Running Head: VAGAL REGULATION AND SOCIAL BEHAVIOR

Vagal Regulation and Observed Social Behavior in Infancy

Cynthia A. Stifter and Janet M. Corey

The Pennsylvania State University

Correspondence should be directed to the first author at 105 White Bldg., Department of Human Development and Family Studies, The Pennsylvania State University, University Park, PA 16802, email: tvr@psu.edu

Abstract

The goal of the present study was to test a recent hypothesis that the ability to suppress cardiac vagal tone during a cognitive challenge was related to social behavior. One hundred thirty-six infants participated with their parents in laboratory visits when infants were 12 (mother visit) and 13 months (father visit) of age. To measure the infants' regulation of cardiac vagal tone, heart rate responses were recorded during the administration of a test of mental development (father visit). Responses to a stranger interaction were measured during the 12 month visit. In addition, experimenters evaluated the infants' behavior across the laboratory sessions using an adaptation of the Infant Behavior Record. Results revealed that invants who were able to suppress vagal tone during the cognitive challenge were rated by the experimenters as more socially approaching at the two laboratory visits. Vagal regulation was unrelated to behavior during the stranger-infant interaction. These findings partially support the hypothesis that infants who are able to regulate their vagal tone have a greater capacity for social engagement.

Key Words: cardiac vagal tone, infant social behavior, stranger-infant interaction, psychophysiology

Vagal Regulation and Observed Social Behavior in Infancy

Initial social interactions are often arousing to young infants as they do not have the

representational capacity to assimilate unfamiliar persons easily (Field, 1981). Infants have, however, the ability to disengage from these encounters. Simply looking away effectively removes the stimulus for the purpose of regulating arousal. Gaze aversion, a momentary disengagement from the stimulus, not only allows for arousal reduction but also rapid re-engagement with the unfamiliar, but attractive, social stimulus (Field, 1981; Stifter & Moyer, 1991; Waters, Matas & Sroufe, 1975). Social interaction, therefore, is at least in part dependent upon the infant's ability to engage, disengage, and re-engage the environment.

The infant's ability to engage and disengage the environment has recently been proposed to be related to the regulation of parasympathetic input to the heart, or vagal regulation (Porges, 1998). This link, however, has not been sufficiently investigated in the young human infants. In the present study, the relationship between vagal regulation and social behavior of one-year-old infants was examined. We specifically examined social behavior with a stranger as this type of interaction was expected to provide a robust opportunity to observe both engagement and disengagement in a social environment.

The cardiac vagal tone index (V_{NA}) developed by Porges (1985) has been identified as a marker for individual differences in temperament, specifically emotional reactivity and regulation (Calkins, 1997; Kagan, 1994; Stifter & Fox, 1991; Stifter & Jain, 1996). More recently Porges (1995; 1997; 1998) has proposed the Polyvagal Theory which suggests that the vagal ventral complex (VVC), a uniquely mammilian neural subsystem, "fosters the development of complex social behaviors" (Porges, 1998, p. 842). The VVC is composed of somatomotor and visceromotor nerve fibers that enervate organs such as the larynx, pharynx, bronchi and heart, as well as facial muscles, all of which can act together to promote social interaction. According to Porges (1995) the efferent pathways from the vagus to the heart act

like a brake. Under most conditions, the nucleus ambiguus vagal source inhibits heart rate. But, under conditions of environmental challenge, this "vagal brake" can be withdrawn. Removal of the brake facilitates increases in cardiac output for the purpose of transitory mobilization, avoiding the metabolic cost associated with activation of the sympathetic-adrenal system. Under conditions of prolonged or intense challenge, the sympathetic-adrenal system can still be activated. However, by re-engaging the vagal brake, the organism has the capacity to inhibit such a response for the purposes of soothing and potential re-engagement.

According to polyvagal theory, baseline measures of cardiac vagal tone represent the homoeostatic function of the vagal system and the "potential" responsiveness of the organism (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). Studies relating baseline levels of V_{NA} to physiological and behavioral measures of reactivity support this hypothesis (Porter, Porges, & Marshall, 1988; Porges et al., 1996; Stifter & Fox, 1991). For example, in the Porter et al. (1988) study, baseline cardiac vagal tone predicted physiological responses to circumcision as well as the degree of negative vocalization.

The vagal brake, on the other hand, is conceptualized as an "adaptive neural physiological mechanism to foster engagement and disengagement of the environment" (Porges, Doussard-Roosevelt, Stifter, McClenny & Riniolo, 1999, p. 15) and indexes the ability of the system to support a shift in resources from a steady state to one with metabolic demands. Accordingly, individual differences in the vagal brake can be assessed by measuring changes in vagal influences on the heart during defined periods of challenge. For example, Porges et al. (1996) found that infants who suppressed cardiac vagal tone during a cognitive challenge were less likely to develop behavior problems two years later. Conversely, DeGangi and colleagues (DeGangi, Di Pietro, Greenspan, & Porges, 1991) showed that infants with regulatory problems

were unable to regulate cardiac vagal tone during the administration of a cognitive examination. Examining vagal changes in response to emotional challenges, Calkins (1997) reported that greater vagal suppression was associated with adaptive behavioral regulation. More specifically and central to the present study, vagal regulation was related to the infants' engagement (looking and talking to) of the experimenter. More recently, Suess & Bornstein (2000) found vagal regulation to be related to more sophisticated play in female toddlers when elicited by an experimenter. Based on these findings and Porges' hypothesis that vagal regulation is an important property of successful social interaction, we examined infant social behaviors globally, over the course of a laboratory visit, as well as specifically, in response to an unfamiliar female person.

Porges (1998) has also suggested that vagal regulation for the purpose of social engagement can only occur if the environment is perceived as safe. Otherwise, cortical regulation of the VVC is depressed and social behavior compromised. The novelty of interacting with a stranger, particularly at the end of the infant's first year, typically elicits wariness (Campos, Emde, Gaensbauer, & Henderson, 1975; Gaensbauer, Emde, & Campos, 1976). Research on stranger wariness, however, has found that differences in the interaction protocol and elements of the context in which the stranger interaction takes place can affect infant social behavior. For example, female strangers who allow the infant to observe them from a distance before approaching promote more affiliative behaviors than male strangers or strangers who are physically intrusive or actually touch the infant (Sroufe, 1977). Likewise, close proximity with mother facilitates affiliative responses while the absence of mother or greater distance from mother promotes more fearful responses and attachment behaviors (Campos, Emde, Gaensbauer, & Henderson, 1975). Taken together, the findings from these various studies suggest that age

and the context and design of a stranger-infant interaction will alter the response set of the infant. In the present study, the stranger-interaction was designed with these issues in ind to elicit the most socially engaging behavior possible given the developmental stage of the infants.

The primary goal of the present study was to examine the relationship between vagal regulation and infant social behavior. Specific infant social responses toward an unfamiliar female were assessed during a laboratory visit at one year of age. In addition, global observations of social behavior and behavioral reactivity were made. Finally, changes in cardiac vagal tone during the administration of a test of mental development provided a measure of the vagal brake. While we expected that the typical one-year-old infants' responses to an unfamiliar adult should be of engagement/disengagement (i.e., wariness) and thus be related to greater vagal suppression, the conditions of the stranger-infant interaction procedure used in the present study suggested an alternative hypothesis. Given that the availability of the mother and the gradual approach of the stranger likely provided the infant with a "safe" environment from which to engage the stranger, we hypothesized that infants who were able to effectively regulate cardiac vagal tone during the cognitive challenge (i.e., exhibit a decrease in vagal tone) would show more social approach behaviors toward the stranger, specifically, and across the laboratory sessions, more generally.

Methods

Participants

Participants were drawn from a longitudinal study of the development of emotion regulation. Infants entered into the study and were initially tested at 2 weeks of age. Criteria for inclusion included normal, full term birth with no complications. One hundred and fifty infants were recruited into the study. At the 12 month follow-up visit 136 families returned (66 males)

whereas at the 13 month visit 127 females were available for analysis (60 males). Mothers averaged 29.7 years of age (SD = 5.5 years) and had a mean 15.6 years (SD = 2.7 years) of education. Fathers mean age was 31.9 years (SD = 6.0 years) and they averaged 16.3 years (SD = 3.3 years) of education. Participants, reflecting the demographics of central Pennsylvania, were predominantly Caucasian (91.8%), with 3.4% African/African-American, 3.4% Asian/Asian-American and 0.7% Hispanic.

Procedures

Families were seen several times during the child's first two years. The present study was based on laboratory visits that occurred when the infants were one year of age. Two visits were scheduled about 3-5 weeks apart, one with the mother (M age = 52.8 weeks, SD = 1.2), and the other with the father (M age = 57.2 weeks, SD - 1.6). To limit the burden on the infant the positive and negative reactivity tasks were distributed among the two visits. The procedures that are the focus of this paper are described below.

Stranger interaction. The stranger interaction, which occurred during the mother visit, was three minutes in length and immediately following free play. The mother and infant were seated on a large sheet that was placed on the floor. Following a protocol based on episode three of the Strange Situation (Ainsworth & Wittig, 1969), an unfamiliar adult female entered the room and sat quietly on the corner of the sheet farthest from the infant for one minute. The mother was asked to refrain from initiating interaction with the infant following the stranger's entrance. After one minute, the stranger began speaking with the mother. Their conversation focused on topics unrelated to the infant. During the third minute, the stranger began interacting with the infant. The stranger was careful to gently approach the infant, mediating approach with a toy, and to try to engage the infant in play.

The infants' responses to the unfamiliar female experimenter were coded every 10 seconds on a 5-point scale designed to capture affiliative and avoidance behaviors typically observed in infants at this age. The coding scale ranged from 1 to 5; 1 = the infant physically withdraws from the stranger and seeks proximity to the parent; 2 = the infant avoids the stranger by establishing visual contact with the parent; 3 = infant is ambivalent (characterized by looks to stranger, looks away, looks to mother); 4 = infant orients toward stranger but remains in position; and 5 = the infant physically approaches the stranger, making a clear social overture. One third of the taped interactions were coded independently by two coders for reliability, resulting in a mean Cohen's kappa of .78.

Scores were averaged across each of the three stranger interaction episodes, respectively labeled stranger entry, stranger/mom, and stranger/baby. Higher scores reflect greater approach toward the stranger. In addition, the frequency with which the infant exhibited either approach (codes 4 & 5), ambivalence (code 3), or withdrawal (codes 1 & 2) across the entire stranger interaction was calculated. The stability of the infants' responses to the stranger across the three episodes was quite good; stranger entry to stranger/baby, $r = .48$, stranger entry to stranger/mom, $r = .69$, stranger/mom to stranger/baby, $r = .69$.

Cardiac procedures and measures. Baseline heart rate recordings were collected at both visits, whereas vagal regulation to a challenge was only measured at the father visit. Following a warm-up period, the infant was placed on the parent's lap and the experimenter affixed three disposable electrodes onto the infant's chest in a triangular pattern. The infant was then placed in a high chair and quietly entertained by a second experimenter. Baseline electrocardiograms (ECGs) were recorded for approximately 5 minutes. At the father visit, once the baseline recording was completed, the infant's seat was pulled up to a table with the father seated by

his/her side. The experimenter sat across from the infant and administered several items (spoon in cup, cubes in cup, book presentation, crayon and paper, peg board) from the Bayley Scales of Mental Development (Bayley, 1969). Heart rate was recorded continuously throughout the procedure, which was terminated after 5 minutes.

Heart rate was collected off-line with a Grass P15 pre-amplifier connected to a lap top computer that was placed out of the child's view. Signals were passed through an A/D converter programmed to display the raw ECG signal. To quantify the signal, the waveform was viewed and a threshold was set to trigger at each R-spike. The resulting square wave impulses produced by the tripper were timed in milliseconds (ms) and organized into a heart period file. Porges' (1985) analytic method was applied to these data and the cardiac vagal tone statistic ($V_{NA)}$ computed. This method detrends the heart period data to remove the variance associated with changing level and oscillations slower than RSA. Using time series analysis, the program extracts the components of heart period within the respiratory frequency band for young children (.24 to 1.04 Hz). The natural logarithm of this variance produces the V_{NA} index. V_{NA} was calculated based on sequential 10 second epochs of the baseline and reactivity recordings.

In cases of excessive infant movement that disrupts the ECG signal, the MXEDIT software program (Delta Biometrics, Bethesda, MD) was used to clean the data. This program exhibits the heart period data in graphic and numerical form, allowing the visual identification of artifact. Where artifactual data were identified, they were edited in accordance with the absolute values within the range of the data. Significant movement artifact (averaging more than one correction per minute), resulted in the deletion of the artifactual data and the creation of a new trial. Mean values from each trial were weighted and averaged. Data streams representing less 90 seconds of continuous heart period activity were not included in the averaging.

Baseline V_{NA} at both the mother and father visit and vagal regulation during the Bayley exam collected during the father visit were used in the analyses. Vagal regulation was computed by subtracting the mean V_{NA} during the cognitive test from the baseline value.

Measures

Infant Behavior Record. After each laboratory visit, an adapted version of the Infant Behavior Record (IBR; Bayley, 1969) was completed. The IBR was developed to capture individual differences in behavior during administration fo the Bayley scales. In the present study, the IBR was applied to behavior observed globally across the entire visit. Because one experimenter might miss important behaviors related to the IBR items, each IBR was completed by two observers in conference immediately following the visit. Eleven items were deemed appropriate to the entire laboratory session: social orientation (responsiveness to persons, examiner and mother), fearfulness, general emotional tone, object orientation, attention span, endurance, activity, reactivity, and irritability. Two scales were created by compositing some of the items according to previous reports (Braungart, Plomin, DeFries & Fulker, 1992; Wilson & Matheney, 1983). Social approach included responsiveness to the examiner, low fearfulness, general emotional tone, endurance, and low irritability. Task orientation included object orientation and attention span. Finally, we retained both the activity item, which reflects the amount of gross bodily movement, and the reactivity item, which measures the child's sensitivity or excitability to stimulus change, as variables in our analyses. Cross-visit correlations showed task orientation and activity level to be modestly stable from 12 to 13 months, $r = .25$, $p < .005$, and $r = .29$, $p < .001$, respectively, whereas the correlations for social approach and reactivity were not significant but in the expected direction $r = .12$ and .13, respectively). Because of the low correlations the scales from each visit were retained in the analyses.

Results

All variables were examined for sex differences. Only one main effect was found: boys were rated as more active by observers than girls, F (1,137) = 4.68, $p < .03$. Since no other main or interaction effects with sex were revealed, all of the following analyses were performed with the male and female infants combined.

Behavioral Responses to the Stranger

Repeated measures analysis of variance was conducted with the infant's behavior toward the stranger during each episode as the repeated factor. As can be seen in Table 1, infants were more approaching of the stranger when she began interacting with the infant than during either the stranger entry episode, F (1,138) = 6.36, $p > .01$, or the stranger/mom episode, F (1,138) = 16.76, $p < .0001$. There were no significant differences between infant behavior exhibited during the stranger entry episode and infant behavior during the stranger/mom episode.

The frequency with which infants displayed approach, ambivalence, and withdrawal as also examined using repeated measures ANOVA with episode (stranger entry, stranger/mom, stranger/baby) and type of behavior as the repeated factors. A significant main effect for behavior was found. Follow-up tests revealed that infants were more likely to exhibit approach behavior toward the stranger than either ambivalent behavior, F (1,135) = 28.0, $p < .0001$, or withdrawn behavior, F (1,135) = 10.24, $p < .0001$. Although infants exhibited more withdrawal than ambivalence, this difference was not significant (see Table 1). An interaction effect for episode by behavior type was also significant, F (4,540) = 35.78, $p < .001$. Follow-up tests revealed several interesting findings. As can be seen in Figure 1, the frequency of approach behaviors was greater than either withdrawn, F (1,135) = 27.67, $p < .001$, or ambivalent behaviors, F (1,135) = 39.96, $p < .001$, during the stranger entry episode. When the stranger

began interacting with the mother, however, withdrawal became significantly more frequent than either ambivalent, F (1,138) = 4.41, p < .04, or approach behaviors, F (1,138) = 11.95, p < .001, which both decreased in frequency. This pattern changed dramatically when the stranger began directing her attention to the infant. Infants exhibited significantly more approach behaviors during this episode than either ambivalent behaviors, F (1,138) = 105.5, p < .001, or withdrawn behaviors, F (1,138) = 58.17, p < .001.

Relationships Among the Behavioral Measures

To examine whether infants who approached or avoided the stranger were consistent across the laboratory procedures, pearson correlations were conducted between the infant behavior during the stranger interaction (episodic scores and cross-episode frequencies) and their scores on the IBR. Of the 48 possible relations with social behavior during the three episodes, 12 significant relations and 5 trends emerged. As can be seen in Table 2, infants who were rated as active by the observers at both visits were more approaching, whereas infants who were more reactive exhibited fewer approach behaviors. These findings are supported by the significant correlations for the frequency of behavior. Infants who were rated as more active showed less withdrawal and more approach behavior during the stranger interaction. Little convergence between measures of approach was found with one exception. Infants rated by observers as high in social approach during the mother visit exhibited more frequent approach behaviors toward the stranger.

Vagal Regulation and Infant Behavior

The average change in the infants' cardiac vagal tone during the Bayley exam was .07 units (SD = .55) with vagal responses ranging from -1.52 to 2.27, an indication that some infants increased their V_{NA} during administration of the Bayley. Indeed, approximately 39% of the

available sample (n = 47) exhibited increases in V_{NA}, while 69 infant participants exhibited decreases in V_{NA} (two infants showed no change in V_{NA}). This is consistent with previous reports that found between 44 to 59% of infants to exhibit increases in vagal tone to a cognitive challenge (Calkins, 1997; DeGangi, et al., 1991; Porges et al., 1996).

Baseline V_{NA} was relatively stable across the two visits, r = .47, p < .001. The baseline V_{NA} measure and the V_{NA} change score from the father visit were positively correlated, r = .32, p < .001. Consequently, baseline levels were controlled for in all subsequent analyses examining the relationship between vagal regulation and behavior.

Vagal regulation and social behavior. Partial correlation analysis was used to test whether the V_{NA} change scores were related to social behavior during the stranger entry, stranger/mom and stranger/baby episodes. No significant relations emerged.

Consistent with the analysis above, partial correlations between V_{NA} change scores and the frequence of behaviors across the stranger interaction were nonsignificant.

Vagal regulation and IBR ratings. Partial correlation analysis relating vagal regulation to social approach as measured with the IBR was significant for both mother visit, r = .26 p < .01, and father visit, r = .23, p < .01. Infants who were able to regulate their vagal tone during a cognitive test were rated by observers during both visits as more engaged with the experimenter, more positive in emotional tone, less fearful and irritable, and showed more endurance across the laboratory procedures. When averaged across the two visits, infants who exhibited high levels of social approach at both visits also exhibited more vagal suppression, r = .32, p < .001. Vagal regulation was unrelated to task orientation, activity level and reactivity measured at both visits.

Baseline Cardiac Vagal Tone and Infant Behavior

Correlations were conducted between concurrent baseline measures of V_{NA} and observed

infant behavior. No significant relations were revealed. When examining the association between the IBR ratings and concurrent baseline V_{NA}, two significant correlations emerged. Infants with higher baseline V_{NA} measured during the father visit were observed to be more active, $\underline{r} = .21$, $\underline{p} < .05$, whereas infants with higher baseline measured during the mother visit were rated as less sensitive to changes in the environment, $\underline{r} = .23$, $\underline{p} < .01$.

Discussion

The primary objective of the present study was to examine the relationship between the ability to regulate cardiac vagal tone and infant social behavior. Based on Porges' (1995; 1997) polyvagal theory, we hypothesized that infants who suppressed V_{NA} during a cognitive challenge would be more socially engaged. In addition to a global assessment of social approach, we specifically focused on infants' behavioral responses to an interaction with an unfamiliar female adult, expecting that it would be a powerful elicitor of social approach and/or withdrawal. Our hypothesis was confirmed, but only by the global ratings of social approach. Infants who regulated their cardiac vagal tone were rated by observers as more responsive toward the experimenter, exhibiting more positive affect, more endurance, and less fear and irritability.

According to polyvagal theory, phylogenetic development of the autonomic nervous system resulted in greater cortical control of arousal and of those behaviors involved in engagement and disengagement of the environment. Such control allows the organism to respond to transitory metabolic demands without activating the sympathetic nervous system (SNS). The SNS mobilizes "flight or fight" behaviors, but does so at substantial metabolic cost. The ability to respond to lower-level environmental challenges by selective environmental engagement and disengagement (without the physiological stress associated with the flight or fight response) would have significant adaptive value. Interacting with an unfamiliar

experimenter and participating in laboratory procedures, particularly at the end of the first year of life, necessitates regulation of the arousal associated with novelty and social interaction. Our findings indicate that individual differences in the ability to regulate this arousal for the purposes of social interaction were related to the efficiency of the vagal brake. That is, infants who were more readily engaged during laboratory procedures, more social with experimenters, more positive and less fearful may have regulated their autonomic arousal such that they could engage, disengage, and re-engage the environment without the physiological cost associated with SNS arousal. On the other hand, infants with less efficient vagal brakes who were less approaching of the experimenter and/or fearful of the novel environment may have engaged the SNS. These findings add to the growing evidence that vagal regulation is associated with social engagement (Calkins, 1997; Porges et al., 1996; Suess & Bornstein, 2000).

Typically, one-year-old infants react to a novel person with wariness (Bretherton & Ainsworth, 1974), a state characterized by both engagement and disengagement. However, we found that the vagally regulated infants were more socially engaged, exhibiting positive, non-fearful responses during an hour long visit. Our findings do not necessarily mean that these infants were not aroused by the novelty of a laboratory visit. Indeed, they may have reacted emotionally, but they may also have had the ability to regulate their reactivity behaviorally. For example, previous research suggests that gaze aversion functions to regulate arousal while keeping the infant oriented toward the social interaction partner (Field, 1981; Stifter & Moyer, 1991; Waters, Mata & Sroufe, 1975). The IBR, however, was not designed to capture subtle regulatory behaviors such as gaze aversion. Thus, it may be that the infants who could effectively regulate V_{NA} used behaviors such as gaze aversion to regulate whatever level of arousal was produced by the unfamiliar person and environment and by doing so were able to

maintain their approach orientation. Importantly, higher baseline V_{NA}, which has been empirically linked to regulatory behavior (Calkins, 1997; Stifter & Jain, 1996), was related to increased vagal regulation in the present study. Future investigations would benefit from close detailed observation of regulatory behaviors during novel situations.

Whereas the infants who were better able to regulate their vagal tone were more responsive and positive in their orientation to the experimenter, no relationship was found for the more closely examined stranger-infant interaction procedure. In addition, social approach as measured by the IBR was unrelated to behavior during the stranger interaction. Despite showing more approach behaviors overall, the average response of the infants toward the stranger appears to vary by episode rather than being predominantly ambivalent as might be expected for infants during this developmental stage. Ambivalence, operationalized as alternately looking toward and away from the stranger, was the behavior least frequently exhibited by infants in our sample. This patterning of response by episode may account for the null finding regrading vagal regulation. Porges (1998) has suggested that vagal regulation occurs only when the environment is perceived as safe, while research on procedural differences during stranger approach indicate that longer and gradual interactions with strangers result in more social engagement (Sroufe, 1977). It may be that the stranger-infant interaction was not perceived as safe by the infant despite the presence of the mother and the gradual approach of the stranger. The brief two minute warm-up (stranger entry and stranger/mother episodes) prior to the stranger interation may have been sufficiently arousing to negate any relationship expected between vagal regulation and social engagement. As the IBR was based on behavior across the entire laboratory visit, infants had ample opportunity to become familiarized with the experimenter and the laboratory setting, and thus, may have exhibited more characteristic behavior.

The context within which vagal regulation was measured may also explain the null relationship with behavior toward the stranger. Though we followed similar procedures found in previous studies (DeGangi, et al., 1991; Porges et al., 1996) by recording heart rate during the administration of the Bayley exam, many infants did not show decreases in vagal tone. Rather, 39% showed an increase in V_{NA}. It is possible that the tasks of the Bayley were not consistently "cognitively challenging" for some of the infants, resulting in significant shifts in cardiac vagal tone across the 5 minute procedure.

Baseline measures of cardiac vagal tone were related to observed behavior. Baseline cardiac vagal tone was positively related to activity level and negatively related to reactivity. Infants who exhibited high baseline V_{NA} were rated by observers as more active and less sensitive to changes in the environment than infants with low baseline V_{NA}. These findings, though modest, are consistent with Porges' (Porges et al., 1996) position that baseline or tonic measures of V_{NA} are distinct from phasic measures of cardiac vagal tone (vagal brake) and represent its homoeostatic function as well as the "potential energy" of the organism. This hypothesis is further supported by the fact that only vagal regulation was related to social approach, while the two dimensions most reflective of homoeostatic function were only related to baseline V_{NA}. Interesting, activity level was the most table dimension of the IBR measured in the present study.

Across the two types of measures -- specific and global -- activity level appears to have emerged as a central factor. Infants who were observed as highly active exhibited fewer withdrawn and more approach behaviors during the stranger interaction, and were rated by observers as higher in social approach. Activity level is the one dimension of temperament that has shown good stability across childhood, a finding which is likely due to its high heretability

(Braungart, Plomin, DeFries, & Fulker, 1992; Fagot & O'Brien, 1994). Although activity level at the extreme has been associated with aggressiveness, impulsivity, and noncompliance (Taylor, 1995), evidence also exists that it is related to more positive outcomes such as sociability and extroversion (Buss, Block, & Block, 1980; Escalona, 1968; Fagot & O'Brien, 1994). For example, Calkins and colleagues (Calkins, Fox & Marshall, 1996) examined the outcomes of four month old infants who exhibited high levels of motor activity as well as high levels of positive affect. Not only were the infants more outgoing at 14 months, but they also exhibited a pattern of brain asymmetry indicative of an approach orientation. Although the vagal regulation data suggest that social approach and activity level are related to different aspects of parasympathetic functioning (i.e. tonic vs. phasic V_{NA}, respectively), taken together they may represent an orientation outward rather than one of avoidance or withdrawal.

In summary, the results of the present study provide modest evidence that the ability to regulate vagal tone is related to social engagement. Because the effect sizes obtained in this study, while significant, were small, replication of the results is needed. In combination with other aspects of physiological and behavioral functioning, however, it appears that vagal regulation may be an important component of an infant's ability and willingness to engage the environment. As social engagement is a cornerstone of development, the ability to suppress vagal tone during emotional or cognitive challenges may have significant implications for the developmental trajectory of the individiual.

References

Ainsworth, M. D. S., & Wittig, B. (1969). Attachment and exploratory behavior of one-year-olds in a strange situation. In B. M. Foss (Ed.), Determinants of Infant Behavior, Volume 4 (pp. 111-136). London: Methuen.

Bates, J., & Bayles, K. (1984). Objective and subjective components in mothers' perceptions of their children from age 6 months to 3 years. Merrill-Palmer Quarterly, 30, 111-130.

Bayley, N. (1969). Bayley Scales of Mental Development. New York: Psychological Corporation.

Bowlby, J. (1982). Attachment and loss. Vol I: Attachment (2nd) ed.). New York: Basic Books.

Braungart, J., Plomin, R., DeFries, J., & Fulker, D. (1992). Genetic influence on tester-rated infant temperament as assessed by Bayley's Infant Behavior Record: Nonadoptive and adoptive siblings and twins. Developmental Psychology, 28, 40-47.

Bretherton, I., & Ainsworth, M. D. S. (1974). Responses of one-year-olds to a stranger in a strange situation. In M. Lewis & L. A. Rosenblum (Eds.), The Origins of fear (pp. 131-164). New York: John Wiley & Sons, Inc.

Buss, D., Block, J., & Block, J. (1980). Preschool activity level: Personality correlates

and developmental implications. Child Development, 51, 401-408.

Calkins, S. (1997). Cardiac vagal tone indices of temperamental reactivity and behavioral regulation in young children. Developmental Psychobiology, 31, 125-135.

Calkins, S., Fox, N., & Marshall, T. (1996). Behavioral and physiological antecedents of inhibited and uninhibited behavior. Child Development, 67, 523-540.

Campos, J. J., Emde, R. N., Gaensbauer, T., & Henderson, C. (1975). Cardiac and behavioral interrelationships in the reactions of infants to strangers. Developmental Psychology, 11(5), 589-601.

DeGangi, G., DiPietro, J., Greenspan, S., & Porges, S. (1991). Psychophysiological characteristics of the regulatory disordered infant. Infant Behavior and Development, 14, 37-50.

Escalona., S. (1968). The roots of individuality. Chicago: Aldine.

Fagot, B., & O'Brien, M. (1994). Activity level in young children: Cross-age stability, situational influences, correlates with temperament, and the perception of behavior problems. Merrill-Palmer Quarterly, 40, 378-398.

Field, T. (1981). Infant arousal, attention and affect during early interactions. In L. Lipsitt (Ed.), Advances in infancy (Vol. 1). New York: Ablex.

Gaensbauer, T. J., Emde, R. N., & Campos, J. J. (1976). Stranger distress: confirmation of a developmental shift in a longitudinal sample. Perceptual and Motor Skills, 43, 99-106.

Goldsmith, H. H., & Rothbart, M. K. (1991). Contemporary instruments for assessing early temperament by questionnaire and in the laboratory. In J. Strelau & A. Angleitner (eds.), Explorations in Temperament (pp. 249-272). New York: Plenum.

Kagan, J. (1994). Galen's prophecy. New York: Basic Books.

Porges, S. W. (1985). Method and apparatus for evaluating rhythmic oscillations in a periodic physiological response system (Patent No. 4,510,944).

Porges, S. W. (1995). Orienting in a defensive world: Mammalian modifications of our evolutionary heritage. A polyvagal theory. Psychophysiology, 32, 301-318.

Porges, S. W. (1997). Emotion: An evolutionary by-product o the neural regulation of the autonomic nervous system. In C. Carter, B. Kirkpatrick, & I. Lederhendler (eds.), The integrative neurobiology of affiliation. New York: Annals of the New York Academy of Sciences.

Porges, S. W. (1998). Love: An emergent property of the mammalian autonomic nervous system. Psychoneuroendocrinology, 8, 837-861.

Porges, S. W., Doussard-Roosevelt, J., Portales, A. & Grennspan, S. (1996). Infant regulation of hte vagal "brake" predicts child behavior problems: A psychobiological model of social behavior. Developmental Psychobiology, 29, 697-712.

Porges, S. W., Doussard-Roosevelt, J., Stifter, C., McClenny, B., & Riniolo, T. (1999). Sleep state and vagal regulation of heart period patterns in the human newborn: An extension of the polyvagal theory. Psychophysiology, 36, 14-21.

Porter, F., Porges, S., & Marshall, R. (1988). Newborn pain cries and vagal tone: Parallel changes in response to circumcision. Child Development, 59, 495-505.

Rothbart, M. K. (1981). Measurement of temperament in infancy. Child Development, 52, 569-578.

Slabach, E., Morrow, J., & Wachs, T. (1991). Questionnaire measurement of infant and child temperament. In J. Strelau & A. Angleitner (eds.), Explorations in temperament (pp. 205-

234). New York: Plenum.

Sroufe, L. A. (1977). Wariness of strangers and the study of infant development. Child Development, 48, 731-746.

Stifter, C. A., & Fox, N. (1991). Infant reactivity: Physiological correlates of newborn and 5-month temperament. Developmental Psychology, 26, 582-588.

Stifter, C. A., & Jain. A., (1996). Psychophysiological correlates of infant temperament: Stability of behavior and autonomic patterning from 5 to 18 months. Developmental Psychobiology, 29, 379-391.

Stifter, C. A., & Moyer, D. (1991). The regulation of positive affect: Gaze aversion activity during mother-infant interaction. Infant Behavior and Development, 14, 111-123.

Suess. P. & Bornstein, M. (2000). Task-to-task vagal regulation: Relations with language and play in 20-month-old children. Infancy, 1, 303-322.

Taylor, E. (1995). Dysfunctions of attention. In D. Cicchetti & D. Cohen (eds.) Developmental psychopathology Volume 2: Risk, disorder, and adaptation (pp. 243-273). New York: Wiley.

Waters, E., Matas, L. & Sroufe, L. A. (1975). Infants' reactions to an approaching stranger: Description, validation, and functional significance of wariness. Child Development, 46, 348-356.

Wilson, R., & Matheny, A. (1983). Assessment of temperament in infant twins. Developmental Psychology, 19, 172-183.

Author Note

Cynthia A. Stifter, Department of Human Development and Family Studies; Janet M. Corey, Department of Human Development and Family Studies.

This study was supported by a grant from the National Institutes of Mental Health (MH50843). We gratefully acknowledge the assistance of Narciestel Perez. We also want to thank the families that participated in the study.

Correspondence concerning this article should be addressed to Cynthia A. Stifter, Department of Human Development and Family Studies, 105 White, The Pennsylvania State University, University Park, Pennsylvania, 16802. Email: TVR@PSU.EDU

Table 1.

Means and Standard Deviations for the Study Variables

Variable	n	Mean	SD	
Autonomic variables				
Baseline V_{NA} (12 months)	133	3.81	.92	
Baseline V_{NA} (13 months)	123	3.84	.94	
Vagal brake[a]	120	.07	.55	
Stranger interaction				
Stranger entry	136	3.56	1.02	
Stranger/mom	136	3.51	1.02	
Stranger/baby	136	3.80	1.12	
Withdrawal	136	1.15	1.81	
Ambivalence	136	.95	1.59	
Approach	136	1.90	1.44	
IBR ratings				
12 Months				
Social approach	136	4.25	.44	
Task orientation	136	5.81	1.26	
Activity level	136	5.47	1.40	
Reactivity	136	6.27	1.24	(table continues)

Variable	n	Mean	SD
13 Months			
Social Approach	127	4.38	.42
Task Orientation	127	5.88	1.26
Activity Level	127	5.10	1.60
Reactivity	127	6.39	1.46

[a]Vagal regulation calculated by subtracting mean V_{NA} during Bayley from baseline V_{NA}. Both measurements taken during the 13 month visit.

Table 2.

Correlations between observer ratings using the IBR and social behavior toward the stranger

	IBR ratings							
	Mom Visit				Dad Visit			
Infant Behavior	Soc App	Task Or	Active	React	Soc App	Task Or	Active	React
Episode[a]								
Stranger entry	.09	.17*	.15+	-.12	-.14	.07	.24**	-.12
Stranger/mom	.08	.10	.18*	-.17*	-.14	.09	.25**	-.13
Stranger/baby	.10	.12	.06	-.29**	-.05	.02	.22**	-.07
Frequency[b]								
Withdrawal	-.07	-.10	-.15+	.14+	.10	-.11	-.26**	.12
Ambivalence	.00	.00	-.03	.00	.13	.05	.01	.17+
Approach	.20*	.18*	.18*	-.09	.08	.16+	.25**	.05

[a] Mean approach behavior during episode (higher levels represent greater approach).

[b] Frequency of behaviors across the entire stranger interaction.

+ - $p < .10$, * - $p < .05$, ** - $p < .01$

Figure Captions

Figure 1. Frequency of withdrawn, ambivalent, and approach behaviors during the three stranger interaction episodes.