one another. In addition, assessing the association between maternal sensitivity and the development of physiological regulation across early infancy allowed for this relation to be examined during a developmental time period characterized by rapid biological maturation and emerging self-regulatory skills. Moreover, the majority of studies assess infants in one context designed to elicit frustration. However, there are varying degrees and intensities of emotion that are likely to impact the physiological response evoked and the regulation strategies employed. Thus, the current study incorporated both a mild and moderate frustration task to begin to better understand differences in children's physiological and behavioral regulation during varying degrees of negative arousal.

Although there are considerable strengths, the study is not without limitations. First, many of the infants who participated in the mildly frustrating toy-removal task did not participate in the moderately frustrating arm-restraint task, making the participants of the arm-restraint task a subsample of the original sample. The infants who did participate in the moderately frustrating arm-restraint task were reported to be better regulated at 5 months and show less negative affect at 10 months. Therefore, there was less data available for the children who were most aroused. Although incorporating both sub-samples allowed the current study to begin to untangle important differences in infants' regulation, and the way in which maternal sensitivity influences infants' regulatory abilities, the nature of the subsample should be kept in mind when interpreting the results. Future research should replicate these findings using a full normative sample to support the current study's findings.

Second, the current study focused on the regulation of frustration. Infants may show different behavioral and physiological responses to other emotionally charged contexts such as fear or excitement. For example, significant relations between maternal sensitivity and self-comforting behaviors during frustration were not found in the current study; however, Gloggler and Pauli-Pott (2008) examined behavioral regulation of fear at 12 and 30 months and found low depression and high sensitivity to predict increased selfsoothing when compared to distraction or orienting behaviors. Thus, future research should attempt to gain a better understanding of the relations addressed in the current study during other emotion eliciting contexts.

A third limitation is that an additional time point in later infancy was not available. As previously stated, toddlerhood is a time during which infants are more autonomous and encounter situations that have greater opportunities for practicing self-regulatory strategies (Calkins, 1997). Similarly, birth to 3 years is a developmental time period during which there is increased maturation of both the parasympathetic and central nervous system. Specifically, the vagal system is thought to undergo rapid biological maturation during the first year of life (Sachis, Armstrong, Becker, & Bryan, 1982), and complex regulatory structures within the frontal cortex are thought to undergo major maturational changes well into toddlerhood (Schore, 1996). However, there was not strong support for mean level increases in vagal withdrawal and EEG activation from 5 months to 10 months. There was individual variation in infants' scores over time, but the time period from 5 to 10 months did not capture average developmental change. Assessing infants' physiological and behavioral regulation at 24 months may have provided important additional insight.

Although the conceptual models presented in the current study suggest that the relation between physiological regulation and behavioral regulation is unidirectional, it is possible that this relation can be better described as transactional. That is, physiological regulation may facilitate specific behavioral regulatory strategies and these regulatory strategies may get internalized in a way that further facilitates the development of physiological systems. Therefore, the study is limited in that it cannot test this transactional relation with only two time points. Future research using multiple measures of physiological and behavioral regulation across many time points would better assess the possibility of a transactional relation.

Finally, the measure of maternal sensitivity used in the current study was a compressed score of general sensitivity and mothers in the current sample scored above average. Therefore, the study is limited in that it cannot speak to the influence of specific sensitive behaviors that may be related to infant's behavioral and physiological regulatory capabilities, nor can it address the effects of insensitivity. It is possible that insensitive or intrusive behavior would be more strongly related to behavioral and physiological regulation. Future research should examine these associations in more at-risk samples with greater variation in caregiving behavior. In addition, conducting research that disentangles the measure of maternal sensitivity into a continuum of specific caregiving behaviors would provide valuable insight into the specific process mechanisms that underlie the relation between sensitive caregiving and infant regulation.

In addition to the future research directions previously mentioned, there are four primary goals for subsequent studies. The first is to examine observed sensitivity during frustration. Although the current study observed sensitivity during play, what has been suggested as particularly salient for the development of regulation is the way in which parents behave when their infants experience negative emotion or distress (Bowlby 1969). It is easier for parents to behave sensitively during a positive or neutral situation than when a child displays negative affect, particularly because children's distress often elicits negative parental emotions (Dix, 1991). That is, engaging in sensitive behaviors such as correctly interpreting infants' cues, and seeing the infants' point of view, becomes increasingly more difficult when parents are attempting to regulate their own emotions. Indeed, research has supported that differential effects of maternal sensitivity to distress and non-distress are associated with children's emotional development (Leerkes, Blankson, & O'Brien, 2009). Second, although fathering has been found to have unique effects on children's development (Hazen, McFarland, Jacobvitz, & Boyd-Soisson, 2010), little work has examined the role of paternal sensitivity for infants' regulation. Thus, future research should examine sensitivity of fathers and how it relates to the development of infants' physiological and behavioral regulation over time. Third, additional research is needed to explore whether there is a hierarchy among physiological regulatory processes. Given that the vagal system is thought to undergo rapid biological maturation earlier than the prefrontal cortex, and that vagal withdrawal was the only measure that related to observed behavior at 5 months, it is possible that vagal functioning is more primitive and has implications for the development of the prefrontal cortex. Finally, future research should begin to explore the way in which additional physiological systems are associated with behavioral regulation and regulatory processes of the parasympathetic and central nervous system. For example, vagal withdrawal measures the withdrawal of parasympathetic influence on the heart; incorporating a measure of central sympathetic influence such as preejection period, may further our understanding of the way in which multiple physiological systems respond to emotionally charged contexts, in addition to understanding how they relate to one another and regulatory behavior.

Overall, this study provides an interesting look at how physiological regulatory processes of the parasympathetic and central nervous system are related to maternal sensitivity and behavior, and has multiple implications for our understanding of emotion regulation and research conducted in this area. The observed relation between vagal withdrawal and EEG activation suggests scientists look further at understanding the way in which these processes are related to the regulation of behavior, and how they are coordinated during negative emotional arousal. Prior work has only acknowledged that multiple physiological systems underlie regulatory behavior; however, the current study illustrates that understanding the coordination of physiological systems within the biological level provides a more comprehensive understanding of the regulation of emotion at the behavioral level. Moreover, the findings of the current study suggest that emotion regulation research should not only assess children in contexts that elicit different emotions, but the intensity of the emotion experienced should also be considered. Finally, the current study highlights the importance of the caregiving environment for the development of behavioral and biological regulation; thus underscoring the need to assess both intrinsic and extrinsic child factors when attempting to understand individual differences in the development of emotion regulation across childhood (Fox and Calkins, 2003).

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APPENDIX A

TABLES AND FIGURES

Table 2. Descriptive Information for Study Variables

	M	SD	Range	N	Skewness
Maternal Sensitivity 5 and 10-months					
Maternal Sensitivity Composite 5 mo	3.57	.40	1.38-4.00	262	-1.47
Maternal Sensitivity Composite 10 mo	3.62	.34	2.00-4.00	247	-1.53
Physiological Regulation 5 and 10-months					
EEG activation during toy-removal 5 mo	.03	.22	-.81-1.54	231	1.25
EEG activation during toy-removal 10 mo	.00	.19	-.55-.76	211	.47
Vagal withdrawal during toy-removal 5 mo	-.34	1.42	-6.05-4.61	236	-.27
Vagal withdrawal during toy-removal 10 mo	-.10	1.30	-5.23-5.03	216	.06
EEG activation during arm-restraint 5 mo	.00	.31	-1.06-1.26	134	.05
EEG activation during arm-restraint 10 mo	.00	.21	-.75-.53	104	-.63
Vagal withdrawal during arm-restraint 5 mo	-.47	1.43	-6.42-2.08	135	-1.30
Vagal withdrawal during arm-restraint 10 mo	.01	1.44	-3.70-3.97	95	.10
Baseline RSA 5 mo	4.05	1.30	1.06-11.11	267	1.63
Baseline RSA 10mo	4.72	1.16	.99-8.87	244	.48
Baseline asymmetry 5mo	.03	.33	-1.22-1.18	263	-.14
Baseline asymmetry 10mo	.05	.34	-1.24-1.26	239	.30
Behavioral Emotion Regulation 5 and 10-months					
Mother orientation during toy-removal 5 mo	.39	.27	.00-1.00	258	.48
Distraction during toy-removal 5 mo	.39	.31	.00-1.00	258	.25
Self-comforting during toy-removal 5 mo	.21	.28	.00-1.00	258	1.32
Mother orientation during toy-removal 10mo	.46	.25	.00-1.00	244	.38
Distraction during toy-removal 10 mo	.56	.27	.00-1.00	244	-.45
Self-comforting during toy-removal 10 mo	.12	.21	.00-1.00	244	2.05
Mother orientation during arm-restraint 5 mo	.41	.33	.00-1.00	163	.41
Distraction during arm-restraint 5 mo	.51	.37	.00-1.00	163	-.10
Mother orientation during arm-restraint 10 mo	.53	.33	.00-1.00	168	-.08
Distraction during arm-restraint 10 mo	.41	.33	.00-1.00	168	.26
Reported Emotion Regulation 5 and 10-months					
Falling Reactivity 5 mo	5.09	.89	1.31-6.88	274	-.42
Falling Reactivity 10 mo	5.06	.83	1.77-7.00	250	-.58
Distress to Limitations 5 mo	3.47	.85	1.44-5.94	274	.24
Distress to Limitations 10 mo	4.16.	.82	2.00-6.00	250	-.08

Table 3. Correlations among Variables Included in Models Examining the Mildly Frustrating Toy-removal Task

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Maternal Sensitivity 5m	.39**	.01	-.09	.07	.03	-.08	-.01	.08	-.03	-.01	-.02	-.01	.05	-.15*	-.02
2. Maternal Sensitivity 10m		.05	.02	-.04	.06	.02	-.01	.02	.05	.01	.01	.02	.06	-.08	-.13*
3. EEG activation toy 5m			-.01	-.06	.05	-.05	.08	.07	-.08	-.01	-.01	.18**	.11	-.11	-.12
4. EEG activation toy 10m				.03	.07	-.07	.13	.12	.11	-.01	-.06	.01	.02	.06	.03
5. Vagal withdrawal toy 5m					.05	-.13*	-.03	.01	-.02	.01	-.01	-.08	-.12	.09	.04
6. Vagal withdrawal toy 10m						-.04	-.05	.11	.03	-.13	.01	-.02	.02	-.12	.02
7. Distraction toy 5m							-.02	-.17**	-.02	-.08	-.03	.04	.08	-.03	-.04
8. Distraction toy 10m								.00	-.23**	.05	-.03	.06	.03	.01	-.06
9. Mother orientation toy 5m									.01	.01	-.03	-.03	-.01	.02	.07
10. Mother orientation toy 10m										.10	-.07	-.06	-.06	-.01	.00
11. Self-comforting toy 5m											.01	.05	.11	.05	-.11
12. Self-comforting toy 10m												.06	-.05	-.01	.03
13. Falling Reactivity 5m													.09	-.13*	-.11
14. Falling Reactivity 10m														-.40**	-.40**
15. Distress to Limitations 5m															.49**
16. Distress to Limitations 10m															

Table 4. Correlations among Variables Included in Models Examining the Moderately Frustrating Arm-restraint Task

	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Maternal Sensitivity 5m	.39**	.14	-.02	.11	.17	.01	-.14	.14	.08	-.01	.05	-.15*	-.02
2. Maternal Sensitivity 10m		.19*	-.03	.02	.10	.06	-.16*	.00	-.06	.02	.06	-.08	-.13*
3. EEG activation arm 5m			.-.02	-.05	-.02	-.05	-.12	.11	-.07	.01	.01	-.14	-.19
4. EEG activation arm 10m				.10	.28*	-.01	-.12	.04	.25*	.01	.10	-.04	.00
5. Vagal withdrawal arm 5m					.28*	.17	-.05	-.16	.05	.00	-.06	.07	.11
6. Vagal withdrawal arm 10m						-.03	-.22*	.11	.22*	-.18	-.03	.02	.18
7. Distraction arm 5m							.13	-.15	.32**	.10	.02	.03	-.08
8. Distraction arm 10m								-.16	-.13	.24**	.18*	-.09	-.11
9. Mother orientation arm 5m									-.01	.02	.06	-.02	.03
10. Mother orientation arm 10m										-.14	-.13	.06	.02
11. Falling Reactivity 5m											.09	-.13*	-.11
12. Falling Reactivity 10m												-.40**	-.40**
13. Distress to Limitations 5m													.49**
14. Distress to Limitations 10m													

Figure 2. Model Illustrating Associations between Physiological Regulation and Behavioral Regulation at 5 Months during the Mild and Moderate Frustration Tasks

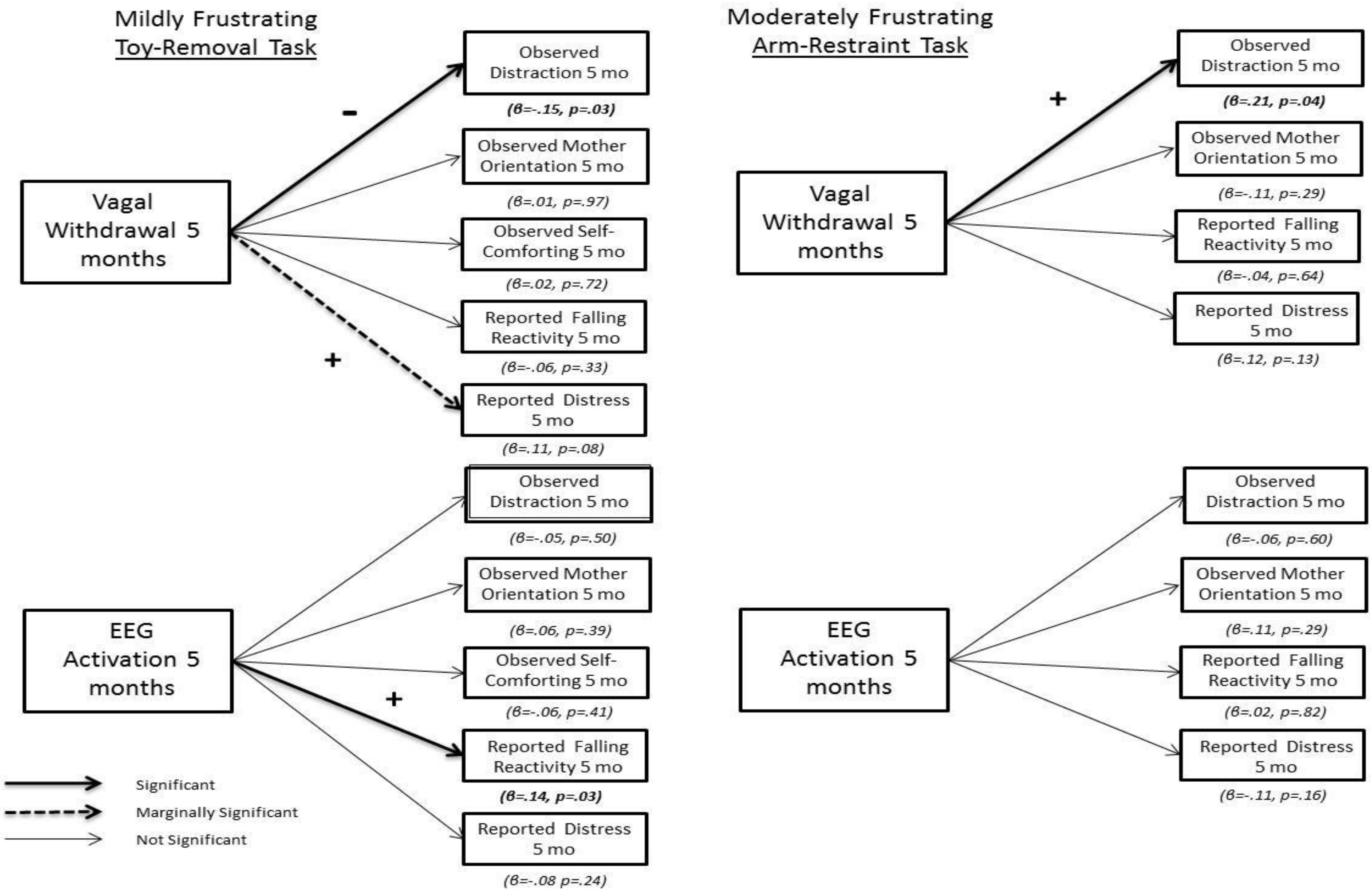

Figure 3. Model Illustrating Associations between Physiological Regulation and Behavioral Regulation at 10 Months during the Mild and Moderate Frustration Tasks.

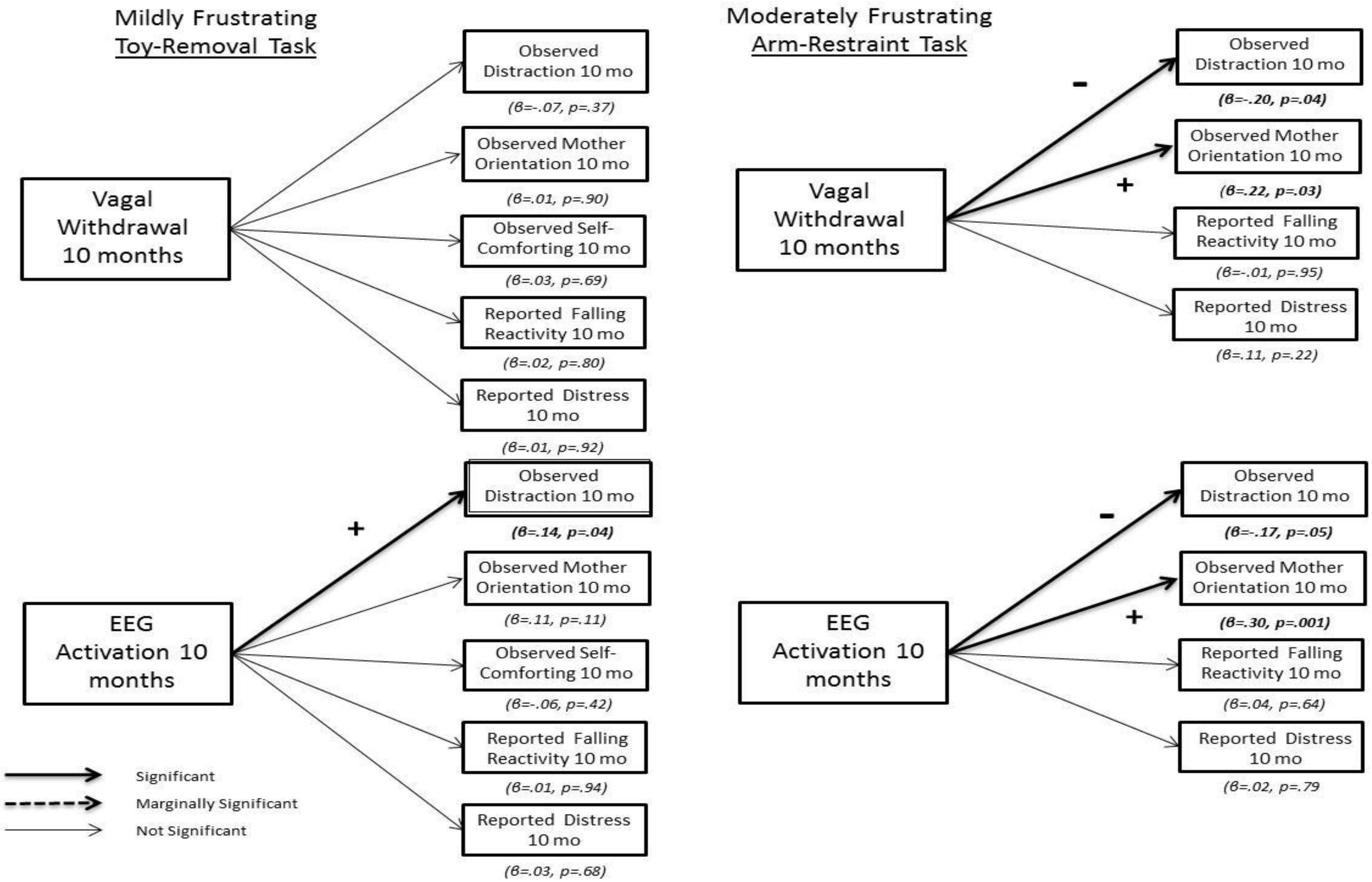

Figure 4. Model Illustrating Associations between Maternal Sensitivity and Behavioral Regulation at 5 and 10 Months during the Mild and Moderate Frustration Tasks

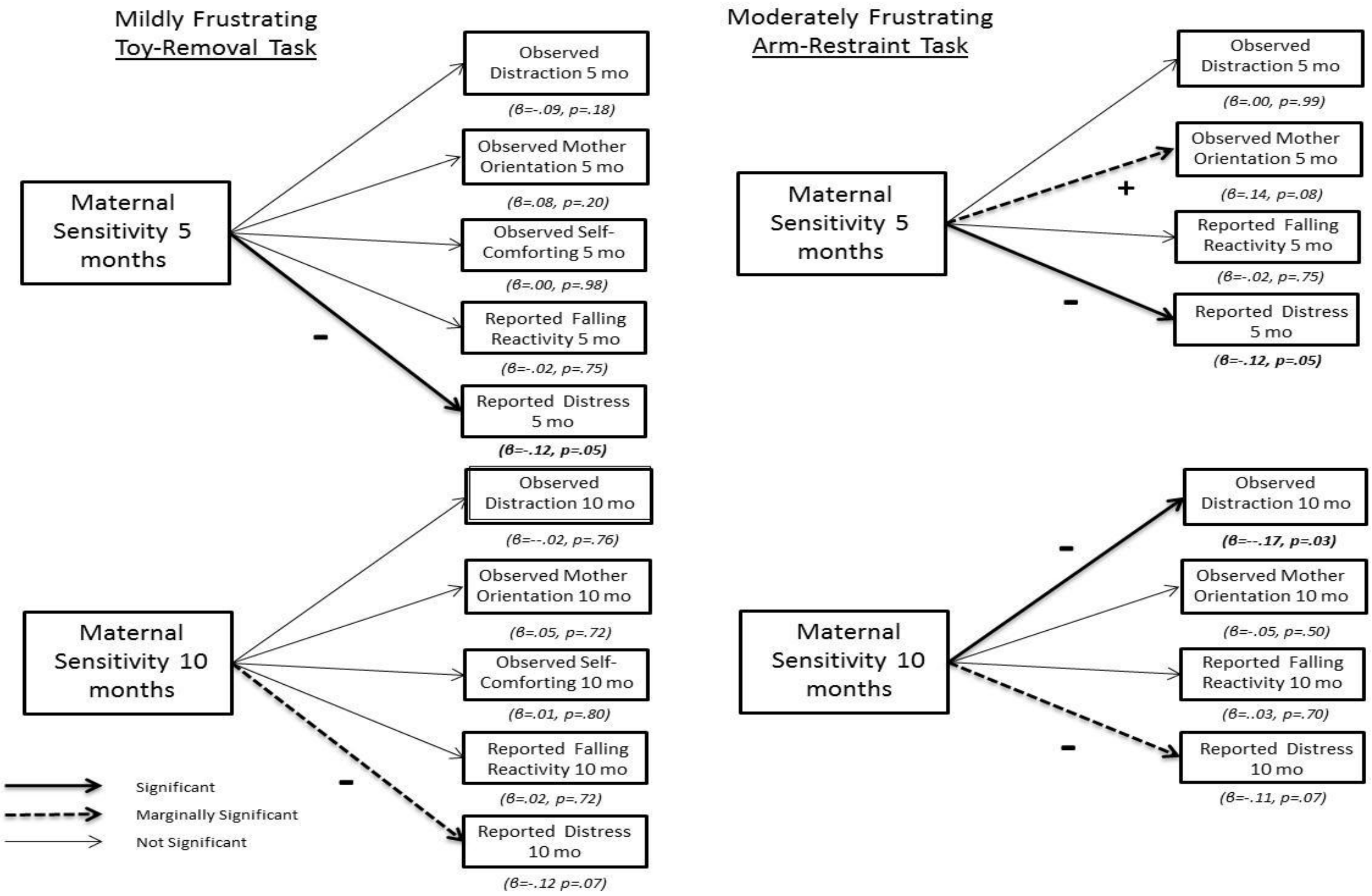

Figure 5. Model Illustrating Associations between Maternal Sensitivity and the Change in Vagal Withdrawal from 5 Months to 10 Months during the Mild and Moderate Frustration Tasks

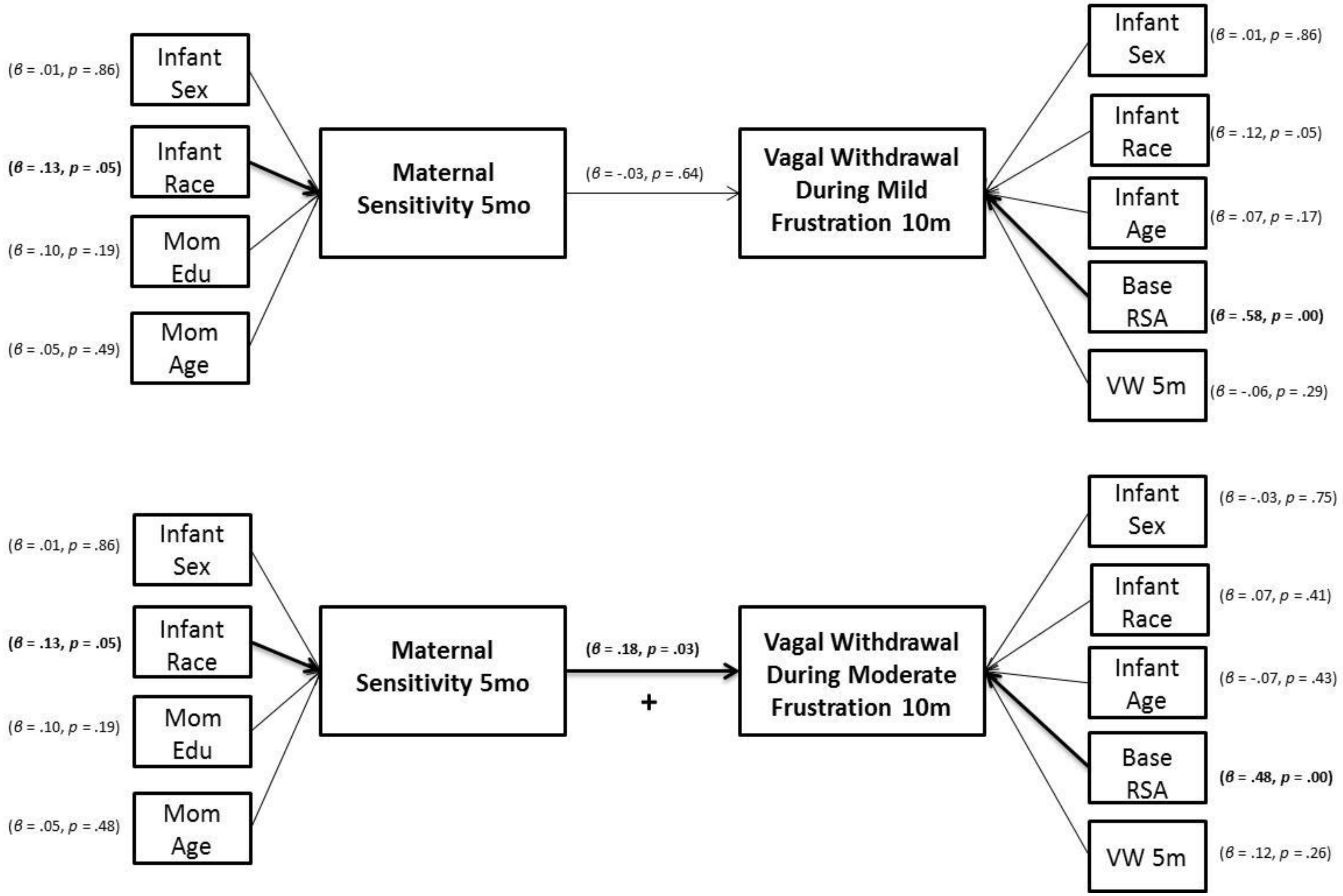

Figure 6. Model Illustrating Associations between Maternal Sensitivity and the Change in EEG Activation from 5 Months to 10 Months during the Mild and Moderate Frustration Tasks