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A Transactional Analysis of the Relation between Maternal Sensitivity and Child Vagal Regulation

Nicole B. Perry¹, Jennifer S. Mackler², Susan D. Calkins^{1,2}, and Susan P. Keane²

Jennifer S. Mackler: jsmackle@uncg.edu; Susan D. Calkins: sdcalkin@uncg.edu; Susan P. Keane: spkeane@uncg.edu

¹Department of Human Development and Family Studies, University of North Carolina at Greensboro

²Department of Psychology, University of North Carolina at Greensboro

Abstract

A transactional model examining the longitudinal association between vagal regulation (as indexed by vagal withdrawal) and maternal sensitivity from age 2.5 to age 5.5 was assessed. The sample included 356 children (171 male, 185 female) and their mothers who participated in the 2.5, 4.5, and 5.5 year laboratory visits. Cardiac vagal tone was obtained during a baseline task and during emotional frustration tasks. Maternal sensitivity was assessed via direct observation during a pretend play and cleanup task. To test for transactional associations, a path model estimating stability paths for vagal withdrawal and maternal sensitivity was compared to a full reciprocal model that included all cross-lagged pathways. A chi-square difference test was used to evaluate if the cross-lagged model explained the data above and beyond the stability model. The vagal withdrawal cross-lagged model was found to fit significantly better than the stability model and revealed that maternal sensitivity at 2.5 years was associated positively with vagal withdrawal at 4.5 years, and vagal withdrawal at 4.5 years was associated positively with maternal sensitivity at 5.5 years. These results suggest that early sensitive responding by mothers was associated with increases in vagal withdrawal, which in turn was associated with higher levels of sensitive parenting.

Keywords

early childhood; maternal sensitivity; parenting; physiological regulation; RSA; self-regulation; vagal tone; vagal withdrawal

The ability to appropriately self-regulate is thought to lay the foundation for healthy social and emotional functioning throughout life (Vohs & Baumeister, 2010). Therefore, understanding self-regulation has been posited as the most crucial goal for advancing the understanding of development and maladjustment (Charles & Carstensen, 2007; Posner & Rothbart, 2000). Researchers have identified self-regulation as an aspect of temperament that is comprised of processes that are hierarchically organized, function at both the behavioral and biological level, and enable individuals to modulate arousal, attention,

emotion, behavior, and cognition in adaptive ways (Calkins, 2011; Vohs & Baumeister, 2010). Self-regulatory processes are thought to build from the basic biological regulation of infancy and early childhood to more intentional regulation of behavior, emotion, and cognition of middle childhood and adolescence (Beauregard, Levesque, & Paquette, 2004; Calkins 2011). Given the biological underpinnings of advanced self-regulation, assessing individual differences in the development of early psychophysiological regulation is an important first step for the understanding of the development and deployment of subsequent regulatory processes throughout childhood.

Recently, researchers have extended the definition of temperament and now refer to differences in individuals' activity, affect, and self-regulation as a product of complex interactions among genetic, biological and environmental factors across time (Shiner et al., 2012). One of the most influential environmental contexts in infants' first years of life is the caregiving environment, and there is some support for a bi-directional association between children's physiological self-regulation and sensitive caregiving behaviors. Specifically, sensitive caregiving practices have been associated with the acquisition of physiological self-regulatory abilities in infancy and early childhood (e.g., Calkins, Graziano, Berdan, Keane, & Degnan, 2004). However, given that greater physiological regulation is thought to underlie better behavioral and attentional control (Calkins, 1997), it is also possible that children with greater physiological regulatory abilities may elicit specific types of caregiving behaviors through behaviors they employ.

Although bidirectional influences in the parent-child relationship have been conceptualized through transactional models of development (Bell, 1968; Belsky, 1984; Shaw & Bell, 1993), empirical research examining these dynamic relations is limited. Some studies have examined the transactional relation between behavioral indices of temperament and parenting (e.g., Bridgett et al., 2009); however, to our knowledge, no study has investigated the dynamic relation between physiological indices of temperament and caregiving across more than two time points, and during a time period that is critical for the development of basic self-regulatory abilities. To the extent that caregivers can provide the support for physiological control early in development by being sensitive to children's early needs and emotions, children should be more successful at using more advanced attentional, behavioral, and emotional processes at later ages. Subsequently, greater attentional, behavioral, and emotional control may make interactions with caregivers easier and in turn reinforce sensitive caregiving. In an effort to address this gap in the literature, the current paper takes a transactional approach to assessing the reciprocal relations between maternal sensitivity and a parasympathetic index of physiological regulation, vagal withdrawal, from age 2.5 to age 5.5.

Parasympathetic Regulatory Processes and Development

Psychophysiological research has underscored the importance of the autonomic nervous system in regulating many biobehavioral processes (Beauchaine, 2001; Calkins 1997). In particular, researchers have identified pathways of the parasympathetic nervous system as playing an important role in individuals' ability to regulate their state, behavior, and emotion (Calkins, Graziano, & Keane, 2007; Kreibig, 2010; Porges, 2003). Parasympathetic

influences on cardiac activity in young children can be assessed by measuring heart rate variability. Porges (1985) developed a method that measures the amplitude and period of the oscillations associated with inhalation and exhalation and referred to it as vagal tone. This measure is conceptualized as the variability in heart rate which occurs at the frequency of breathing (respiratory sinus arrhythmia, RSA) and is thought to reflect parasympathetic influence on the heart by way of the vagus nerve. Specifically, the vagus nerve sends input to the heart and causes changes in cardiac activity that allow the body to transition between sustaining metabolic processes and generating responses to the environment (Porges, 2007). In this way, measures of heart rate variability may be usefully studied as a physiological indicator of regulation.

Research on the study of self-regulation has been particularly focused on vagal regulation of cardiac activity during environmentally challenging contexts. During environmentally challenging situations, withdrawal of vagal input and increased heart rate allows individuals to transition from maintaining internal homeostasis to increasing the demand on internal resources necessary for coping and the control of affect and behavior (Porges, 1995). Thus, vagal withdrawal is a physiological mechanism that allows for an increased attention span and adaptive coping, is thought to be mediated by the parasympathetic nervous system, and necessary for self-regulation (Porges, 1996; Wilson & Gottman, 1996). Although some recent research suggests varying or moderate levels of vagal withdrawal and vagal augmentation may be most adaptive in some social, emotional, and cognitive contexts (e.g., Calkins et al., 2007; Gazelle & Druhen, 2009; Marcovitch et al., 2010), most research has found more vagal withdrawal (i.e., greater decreases in vagal tone from baseline to task) in emotionally challenging situations to be linked to adaptive developmental outcomes such as fewer behavior problems and less emotional negativity (Calkins & Keane, 2004), positive coping strategies (Calkins, 1997), greater behavioral regulation (Calkins & Dedmon, 2000), fewer sleep problems (El-Sheikh & Buckhalt, 2005), and fewer depressive symptoms (Gentzler, Santucci, Kovacs, & Fox, 2009).

The Effect of Maternal Sensitivity on Parasympathetic Physiological Functioning

During the first years of life, children make a dramatic transition from primarily external regulation of affect and arousal to increasing levels of self-regulation (Kopp, 1982; 1989). Thus, given young children's very minimal self-regulating capacities, attachment theory and theories of the development of self-regulation suggest that the emotional nature of the parent-child relationship is an important dyadic context for the development of self-regulatory abilities (Diener, Mangelsdorf, Mchale, & Frosch, 2002; Sroufe, 1996). Caregiver sensitivity, characterized by promptly responding to and correctly interpreting children's cues (Ainsworth, Blehar, Waters, & Wall, 1978), is critical for the reduction of young children's distress in emotionally arousing situations; caregivers who are more responsive to their children's negative emotions may influence their children's experience of negative emotions and create a context in which children are able to develop, employ, and practice the ability to modulate arousal (Gianino & Tronick, 1988; Kopp, 1989). A number of studies have demonstrated the influence of sensitive and supportive parenting on behavioral indices

of children's regulation and negative reactivity (e.g., Rubin, Burgess, Dwyer, & Hastings, 2003; von Suchodoletz, Trommsdorff, & Heikamp, 2011). However, fewer studies have assessed the association between parenting and physiological indices of temperament, and less is known regarding the mechanisms through which this effect takes place.

Although the exact process through which sensitive caregiving influences infants' physiology is not known, several hypotheses have been posited. Sensitive caregiver responses may impact young children's ability to regulate physiological stress by facilitating physiological homeostasis as caregivers help infants find a balance between meeting their individual needs and coping with environmental stimuli during emotionally challenging contexts (Hofer, 1987; Spangler & Grossman, 1993). Recently, Porges and Furman (2011) have posited that social interaction with a caregiver can calm and soothe an infant's physiological state and that caregiving may facilitate greater myelination of vagal fibers and development of the vagal system. Subsequently, an increase in the myelination of vagal fibers may improve the modulation of physiological arousal and enable infants to engage in greater behavioral and attentional regulation, as well as positive social interactions (Porges & Furman, 2011).

A number of empirical studies have demonstrated a direct association between caregiving behavior and vagal regulation (as indexed by 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 of baseline vagal tone following distress (Moore & Calkins, 2004). Further, maternal-child relationship quality has been found to predict the degree of children's vagal withdrawal at 5-years-old even after controlling for behavior problems and vagal withdrawal at age 2, such that children with poorer early maternal-child relationships displayed significantly poorer vagal regulation at a later age (Calkins et al., 2008). In a similar study assessing the effects of maternal emotional support on the trajectory of vagal regulation, children of mothers who provided greater 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). Maternal negative control has also been associated with less vagal withdrawal (Calkins, Smith, Gill, & Johnson, 1998), and maternal positive touch has been found to reduce infant's physiological reactivity to stress (Feldman, Singer, & Zagoory, 2010). Finally, 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 vagal regulation in young children.

The Effect of Parasympathetic Physiological Functioning on Maternal Sensitivity

Although there is evidence that maternal sensitivity may be associated with children's greater vagal regulation, children with greater vagal regulation may also elicit more sensitive parenting through everyday behaviors. Researchers examining behavioral characteristics of

child temperament have documented certain characteristics reflecting emotion regulation processes as predictors of parenting behaviors and beliefs. Specifically, children identified as soothable, sociable, and not easily aroused tend to have parents who are warm and responsive, whereas children who are upset more easily and difficult to soothe tend to have parents who are more rejecting and less sensitive (for a review, see Putnam, Sanson, & Rothbart, 2002). Sensitivity is often defined as attentiveness, responsiveness, emotional availability, and lack of irritation and anger (Ainsworth et al., 1978; NICHD Early Child Care Research Network, 1999). In order to behave in these ways, caregivers must regulate their own emotional and behavioral responses, and doing so may be more difficult when engaging children who are unable to manage arousal in effective and appropriate ways (Dix, 1991; Mills-Koonce et al., 2007). Vagal regulation has been thought of as a mechanism through which children are able to focus attention and gain cognitive, emotional, and behavioral control (Posner & Rothbart, 1992). In addition, greater vagal regulation has been empirically linked to fewer behavior problems and sleep disruptions, soothability, and increased social skills (Calkins & Keane, 2004; El-Sheikh & Buckhalt, 2005; Richards, 1985; Stifter & Fox, 1990). Therefore, one way in which vagal regulation may elicit specific parenting behaviors is through regulated behaviors and easier daily transitions. For example, a child who is able to focus his or her attention and listen to directions, while at the same time controlling his or her excitement, would not tax a parent's own regulatory capacity and patience as easily as a child who was unable to focus and manage their emotions, or had difficulty transitioning from one task to another; thus increasing the likelihood the parent might respond in a more sensitive manner. In contrast, poorer vagal regulation may lead to patterns of unpredictable, unmanageable, and difficult behavior such as increased crying, sleep irregularity, and behavior problems that stress the parent-child relationship, which in turn may facilitate less sensitivity and more negative, hostile, and non-supportive parenting.

Combined, this work suggests that children's vagal regulation might not only be impacted by caregiver behavior, but may also elicit parenting behavior through everyday behaviors children display when in emotionally challenging situations. Correlational studies and unidirectional predictions of parenting and child physiology are based on the premise that children and their environments are constant and maintain the same relation over time, but theoretical work suggests there may be a more complex transactional relation (Gottlieb & Lickliter, 2007; Sameroff, 2000). Thus, it is crucial that researchers move beyond correlational and unidirectional studies and focus on the effect of the dynamic interplay between environmental and child factors over time in order to more accurately understand the development of children's emotional competence and regulatory capabilities.

The Current Study

Theorists have acknowledged that failing to consider both environmental and biologically-based individual characteristics over time does not provide a complete picture of development (Lerner, 2002; Rothbart & Bates, 1998). Thus, the current study used a 3-wave design (i.e., ages 2.5, 4.5, and 5.5) and a transactional analysis to assess the nature of the relation between parasympathetic vagal regulation and maternal sensitivity from late infancy through early childhood.

Given the shift from dyadic regulation to self-regulation as children mature (Sameroff, 2010), and the established link between early maternal sensitivity and young children's vagal regulation in the literature, it is hypothesized that maternal sensitivity at age 2.5, when biological systems are quickly maturing and myelination is occurring at a more rapid pace, will be associated positively with greater vagal withdrawal at age 4.5 (i.e., greater decreases in vagal tone from baseline to task). By the end of the preschool period, biological maturation of the autonomic nervous system has slowed and vagal regulation has been found to be more strongly associated with behavioral and emotional control. Therefore, vagal withdrawal at 4.5 is hypothesized to be associated positively with maternal sensitivity at age 5.5, such that the extent to which preschool children's physiological regulatory abilities allow them to manage day-to-day tasks and transitions and demonstrate greater emotional and behavioral control, will likely have an impact on the parenting they receive.

Method

Recruitment and Attrition for Full Project Sample

The current sample utilized data from three cohorts of children who are part of a larger, ongoing longitudinal study. The goal for recruitment was to obtain a sample of children who were representative of the surrounding community in terms of race and socioeconomic status (SES), and who were at risk for developing future externalizing behavior problems. All cohorts were recruited through child day care centers, the County Health Department, and the local Women, Infants, and Children program. Potential participants for Cohorts 1 and 2 were recruited at 2.5 years of age (Cohort 1, 1994–1996; Cohort 2, 2000–2001) and screened using the Child Behavior Checklist (CBCL; Achenbach, 1992) completed by the mother in order to oversample for externalizing behavior problems. Children were identified as being at risk for future externalizing behaviors if they received an externalizing T score of 60 or above. Efforts were made to obtain approximately equal numbers of males and females. A total of 307 children were selected. Cohort 3 was initially recruited when infants were 6 months of age (in 1998) for their level of frustration based on laboratory observation and parent report and followed through the toddler period (for more information, see Calkins, Dedmon, Gill, Lomax, & Johnson, 2002). From Cohort 3, children whose mothers' completed the CBCL at 2.5 years of age were included in the current study ($n = 140$). Of the entire sample ($N = 447$), 37% of the children were identified as being at risk for future externalizing problems. There were no significant demographic differences between cohorts with regard to gender, $\chi^2(2, N = 447) = 0.63, p = .73$, race, $\chi^2(2, N = 447) = 1.13, p = .57$, or 2.5-year SES, $F(2, 444) = 0.53, p = .59$. Cohort 3 had significantly lower average 2.5-year externalizing T scores ($M = 50.36$) compared to cohorts 1 and 2 ($M = 54.49$), $t(445) = -4.32, p < .01$. Of the 447 original participants, six were dropped because they did not participate in any 2.5-year data collection.

At 4.5 years of age, 399 families participated. Families lost to attrition included those who could not be located, moved out of the area, declined participation, or did not respond to phone and letter requests to participate. There were no significant differences between families, who did and did not participate in terms of gender, $\chi^2(1, N = 447) = 3.27, p = .07$, race, $\chi^2(1, N = 447) = 0.70, p = .40$, or 2.5-year SES, $t(424) = 0.81, p = .42$. At 5.5 years of

age 365 families participated including four that did not participate in the 4.5-year assessment. Again, there were no significant differences between families, who did and did not participate in terms of gender, $\chi^2(1, N = 447) = 0.76, p = .38$, race, $\chi^2(1, N = 447) = 0.17, p = .68$, or 2.5-year SES, $t(424) = 1.93, p = .06$.

Participants

The sample for the current study included 356 children (171 male, 185 female) who had laboratory data collected on at least one observed variable across all time points. Although the full sample at each time point was much larger, some participants only completed questionnaires, and did not attend the laboratory visit where data for the current study was collected. As such, participants for which there was no data for the current study variables were dropped from analyses, resulting in a final sample of 356. At the 2.5, 4.5, and 5.5-year laboratory visits, children's average ages were as follows: 31 months ($SD = 3.73$ months); 54 months ($SD = 3.66$); and, 68 months ($SD = 3.26$), respectively. At the 2.5 year laboratory visit, 67% were European American ($n = 236$), 27% African American ($n = 98$), 4% biracial ($n = 15$), and 2% other ($n = 7$). Families were economically diverse based on Hollingshead SES scores (2.5 year: $M = 39.43, SD = 11.11$; 4.5 year: $M = 42.06, SD = 10.77$; 5.5 year: $M = 42.81, SD = 10.63$). Hollingshead scores that range from 40 to 54 reflect minor professional and technical occupations considered to be representative of middle class (Hollingshead, 1975).

Procedures

Children and their mothers came to the laboratory when children were 2.5, 4.5, and 5.5 years of age. The current study includes data from laboratory assessments, including child physiological measures and observational codes of maternal behavior. During the laboratory assessments, children and their mothers engaged in tasks designed to elicit emotional and cognitive responses. During these tasks, children wore heart rate electrode stickers and heart rate data on the child was collected. Families received \$50 for each laboratory visit.

Measures

Parasympathetic Cardiac Measures—To measure vagal activity, EKG was recorded during a baseline procedure in which children watched an emotionally neutral 5-minute video and during frustration tasks derived from the Laboratory Temperament Assessment Battery (Lab-TAB; Goldsmith & Reilly, 1993), in addition to methods used in prior work (Calkins, 1997; Calkins & Keane, 2004; Kochanska, Murray & Coy, 1997). The experimenter placed three electrodes in an inverted triangle pattern on the child's chest while the mother was seated next to the child. The electrodes were connected to a preamplifier, the output of which was transmitted to a vagal tone monitor (VTM-I, Delta Biometrics, Inc, Bethesda, MD) for R-wave detection. The vagal tone monitor displayed ongoing heart rate and computed and displayed an estimate of RSA (vagal tone) every 30 seconds. This epoch duration was used to maximize the use of available data from each task and is typical for studies of short-duration tasks with a developmental population (Calkins and Keane, 2004; Doussard-Roosevelt et al., 2003; Marcovitch et al., 2010).

Estimates of vagal tone were calculated using Porges' (1985) method of analyzing interbeat interval (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. This frequency band has been consistently examined and identified as having associations with child functioning (Huffman et al., 1998; Stifter & Fox, 1990). Vagal regulation is thought to be indexed by vagal withdrawal (a decrease in vagal tone) during situations where coping or emotional regulation is necessary. Thus, to calculate vagal withdrawal, vagal tone during a challenging task is subtracted from vagal tone during a baseline task so that positive values indicate greater withdrawal and increased vagal regulation. The MXEDIT software was used to analyze and edit IBI files. Editing the files consisted of scanning the data for outlier points relative to adjacent data and replacing those points by dividing them or summing them so that they would be consistent with the surrounding data. Data files that required editing of more than 5% of the data were not included in the analyses.

Frustration tasks: All available data for vagal withdrawal during frustration was utilized. At 2.5 years, children participated in one frustration task where heart rate data was collected. During the Locked Box task participants were given a desirable object (i.e. a toy or cookie) in a container that could not be opened and left with the container for several minutes. At 4.5 years, children participated in two frustration tasks for which physiological data was collected. During the Impossibly Perfect Circles task adapted from Goldsmith and Reilly (1993), children were given a sheet of white paper and a marker. In a neutral tone, an experimenter repeatedly asked the child to draw a perfect circle and gently criticized previous circles drawn. Critiques did not provide the child with enough information to fix the problem, but they were specific (e.g., too small or too bumpy). In the Candy Land task, the mother and child played the game Candy Land together. The cards were ordered such that the child experienced multiple moves backwards while the mother advanced forward. At 5.5 years, children participated in one frustration task, the Not Sharing task. During this task, the experimenter divided candy between themselves and the child. The experimenter gave themselves more candy than the child and also took the child's candy and ate it.

Given that vagal withdrawal data was collected for two frustration tasks at year 4.5, a mean vagal tone score was created for the current study. Mean vagal tone from the Impossibly Perfect Circles and Candy Land task was averaged to produce one vagal withdrawal score. The two tasks were correlated $r = .69, p < .01$.

Maternal Sensitivity—Global codes of maternal sensitivity were adapted from the Early Parenting Coding System (Winslow, Shaw, Bruns, & Kiebler, 1995). Maternal sensitivity was observed during a pretend play and clean-up task at ages 2.5, 4.5, and 5.5. During the pretend play task the mother and child were given an array of toys to play pretend with and the mother was instructed to play with the child as she normally would at home. The clean-up task was a compliance task where the mom was told to work with the child to clean-up toys used during a previous interaction task as they typically would at home. Sensitivity (mother's promptly and appropriately responding to the child's bids to her) was coded once

for each episode on a 4-point scale (1- *low* to 4- *high*). At each year, teams of two coders were trained on 10% of the videotaped sessions and independently coded another 10% for reliability. The coder pairings changed at age 4 and at age 5. The adjusted Kappas for global codes were all above .70. A sensitivity composite was created by summing the global sensitivity codes for pretend play and clean-up at each year. The correlation between tasks at each year was appropriate for a composite to be created (2.5 year: $r = .53, p < .01$; 4.5 year: $r = .61, p < .01$; 5.5 year: $r = .60, p < .01$).

Results

Analytic Approach

Preliminary analyses were conducted to examine descriptive information for study variables (see Table 1) and correlations among study variables (see Table 2). Data screening was conducted to assess for normality and outliers. Mean vagal withdrawal evidenced a decrease from age 2.5 to age 5.5 and maternal sensitivity was consistent at ages 2.5, 4.5, and 5.5. Associations between vagal withdrawal and maternal sensitivity were estimated using Mplus (Version 7; Muthen & Muthen, 2012) and full information maximum likelihood (FIML) estimation was used to handle incomplete data. The current sample included participants for whom data on at least one study variable was present. FIML estimation utilizes all available information to account for missing data; however, the Mplus software drops cases for which there is no data for all variables at all time points. Race, sex, SES, and externalizing behavior at 2.5 years were examined as covariates in all models. Baseline vagal tone at ages 2.5, 4.5, and 5.5 was also examined as a control for vagal withdrawal at those respective years. Results were consistent whether these covariates were included or excluded; therefore, for parsimony the results below reflect models run without these controls.

As suggested by de Jonge, Dormann, Janssen, Dollard, Landeweerd, & Nijhuis (2001), a stability model was compared to the more complex, cross-lagged model. Therefore, the following models were estimated: a stability model for vagal withdrawal and maternal sensitivity with no cross-lag paths, and a full reciprocal model for vagal withdrawal and maternal sensitivity. Across models, concurrent associations between vagal withdrawal and maternal sensitivity were estimated. Thus, the stability model estimated the following autoregressive paths: 2.5-year vagal withdrawal with 4.5-year vagal withdrawal, 4.5-year withdrawal with 5.5-year vagal withdrawal, 2.5-year maternal sensitivity with 4.5-year maternal sensitivity, and 4.5-year maternal sensitivity with 5.5-year maternal sensitivity. The cross-lagged model included the additional paths assessing year 2.5 vagal withdrawal to year 4.5 maternal sensitivity, year 2.5 maternal sensitivity to year 4.5 vagal withdrawal, year 4.5 vagal withdrawal to year 5.5 sensitivity, and year 4.5 sensitivity to year 5.5 vagal withdrawal. Given that the stability and cross-lagged models were nested, a chi-square difference test was used to evaluate if the cross-lagged model explained the data above and beyond the stability model (de Jonge et al, 2001; Kline, 2005).

Structural Model Comparisons

Vagal withdrawal stability model—Autoregressive coefficients were constant over time for the stability model estimating vagal withdrawal and maternal sensitivity (see Figure 1).

The standardized path coefficients for maternal sensitivity demonstrated moderate stability from ages 2.5 to 5.5 and were significant (age 2.5 to 4.5: $\beta = .57, p < .001$; age 4.5 to 5.5: $\beta = .64, p < .001$). For vagal withdrawal, the autoregressive paths were significant and demonstrated low to moderate stability (age 2.5 to 4.5: $\beta = .20, p < .01$; age 4.5 to 5.5: $\beta = .27, p < .001$). Within time correlations revealed that vagal withdrawal was not associated with concurrent maternal sensitivity at 2.5, 4.5, or 5.5 years ($r = 0.04$; $r = 0.00$; $r = 0.06, p > .05$). The withdrawal stability model had adequate fit to the data, $\chi^2 (8) = 25.11, p < .01$, CFI = 0.94, RMSEA = 0.08, SRMR = 0.05 (see Table 3). In sum, maternal sensitivity was moderately stable from ages 2.5 to 5.5 and vagal withdrawal demonstrated low to moderate stability across early childhood; however, vagal withdrawal was not associated with concurrent maternal responding.

Vagal withdrawal cross-lagged model—The withdrawal cross-lagged model demonstrated good model fit, $\chi^2 (4) = 14.40, p < .01$, CFI = 0.96, RMSEA = 0.09, SRMR = 0.03, and the chi-square difference test revealed that the cross-lagged model significantly improved fit over the stability model, $\chi^2 (4) = 10.71, p < .05$ (see Figure 2). As such, the cross-lagged model better explained the development of vagal withdrawal and maternal sensitivity from ages 2.5 to 5.5, and the model was interpreted. Within the withdrawal cross-lagged model, all autoregressive paths were positive and significantly different from zero, indicating that both vagal withdrawal and maternal sensitivity were stable over time. The cross-lagged paths revealed that vagal withdrawal at 2.5 years was not associated with maternal sensitivity at 4.5 years ($\beta = -0.02, p > .05$), and 4.5-year maternal sensitivity was not associated with 5.5-year vagal withdrawal ($\beta = 0.01, p > .05$). Maternal sensitivity at age 2.5 however, was associated with greater vagal withdrawal at age 4.5 ($\beta = 0.13, p < .05$), and withdrawal at age 4.5 was subsequently associated with greater maternal sensitivity at age 5.5 ($\beta = 0.12, p = .01$) (see Figure 1). Therefore, the cross-lagged model supported our hypotheses and revealed a transactional relation between vagal withdrawal and maternal sensitivity such that maternal sensitivity at 2.5 years was associated with greater 4.5-year vagal withdrawal, which was associated with subsequent maternal sensitivity at 5.5 years.

Discussion

The current study utilized a transactional design to examine the longitudinal associations between vagal regulation and maternal sensitivity from age 2.5 to age 5.5. Our design was advantageous over previous research in that it allowed us to examine the direction and nature of the relation between a physiological indicator of self-regulation and maternal sensitivity across three time points that have been implicated as integral in the development of self-regulation abilities (Kopp, 1982). In addition, using transactional models allowed us to analyze the stability of vagal regulation and maternal sensitivity and determine the cross-construct relations that emerge over and above the contributions of the stability of these constructs over time (Burkholder & Harlow, 2009). Interestingly, there were no within-time correlations between maternal sensitivity and vagal withdrawal at any of the three time points, indicating that these constructs were not associated when measured concurrently. However, significant longitudinal associations between the two constructs emerged in the path model. These findings suggest an underlying developmental process and highlight the

need for future research to continue to examine these relations longitudinally and move beyond focusing on single time points.

Results revealed that vagal withdrawal at age 2.5 was not associated with maternal sensitivity at age 4.5. Although empirical work has suggested that children's temperament and behavioral control may play a role in the parenting they receive (e.g., Dumas & Wekerle, 1995; Lengua & Kovacs, 2005), most studies linking vagal withdrawal to maladaptive behavioral and psychological symptoms assess children over the age of 2 (e.g., Calkins & Keane, 2004; Calkins 1997; El-Sheikh & Buckhalt, 2005; Gentzler et al, 2009). It is possible that 2.5 year-olds' vagal regulation is still rapidly maturing and is not as strongly linked to specific maladaptive psychological and behavioral outcomes as is evidenced in later childhood; thus, vagal regulation at age 2.5 may be less strongly associated with maternal sensitivity than vagal regulation in early and middle childhood. Indeed, findings of the current study indicated that children's vagal regulation at age 4.5 was associated positively with maternal sensitivity at age 5.5. Because previous studies have established a link between greater physiological regulation and more adaptive emotional, cognitive, social, psychological, and behavioral outcomes in early and middle childhood (e.g., Blair & Peters, 2003; Calkins & Keane, 2004; Calkins & Dedmon, 2000), it is possible that these serve as mediating mechanisms through which increased vagal withdrawal may predict more sensitive parenting of older children.

Maternal sensitivity when children were 2.5 years-old was associated positively with vagal withdrawal at age 4.5. However, maternal sensitivity at age 4.5 was not related to vagal withdrawal at age 5.5. These findings suggest that maternal sensitivity may be more strongly related to the development of vagal withdrawal from age 2.5 to age 4.5 when children's internal regulatory abilities are rapidly maturing, than at later ages when the nervous system is more developed. Porges and Furman (2011) posit that a possible mechanism through which parenting may affect vagal regulation is through myelination of the vagus nerve. Therefore, it is possible that as this biological system matures and myelination slows, parenting may have less influence on children's ability to physiologically regulate. Further, as children age they may begin to vary more in terms of their behavioral regulatory abilities and rely less on physiological regulation.

Limitations and Conclusions

Potential genetic mechanisms may account for the association between maternal sensitivity and children's vagal withdrawal. Twin studies have indicated that genetic influences account for heart rate variability during stressful contexts and that vagal tone may be heritable (e.g., Boomsma, van Baal, & Orlebeke, 1990; Wang et al., 2009), such that the quality of caregiver's responses to children's needs may partially depend on the vagal regulation of the caregiver. That is, maternal sensitive responding to infant distress may be associated and supported by mothers' own vagal regulation thus confounding sensitivity with a genetic predisposition to greater vagal control. Future research is needed to better understand the unique contributions of genes and environment.

Overall, the cross-lagged model supported our proposed hypotheses. However, we did not have additional time points that allowed us to further assess this relationship from early

infancy through middle childhood. If we were able to account for earlier time points, it is possible that maternal sensitivity would have been more strongly associated with vagal withdrawal in early infancy when myelination of the vagus nerve is even more rapid. Further, we are unable to assess whether vagal regulation continues to predict maternal sensitivity into middle childhood. Vagal regulation has been shown to become increasingly stable (Calkins & Keane, 2004; Perry et al., in press) and it is unclear whether the relation between caregiving and physiological regulation would remain the same in middle childhood or adolescence. Future research should examine these associations across these developmental time periods to get an even more accurate assessment of the relation between physiological functioning and vagal withdrawal over time.

An additional limitation of the current study is that we only measured vagal withdrawal in response to emotionally frustrating tasks and did not include vagal regulation to social or cognitive challenge. Therefore, we are limited in our ability to generalize our findings across all contexts. However, given that some studies have found different patterns of vagal functioning to be adaptive in cognitive and social contexts (e.g. Marcovitch et al, 2010; Hastings et al. 2008), as well as the strong emotional nature of the parent–child relationship during infancy and early childhood, assessing physiological regulation during emotional challenge is highly appropriate. Further, we believe that vagal withdrawal to frustration is more likely to be associated with maternal behavior than vagal responses to cognitive or social tasks; particularly given that children’s reactions to negative emotion may be similar to the challenges caregivers face when parenting poorly regulated children. We also utilized different tasks at different ages to assess frustration and we cannot be sure that the frustration tasks were equally emotionally challenging. However, we believe the tasks continued to provide a valid measure of vagal regulation because the majority of children demonstrated vagal withdrawal and there is substantial variability in the scores at each age. It may be beneficial for future studies to examine these associations with the same task and across multiple contexts using both social and cognitive tasks. It should also be noted that in order to utilize all available data a composite measure comprised of vagal withdrawal during two frustration tasks was used at the 4.5-year time point. Although we do not see this as a limitation, it is possible that there were minor effects. After re-analyzing the data with a single task at age 4, the same pattern emerged; therefore, we are confident the effects of using the composite score were not substantial.

Finally, children are influenced by caregivers other than mothers. Data on fathers may help provide insight into the specific kinds of paternal behaviors that affect children’s biological functioning, and the development of children’s vagal regulation may be more or less associated with specific father behaviors. It is also possible that the joint contribution or interaction of mother and father behaviors influence the development of children’s vagal regulation. Therefore, future work should examine a more comprehensive model with both mother and father data to attempt to gain a better understanding of the relation between vagal regulation and parenting over time.

Using a transactional approach to assess the relation between maternal sensitivity and vagal regulation over three time points in early childhood both extends the current literature and allows for a greater understanding of the direction of effects between these constructs during

early childhood. The current study has supported the importance of caregiving for the development of young children's vagal regulation and provided evidence that parenting might also be influenced by children's ability to physiologically regulate later in development. Thus, our findings highlight the importance of studying the longitudinal relation between both contextual and individual characteristics when gaining insight into developmental processes thought to be environmentally influenced.

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Figure 1.
Stability model of vagal withdrawal and maternal sensitivity.

Figure 2.

Cross-lagged panel model between vagal withdrawal and maternal sensitivity.

Table 1

Descriptive Information for Study Variables.

	<i>N</i>	<i>M</i>	<i>SD</i>	Range	Skewness
2.5 yr Withdrawal	329	0.60	0.75	−1.92–3.10	.40 (.13)
4.5 yr Withdrawal	283	0.32	0.60	−1.25–2.87	.64 (.15)
5.5 yr Withdrawal	237	0.26	0.70	−2.04–2.50	.07 (.16)
2.5 yr Sensitivity	355	6.50	1.46	0.00–8.00	−.85 (.13)
4.5 yr Sensitivity	293	6.26	1.53	0.00–8.00	−.77 (.14)
5.5 yr Sensitivity	269	6.53	1.36	0.00–8.00	−1.00 (.15)

Table 2

Correlations for Study Variables.

	1	2	3	4	5
1. 2.5 yr Withdrawal					
2. 4.5 yr Withdrawal	.18**				
3. 5.5 yr Withdrawal	.04	.28**			
4. 2.5 yr Sensitivity	.04	.14*	.02		
5. 4.5 yr Sensitivity	-.02	.06	.03	.59**	
6. 5.5 yr Sensitivity	.04	.16*	.09	.55***	.66***

* $p < .05$.

** $p < .01$.

Table 3

Model fit and model comparisons

Model	χ^2	df	χ^2/df	CFI	RMSEA	SRMR
Stability	25.11**	8	—	0.94	0.08	0.05
Cross-lagged	14.40**	4	10.71 (4)*	0.96	0.09	0.03

* $p < .05$

** $p < .01$.