

## Infant Temperament and Cardiac Vagal Tone: Assessments at Twelve Weeks of Age

Lynne C. Huffman, Yvonne E. Bryan, Rebecca del Carmen, Frank A. Pedersen, Jane A. Doussard-Roosevelt, and Stephen W. Porges

Sixty 12-week-old infants participated in a laboratory study to explore the relations between temperament and cardiac vagal tone. Temperament was evaluated via laboratory observations and maternal ratings. Cardiac vagal tone, measured as the amplitude of respiratory sinus arrhythmia, was quantified from beat-to-beat heart period data collected during a resting baseline period and during the laboratory assessment of temperament. Specific hypotheses were investigated relating temperament to both basal cardiac vagal tone and changes in cardiac vagal tone during social/attention challenges. Infants with higher baseline cardiac vagal tone were rated in the laboratory as showing fewer negative behaviors and were less disrupted by the experimental procedure. Infants who decreased cardiac vagal tone during the laboratory assessment were rated on maternal report temperament scales as having longer attention spans, and being more easily soothed.

### INTRODUCTION

The neural regulation of the autonomic nervous system frequently has been hypothesized to be related to behavioral dimensions of temperament (e.g., Kagan, 1982; Porges & Doussard-Roosevelt, in press; Rothbart, 1989). Specifically, two behavioral dimensions, reactivity and self-regulation, have been the focus of research and theory attempting to relate temperament to individual differences in autonomic activity (e.g., Rothbart & Derryberry, 1981). Reactivity refers to emotional, attentional, and motoric responses that are elicited by external stimuli (e.g., Rothbart, 1989; Strelau, 1989). In contrast, self-regulation ("activity" in Strelau's theory) implies an awareness of social and/or environmental context and reflects an internal control of behavior and visceral tone during which the individual systematically selects characteristics of the environment with which to engage and disengage. Selective attention and social interactions seem to be manifestations of this temperamental dimension of self-regulation (Eisenberg, 1996; Eisenberg et al., in press) and thus may share a common neurophysiological mechanism.

Porges (1976, 1992, 1995) proposed that measures of cardiac vagal tone, computed as the amplitude of respiratory sinus arrhythmia (RSA),<sup>1</sup> would provide

1. There is scientific discussion surrounding the use of RSA to index cardiac vagal tone. It has been argued that RSA is not a direct equivalent to tonic vagal control of the heart because it is determined by multiple peripheral and central processes; further, because predictive relations between RSA and vagal outflow can be degraded by ceiling and floor effects, cardiac or neural abnormalities, and variations in respiratory parameters (see Society for Psychophysiological Research Committee on Heart Rate Variability, Committee Report authored by Berntson et al.,

a sensitive index of an individual's ability to cope with disruptions to homeostasis (i.e., stress) and thus should be related to behavioral dimensions of reactivity, expressiveness, and self-regulation (Porges, 1991). Porges has argued that a primary role of the vagal system is to support mammalian growth and restoration. In this model, the vagal system functions as a physiological substrate for the supportive and organizing behaviors associated with feeding, social interactions, and calming. Several studies provide support for these hypotheses. Higher cardiac vagal tone has been associated with healthier newborns (Hofheimer, Wood, Porges, Pearson, & Lawson, 1995; Porges, 1992, 1995), greater behavioral reactivity in infants (Porges, Doussard-Roosevelt, Portales, & Suess, 1994), a more positive clinical course in neurosurgery patients (Donchin, Constantini, Szold, Byrne, & Porges, 1992), and greater social competency in young children (Doussard-Roosevelt, Porges, Scanlon, Alemi, & Scanlon, 1997).

The potential for cardiac vagal tone to serve as an index of temperament has been explored by Fox and his associates (e.g., Calkins & Fox, 1992; Fox, 1989; Fox & Calkins, 1993; Fox & Stifter, 1989; Stifter, Fox, & Porges, 1989). In these cross-sectional and longitudinal studies of infants between 5 and 14 months of age, baseline cardiac vagal tone was significantly related to measures of behavioral reactivity. Specifically, baseline cardiac vagal tone was positively cor-

1997). Nevertheless, the Committee has concluded that RSA is an important noninvasive window through which the complexities of the interaction between psychological states and autonomic control can be observed.

related with infants displaying interest, joy, and look-away behaviors when interacting with an unfamiliar adult (Stifter et al., 1989) and with infant emotional reactivity to positive, novel, and mildly stressful stimuli (Calkins & Fox, 1992; Fox, 1989; Fox & Calkins, 1993). These findings were supported by other data collected by Richards and Cameron (1989), who employed spectral analysis to measure the "extent of respiratory sinus arrhythmia" in infants at 14, 20, and 26 weeks of age concurrently with a mother-rated temperament questionnaire; these reports also suggest that infants with high heart rate variability (usually associated with high cardiac vagal tone) tend to be less behaviorally inhibited (i.e., more reactive) and exhibit more frequent approach behaviors.

Although cardiac vagal tone is relatively stable under steady state such as a quiet alert baseline condition (Fracasso, Porges, Lamb, & Rosenberg, 1994; Izard et al., 1991; Porges et al., 1994; Porter, Bryan, & Hsu, 1995; Richards & Cameron, 1989), it is sensitive to environmental demands and stimulation (e.g., DiPietro & Porges, 1991; Hofheimer et al., 1995; Porter, Porges, & Marshall, 1988). Rapid changes in cardiac vagal tone often parallel shifts in the cardiac output required to match metabolic demands (i.e., withdrawal of cardiac vagal tone promotes increased heart rate and cardiac output). For example, the increased sucking activity observed during feeding requires a shift in metabolic resources to support ingestive behavior and is characterized by a decrease in cardiac vagal tone (Portales et al., in press). Likewise, pain cries in response to circumcision are paralleled by decreased cardiac vagal tone (Porter et al., 1988).

Recently, Porges has proposed a Polyvagal Theory (1995, 1997) that provides a neuroanatomical and neurophysiological justification for studying cardiac vagal tone as an index of behavior and behavioral style or temperament. According to the Polyvagal Theory, the evolution of the mammalian autonomic nervous system, and especially the brainstem regulatory centers of the vagus and related cranial nerves, provides the neurophysiological substrates for the affective processes that are a major component of social behavior. The polyvagal system comprises the more primitive, unmyelinated dorsal motor nucleus of the vagus and the more phylogenetically recent ("mammalian"), myelinated nucleus ambiguus.<sup>2</sup> An evolu-

tionary shift in the primary regulation of heart rate from the dorsal motor nucleus of the vagus to regulation via the nucleus ambiguus is associated with the acquisition of behavioral strategies that include emotional expression, movement, and communication.

The Polyvagal Theory articulates how these three phylogenetically ordered components of the autonomic nervous system (i.e., nucleus ambiguus vagal system, sympathetic nervous system, and dorsal motor vagal system) are related to the expression of emotion, social engagement behaviors, and visceral regulation. Although aspects of emotion are observable on all three levels, the more flexible and prosocial emotions (e.g., conveyed through facial expressions, vocalizations) are associated with the nucleus ambiguus system (see Porges, 1997). Successful emotion and behavioral regulation are dependent on the maintenance of control of the mammalian (nucleus ambiguus) vagal system. The commonly used index of cardiac vagal tone is actually an index of the influence of nucleus ambiguus vagal tone on the heart. The functional output of the vagal fibers originating in the nucleus ambiguus and terminating on the sino-atrial node produces a heart rate pattern with the characteristic respiratory rhythm, respiratory sinus arrhythmia (Richter & Spyer, 1990). Thus, the calculation of the amplitude of respiratory sinus arrhythmia provides an estimate of the nucleus ambiguus vagal system. The ability to document both level of cardiac vagal tone and the systematic withdrawal and reengagement of the "vagal brake" as a mechanism to rapidly regulate metabolic output and change state in support of the behavioral response to challenge may provide quantifiable indices of individual differences associated with emotion reactivity and regulation or temperament.<sup>3</sup>

Two aspects of cardiac vagal tone, basal level and change in cardiac vagal tone (i.e., the regulation of the vagal brake), often are correlated; however, each aspect appears to be more strongly related to different dimensions of temperament (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). Basal level

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mobilization of fight or flight behaviors. And finally, if fight or flight behaviors do not provide the desired effect, the more primitive dorsal vagal system may be elicited, a system that is metabolically conservative and functionally adaptive for reptiles, but potentially lethal for mammals.

3. Because the intrinsic heart rate in humans is substantially faster than the resting level, the regulation of vagal control of the heart (via myelinated pathways originating in the nucleus ambiguus) provides the primary mechanism to rapidly increase and decrease heart rate. These transitory decreases and increases in cardiac vagal tone function like the removal and reengagement of a "vagal brake." Comparison of cardiac vagal tone estimates across conditions provides an index of the regulation of the "vagal brake."

2. It has been proposed that neural responses to environmental (and other) challenges are hierarchical (see Jackson, 1958). There is an initial response with gradations of the new vagal system (i.e., pathways originating in the nucleus ambiguus) to regulate metabolic output via chronotropic control of the heart and to provide facial gestures and vocalizations. If the nucleus ambiguus vagal system is not effective, then the metabolically costly sympathetic nervous system is engaged to promote the

of cardiac vagal tone has been correlated with behavioral reactivity and state maintenance or change. Thus, basal cardiac vagal tone appears to be related to the behavioral consequences of disrupting homeostasis and the ability of the infant to return to behavioral and /or physiological homeostasis, independent of social intervention. In contrast, the vagal brake provides a neurophysiological mechanism for the infant to utilize social and attentional behaviors that require an awareness of environmental context and an ability to actively engage or disengage with elements in the environment. Thus the appropriate use of the vagal brake would promote the development of regulatory strategies. Data from 24 9-month-olds support the model of the vagal brake, demonstrating that infants with difficulties in decreasing cardiac vagal tone during a social / attentional task at 9 months of age exhibited significantly more behavior problems at 3 years of age than did peers who decreased cardiac vagal tone during the task (Porges et al., 1996).

The current study evaluates whether the two dimensions of cardiac vagal tone (basal level and change in cardiac vagal tone during challenge) are related differentially to temperamental dimensions of emotional reactivity and regulation in 12-week-old infants. At this age, emotional reactivity is manifested as individual differences in the onset, duration, and intensity of expressions of happiness, fussiness, and distress to limits, whereas regulation is marked by attentional persistence or duration of orienting as well as soliciting and keeping contact with social stimulation (Rothbart, 1986). The age selected for this study is important as it corresponds to the earliest qualitative turning point in behavioral development, as proposed by Spitz (1965; Spitz, Emde, & Metcalfe, 1970) and further documented by Emde (see "biobehavioral shifts" in Emde, Gaensbauer, & Harmon, 1976). This stage of developmental reorganization is marked by the disappearance of endogenous (reflexive) smiling and infantile fussiness as well as the emergence of exogenous (social) smiles and a beginning recognition of objects (Sroufe, 1996). At this age, seeking and maintaining social contact becomes more prominent (Emde et al., 1976). Longitudinal studies of continuity and change in the emotional dimensions of temperament have concluded that, around 6–8 weeks of age, there are significant increases in happiness and interest, a declining trajectory for anger, and stability of soothability (Denham, Lehman, Moser, & Reeves, 1995; Rothbart, 1986; Worobey & Blajda, 1989). In this study, a 12 week criterion has been utilized to ensure a richness and consistency of behavioral patterning (see Thomas &

Chess, 1977). It is likely that this is the earliest age at which a correspondence between specific aspects of cardiac vagal tone and dimensions of temperament may be evident. Early identification of correspondence patterns ultimately has implications for the design of early intervention strategies for regulatory-disordered and other infants (DeGangi, DiPietro, Greenspan, & Porges, 1991; DeGangi, Porges, Sickel, & Greenspan, 1993).

## METHOD

### Participants

Sixty-five infants born to married couples were recruited as part of a longitudinal investigation of early influences on infant behavioral and developmental outcome. Mothers had a mean age of 29.8 years ( $SD = 3.4$ ), fathers had a mean age of 30.8 years ( $SD = 5.8$ ), and mean length of marriage was 3.6 years ( $SD = 2.2$ ). All participants were from middle- to upper-middle socioeconomic classes (determined by number of years of paternal education;  $M = 16.8$ ,  $SD = 2.3$ ) and were predominantly European American. Of the 65 firstborn children, five infants were excluded on the following medical grounds: one infant born prematurely (<37 weeks) had neonatal apnea and required a respiratory monitor for 6 months, one infant had trisomy 21, two infants were readmitted to the hospital with unconjugated hyperbilirubinemia requiring phototherapy, and one infant was born with meconium aspiration syndrome and low Apgar scores. Preliminary analyses confirmed that the infants in this subgroup were outliers in the data distribution on many of the temperament variables. These analyses supported the clinical basis for exclusion. Of the 60 healthy infants included in the present analyses, 31 were males and 29 were females. Mean age at testing was 11.7 weeks ( $SD = .5$ ).

### Materials

*Laboratory-rated temperament.* The Behavioral Response Paradigm (BRP) was used as a laboratory assessment of temperament (Garcia Coll et al., 1988; Wolk, Zeanah, Garcia Coll, & Carr, 1992). The BRP consists of a series of 17 vignettes, each 30 s in length, incorporating visual, auditory, and tactile stimuli. The procedure takes approximately 15 min, during which the examiner presents each stimulus in a fixed order to the infant. The initial vignettes elicit reactions to social stimulation, whereas the last vignettes use sensory stimuli that are presumed to be increasingly discrepant from the infant's usual experiences.

Exploration of concurrent validity at 3 months of age in a group of combined term and preterm infants (Garcia Coll, Halpern, Vohr, & Seifer, 1992) has suggested that individual differences in positivity, negativity, sociability, and the amount of calming required are related to Difficulty and Unadaptability on the caregiver-rated Infant Characteristics Questionnaire (ICQ; Bates, Bennett-Freeland, & Lounsbury, 1979). Specifically, ICQ Difficulty was positively correlated with BRP Negativity, whereas ICQ Difficulty was negatively correlated with BRP Positivity and Sociability scores.

*Parent ratings of temperament.* The Infant Behavior Questionnaire (IBQ) is a caregiver report instrument for assessing infant temperament, with 87 items rated on a 7 point scale (Rothbart, 1981). The IBQ is grounded in a psychobiological theory of temperament and is designed to describe the frequency of specific concrete behaviors of infants. Internal reliability for six temperament dimensions, as estimated by coefficient alpha, range from .67 to .85, with a median value of .80 (Rothbart, 1981). Further, the IBQ has demonstrated moderate convergence with home observation assessments of temperament (average  $r_s = .47, .40,$  and  $.67$  at 3, 6, and 9 months of age, respectively), as well as relative stability of positive reactivity measures across 3 and 6 month periods (Rothbart, 1986). Responses are made on the basis of the infant's behavior during the previous week. After the laboratory visit, mothers completed the IBQ at home and returned the forms by mail.

### Design and Procedure

The experimental session was scheduled for a time determined by the mother to be optimal with regard to the infant's sleep schedule (i.e., when the infant would be alert and rested) and immediately before an expected feeding. On arrival at the laboratory, the infant was fed and, if necessary, changed. One of the 60 infants was too sleepy to begin the session and required rescheduling. Informed consent was obtained from the mother of the child. The entire session lasted about 20 min and was videotaped. The experimental session consisted of a baseline period for the monitoring of the heart rate variables, and a laboratory-administered evaluation of infant temperament. Infant electrocardiogram (ECG) was monitored during the baseline and temperament evaluation via two disposable Ag-AgCl electrodes placed on the infant in a cross-chest fashion. ECG data were acquired using a Transkinetics telemetry monitoring system and stored on a Vetter FM tape recorder (model C-4) for off-line analyses.

During a baseline period, the infant was placed on a soft pad in the supine position. When the infant was noted to be in a stable, quiet, alert state, the heart rate data were collected for at least 2 continuous minutes. At the start of the laboratory evaluation of temperament, the infant was seated in an infant seat and allowed to return, if necessary, to a quiet alert state. ECG was recorded continuously during the administration of the BRP. The only interruptions were during calming required to return a distressed infant to a quiet alert state. By virtue of these calming procedures, all infants were able to complete the BRP.<sup>4</sup>

### Quantification of Data

*Behavioral Responsiveness Paradigm.* Videotapes of the BRP were reviewed by trained research assistants. Each stimulus presentation was coded using criteria described by Garcia Coll et al. (1988). Summary scores for five scales were calculated: Positive and Negative reactivity (high scores = more positive or more negative responses to stimuli), Sociability (high score = more sociable approach behavior), Soothing or calming required (high score = more frequent and greater degree of soothing by experimenter required to complete paradigm), and Overall Activity (high score = total frequency of behavioral responses, independent of affect) were derived from behavioral observations by coders who were unaware of the infants' characteristics. Fourteen percent of the infants were assessed for intercoder reliability. Using intraclass correlation coefficients (ICC; Bartko, 1966), which provide a measure of agreement between raters on dimensional rating scales, reliability for each composite factor score was achieved, first to a criterion measure (scored videotapes provided by Garcia Coll) and maintained (ICCs .90–1.0, except Overall Activity ICC = .69). Due to the relatively poor reliability, the Overall Activity scale was not analyzed.

*Infant Behavior Questionnaire.* For the IBQ, six scales were calculated. As described by Rothbart and

4. Although the shift from supine during baseline to "sitting" in the infant seat during testing does confound posture change with the condition change, there is little reason to believe that change in vagal tone in response to the testing could be attributed to the posture shift. Evidence from adult data suggests that although there are changes in Traube-Hering-Meyer variance associated with baroreceptor response to posture shifts, there is no significant change in vagal tone as a result of the shift from supine to tilt position (Byrne & Porges, 1992). The infant positioning (supine versus infant seat) was chosen in this study to decrease environmental stimulation during the baseline while facilitating unencumbered infant head and limb movement as well as infant-examiner eye contact during testing.

Derryberry (1981), scales reflected the following temperament dimensions: (1) Activity (high score = high activity), (2) Smiling (high score = positive emotionality), (3) Fear or Distress and Latency to Approach Novel Stimuli (high score = long latency to approach novelty), (4) Distress to Limitations (high score = high distress to limits), (5) Soothability (high score = easily soothed), and (6) Duration of Orienting (high score = long visual fixation span).

Heart period and cardiac vagal tone measures (index of cardiac vagal tone [ $V_{NA}$ ]). The data were quantified off-line by replaying the tape into a PDP 11/23 computer to detect the peak of the R-wave of the EKG and to time sequential heart periods (i.e., R-R intervals) to the nearest millisecond. A file of sequential heart beats was stored on a PC. MXedit software (Delta-Biometrics, Inc.) was used to visually display the heart period (HP) data, to edit outliers, and to quantify task-related measures of heart period and cardiac vagal tone. MXedit incorporates the Porges (1985) method of calculating the amplitude of RSA. The method, when applied to infants, employs heart period values measured to the nearest millisecond. The sequential heart periods are resampled into equal time intervals every 250 msec. The time-sampled data are detrended with an algorithm designed to remove from the heart rate pattern the variance associated with complex changing base level and oscillations with periodicities slower than RSA. The detrending algorithm applies a moving polynomial filter (3rd order 21-point) to remove aperiodic baselines and slow oscillations. The residual output of the moving polynomial is bandpassed, and the heart period variance in the frequency band associated with spontaneous breathing in young infants (i.e., 0.24–1.04 Hz) is quantified and reported in units of  $\ln(\text{msec})^2$ . This value represents the amplitude of RSA and is the index of cardiac vagal tone. In earlier papers, this index has been designated as  $V$  (e.g., Porges, 1992; Porges et al., 1994). To emphasize that RSA is neurophysiologically the product of only the vagal pathways originating in the nucleus ambiguus, the index is now designated  $V_{NA}$ . Note that vagal tone, even to the heart, is a complex construct, and vagal pathways may originate in several areas of the brainstem. However, there is neurophysiological and electrophysiological evidence to support the unique contribution of the nucleus ambiguus to RSA (see Porges, 1995, 1997 for reviews).

The data were quantified during two phases: (1) Baseline, and (2) Challenge (final portion of the BRP; this portion was selected to evaluate the behavioral and physiological state of the infant during the most arousing vignettes). Baseline HP and baseline  $V_{NA}$  were quantified for 120 s during a quiet behav-

ioral state (see above). Heart period and  $V_{NA}$  also were quantified for the final 120 s of the BRP (Challenge) condition. Heart period and  $V_{NA}$  were calculated for sequential 10 s epochs within each condition from the beat-to-beat HP data files. The Porges method (1985), incorporated in the MXedit software, enables the calculation of RSA as an index of cardiac vagal tone over sequential short epochs. Twelve sequential 10 s epochs were selected to minimize the input of outlier behaviors and to maximize a measure of central tendency. The data for each infant included 12 epochs each for Baseline and Challenge. To examine physiological change elicited by social and cognitive challenges during the BRP, difference scores were calculated by subtracting the Baseline values from the Challenge values for both HP and  $V_{NA}$  (i.e., negative scores reflect shorter heart periods and lower cardiac vagal tone during the final portion of the BRP Challenge relative to the Baseline condition).

## RESULTS

To explore the relations between temperament and cardiac vagal tone, analyses were conducted in two phases: First, descriptive statistics were used to describe scores on physiological and temperament variables, and correlation analyses were run to examine the intercorrelations among variables within each construct. Second, the infants were divided into groups based on baseline cardiac vagal tone and the direction of change during the BRP. There was little reason to believe that each gradation of change in baseline cardiac vagal tone would be associated with a unique temperamental profile. However, there is evidence to suggest that higher rather than lower cardiac vagal tone is associated with more difficult temperament (e.g., Porges, Doussard-Roosevelt, Portales, & Suess, 1994). Thus, infants were divided into two groups (mean split) based on baseline cardiac vagal tone for analyses. In addition, there is evidence to suggest that suppression of cardiac vagal tone during a challenge is related to temperamental and behavioral differences. Thus, another set of analyses was conducted, comparing infants who suppressed cardiac vagal tone during the challenge to those who did not. One-way analyses of variance were conducted relating baseline cardiac vagal tone categories (high baseline  $V_{NA}$  versus low baseline  $V_{NA}$ ) and change in cardiac vagal tone (increase versus decrease) to each of the 10 temperament scales.

### Descriptive Statistics and Correlations

Table 1 presents the means and standard deviations for the BRP and IBQ scales as well as the auto-

**Table 1 Means and Standard Deviations for Autonomic and Temperament Data ( $n = 60$ )**

Variable	<i>M</i>	<i>SD</i>
BRP:		
Positivity	3.3	2.2
Negativity	5.0	2.3
Sociability	35.9	17.2
Calming required	2.4	2.2
IBQ:		
Activity	3.4	.8
Smiling	3.7	.7
Fear	2.3	.7
Distress to limits	3.6	1.2
Soothability	4.3	1.1
Orienting	4.5	.9
Autonomic measures:		
Heart period baseline (msec)	403.4	30.9
Heart period during challenge (msec)	403.4	32.3
Change in HP (msec)	-.02	25.2
Cardiac vagal tone baseline (ln msec <sup>2</sup> )	2.60	.82
Cardiac vagal tone during challenge (ln msec <sup>2</sup> )	2.73	.73
Change in cardiac vagal tone (ln msec <sup>2</sup> )	.14	.67

autonomic measures. Table 2 provides the correlations among the temperament scales, and Table 3 presents the correlations among the autonomic measures.

*Temperament.* Correlations were calculated to investigate the relations among scales within and between each temperament instrument (Table 2). All scales of the BRP were interrelated. There were greater distinctions among the IBQ scales, with Smiling correlated positively with Activity and negatively with Duration of Orienting as well as positive correlations among Distress to Limits, Soothability, and

Duration of Orienting. These correlations are consistent with Rothbart's report (1986) that utilized a principal components analysis to establish the derivation of two summary temperament factors for 3-month-olds: positive reactivity (smiling and laughter, vocal activity, and general activity) and negative reactivity (including fear and distress to limitations). We did not find the expected correlations between Fear and Distress to Limits; this may be attributed to the relatively low levels and low standard deviations of ratings of fearfulness in our sample. As Rothbart did not operationalize Duration of Orienting in her study of 3-month-olds, it is not possible to compare our correlations linking Duration of Orienting with Smiling, Distress to Limits, and Soothability. Of interest, save some trends (BRP Positivity tended to be positively correlated with IBQ Activity, whereas BRP Sociability tended to be negatively correlated with IBQ Fear and positively correlated with IBQ Distress to Limits), there were no intercorrelations between IBQ and BRP scales. This suggests that, in this population, the two measures of temperament were assessing independent processes.

*Heart period and cardiac vagal tone index.* Table 1 presents the means and standard deviations for the autonomic measures of basal HP and  $V_{NA}$  (Baseline), HP and  $V_{NA}$  during the BRP (Challenge), and the HP and  $V_{NA}$  difference scores (Change from Baseline to Challenge). As shown in Table 3, there were significant and strong correlations among all autonomic measures, with the exception of the  $V_{NA}$  difference score. The Change  $V_{NA}$  showed no relation to Challenge HP and a weak negative correlation with Baseline HP. Of theoretical interest, there was a negative correlation between Baseline  $V_{NA}$  and Change  $V_{NA}$ ,  $r(60) = -.53$ ,  $p < .005$ , demonstrating that infants with higher baseline cardiac vagal tone exhibited significantly

**Table 2 Intercorrelations among Temperament Scales ( $n = 60$ )**

	BRP				IBQ					
	Positivity	Negativity	Sociability	Calming Required	Activity	Smile	Fear	Distress to Limits	Soothability	Duration of Orienting
BRP Positivity		-.30*	.56***	-.39***	.23	.02	-.17	.20	.13	.21
BRP Negativity			-.34**	.47***	-.04	-.01	.14	-.09	-.19	-.05
BRP Sociability				-.33**	.09	-.09	-.24	.24	.05	.17
BRP Calming required					-.12	-.03	.01	.03	.08	.05
IBQ Activity						.36**	.25	-.03	-.11	-.05
IBQ Smiling							.06	.09	-.12	-.28*
IBQ Fear								-.16	-.10	.03
IBQ Distress to limits									.52***	.38***
IBQ Soothability										.53***
IBQ Duration of orienting										

\*  $p < .05$ ; \*\*  $p < .01$ ; \*\*\*  $p < .005$ .

**Table 3 Intercorrelations among Physiological Variables (*n* = 60)**

	Baseline HP	Challenge HP	Change HP	Baseline V <sub>NA</sub>	Challenge V <sub>NA</sub>	Change V <sub>NA</sub>
Baseline HP		.68***	-.35**	.53***	.36***	-.26*
Challenge HP			.44***	.37***	.49***	.08
Change in HP				-.18	.18	.42***
Baseline V <sub>NA</sub>					.64***	-.53***
Challenge V <sub>NA</sub>						.32*
Change in V <sub>NA</sub>						

\* *p* < .05; \*\* *p* < .01; \*\*\* *p* < .005.

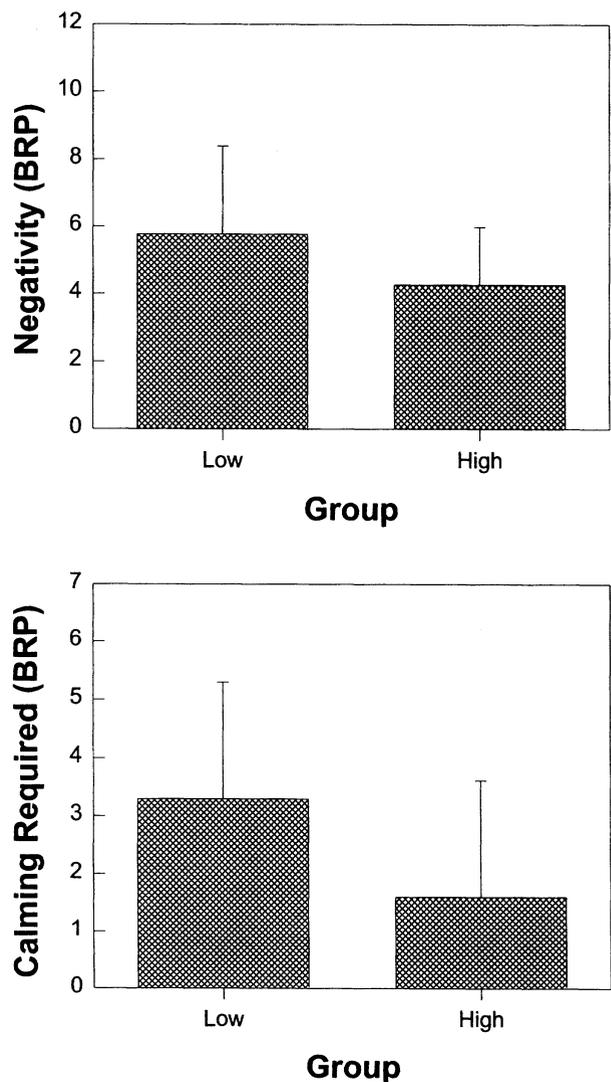
greater decreases in cardiac vagal tone during the BRP. Gender and weight variables were not related to Baseline V<sub>NA</sub>.

Grouping variables were derived from the Baseline V<sub>NA</sub> values and the V<sub>NA</sub> change scores. Based on a mean split (median split yielded the same division), infants were divided into high Baseline V<sub>NA</sub> (*M* = 3.26, *SD* = .47) and low Baseline V<sub>NA</sub> (*M* = 1.93, *SD* = .48). Similarly, infants were divided into two groups based on change in the cardiac vagal tone index by the end of the BRP relative to baseline level. Participants who decreased cardiac vagal tone during BRP Challenge (*n* = 22) were assigned to a negative change score group (*M* = -.54, *SD* = .36), and those who increased or did not change cardiac vagal tone (*n* = 38) were assigned to a positive change score group (*M* = .53, *SD* = .46).

**Relation of Autonomic and Temperament Measures**

Analyses of variance were used to examine the relation between cardiac vagal tone groups and temperament scales from the BRP and IBQ. One-way analyses of variance on ranks, with baseline cardiac vagal tone (high, low) as a grouping factor, indicated significant effects for baseline cardiac vagal tone as a grouping variable for two of the scales of the BRP: Negativity, *F*(1, 58) = 5.19, *p* < .05, and Calming Required, *F*(1, 58) = 9.51, *p* < .01. As illustrated in Figure 1, the groups of infants with high baseline cardiac vagal tone (V<sub>NA</sub>) were less negative and required less Calming to complete the laboratory BRP than the infants who had low baseline cardiac vagal tone. There were no main effects of baseline cardiac vagal tone grouping for the scales of the BRP, nor were there significant baseline group × regulation group interactions.

In contrast, one-way analyses of variance indicated significant effects for the regulation of cardiac



**Figure 1** Negativity and calming required scores from the Behavioral Responsiveness Paradigm as a function of groups based on baseline cardiac vagal tone (low baseline V<sub>NA</sub> [*n* = 30] versus high baseline V<sub>NA</sub> [*n* = 30]).

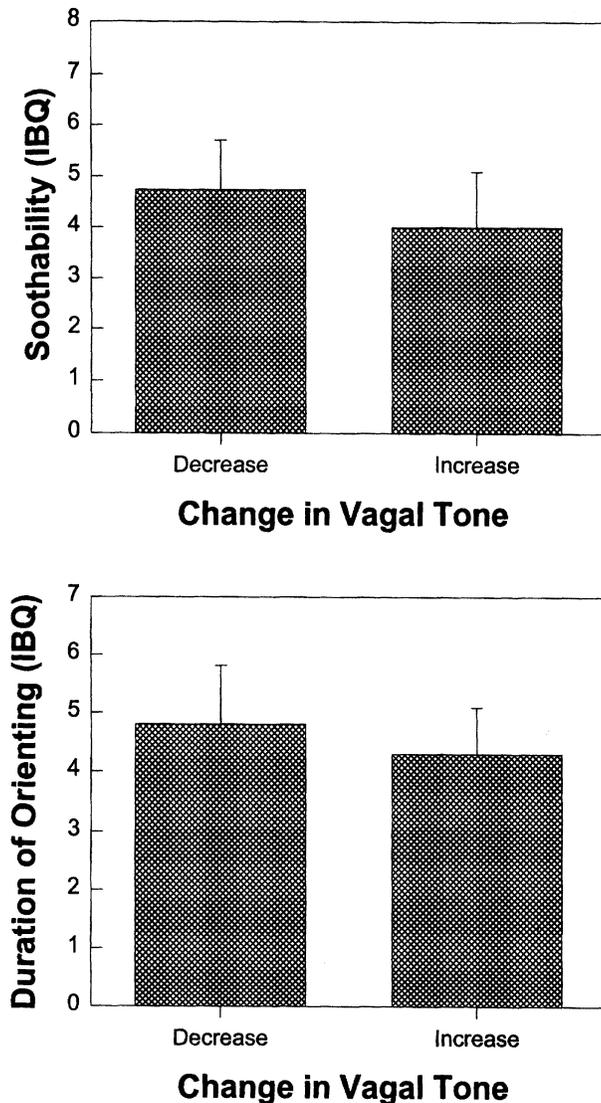


Figure 2 Soothability and duration of orienting scores from the Infant Behavior Questionnaire as a function of groups based on change in cardiac vagal tone during challenge (decrease in  $V_{NA}$  from baseline [ $n = 22$ ] versus increase in  $V_{NA}$  from baseline [ $n = 38$ ]).

vagal tone as a grouping variable for two of the scales of the IBQ: Soothability,  $F(1, 58) = 6.93, p < .05$ , and Duration of Orienting,  $F(1, 58) = 4.68, p < .05$ . As illustrated in Figure 2, infants who decreased cardiac vagal tone during challenge were rated by their mothers as being easier to soothe and calm and as having longer durations of orienting. Infants who did not exhibit regulation of cardiac vagal tone during the BRP challenge (i.e., no decrease in  $V_{NA}$ ) were reported to be more difficult to soothe, and to have shorter durations of orienting. There were no main effects of regulation group on the scales of the IBQ,

nor were there significant baseline group  $\times$  regulation group interactions.

## DISCUSSION

This study was conducted to evaluate several hypotheses relating to associations between temperament and cardiac vagal tone. First, based on the Polyvagal Theory (Porges, 1995, 1997; Porges et al., 1996), it tested whether base level cardiac vagal tone and the regulation of the vagal brake (i.e., changes in cardiac vagal tone in response to a challenge) were related to different dimensions of temperament. Second, this study provided an opportunity to evaluate the proposed link between the Rothbart reactivity/self-regulation model of temperament (Rothbart & Derryberry, 1981; Rothbart & Posner, 1985) and the two measures of cardiac vagal tone, which have been proposed to be mediators of reactivity/self-regulation (e.g., Fox, 1989; Porges, 1991; Porges, Doussard-Roosevelt, & Maiti, 1994). Third, the study evaluated the relation between an objective laboratory observation and a maternal questionnaire-based measure of temperament.

The findings demonstrated that the two cardiac vagal tone measures (i.e., baseline and change in cardiac vagal tone during challenge) were correlated,  $r(1, 59) = -.53$ ; nonetheless, each was more strongly related to different dimensions of temperament. Baseline  $V_{NA}$ , which was related to negativity and the amount of experimenter intervention required to calm the infant during the experimental paradigm, appears to subserve an individual's ability to maintain an organized behavioral state. Basal cardiac vagal tone may reflect a physiological substrate that is sensitive to an individual's level of arousal or reactivity (positive or negative). The present study has shown a relation with negativity, whereas previous research has shown a relation between higher baseline  $V_{NA}$  and both positive and negative behavioral reactivity (e.g., Fox, 1989). Taken together, extant data suggest that higher baseline should be related to appropriate reactivity. In situations of physical restraint (e.g., Fox, 1989; Stifter et al., 1989), circumcision (Porter et al., 1988), or heelstick (Gunnar, Porter, Wolf, Rigatuso, & Larson, 1995), the appropriate response would be negative reactivity. However, in response to social and attentional stimulation, as in this study, less negative reactivity is the adaptive response. Overall, low baseline cardiac vagal tone might index hypersensitivity or a vulnerability to disruption of behavioral homeostasis.

In contrast, change in cardiac vagal tone or regulation of the vagal brake, which was related to the IBQ

scales of orienting and soothability, appears to index social and attentional behaviors. These findings suggest that the appropriate regulation of the vagal brake provides a physiological metaphor for the Posner and Rothbart (1980) model that considers attention as an important behavioral strategy for self-regulation and arousal modulation. Consistent with the Posner and Rothbart model, the vagal brake provides the transitory changes in vagal inhibition of the heart that occur during attention and prosocial strategies of social engagement. This study of 3-month-olds supports research findings in 9-month-old infants (Porges et al., 1996) and older children (Eisenberg, 1996; Gottman, Katz, & Hooven, 1996) in proposing that the optimal regulation of the vagal brake is related to positive social and attentional behaviors that require an awareness of environmental context.

The consistency in these findings may be explained by the Polyvagal Theory (Porges, 1995) and an elaboration of how the vagal brake might be related to social behavior (Porges et al., 1996). In these papers, Porges and his colleagues propose that baseline measures of cardiac vagal tone are related to visceral homeostasis, and that changes in cardiac vagal tone (i.e., regulation of the vagal brake) reflect the individual's strategy to engage and disengage with elements in the environment. Accordingly, strategies of increasing and decreasing cardiac vagal tone would be paralleled by shifts in metabolic output and behavior to cope with changing environmental demands. To promote parallel increases in metabolic output and behavioral activity, the vagal brake would be withdrawn to remove its inhibitory effect on heart rate. To promote parallel decreases in metabolic output and increases in calmness, the brake would be reengaged.

The neural mechanisms underlying the regulation of the vagal brake have been hypothesized to involve specific pathways descending from frontal cortex via corticobulbar pathways and synapsing directly on the source nucleus of the vagal efferent pathways (i.e., nucleus ambiguus) that regulate the amplitude of RSA (i.e., cardiac vagal tone index) (see Figure 14-23, "Diagram of the 'corticobulbar' pathways in the brain stem"; Truex & Carpenter, 1969). Thus, executive functions such as attention and voluntary attempts to socially engage others may be mapped functionally into the response profile of the vagal brake and may be quantified as changes in cardiac vagal tone. In contrast to the role that the vagal brake plays in the dynamic regulation of cardiac output, base level cardiac vagal tone is more sensitive to the status of the negative feedback between the heart and the brainstem. Higher cardiac vagal tone would re-

flect a negative feedback system less vulnerable to disruption and more supportive of growth and restoration functions. The temperament dimensions observed in this study, which were correlated with the two cardiac vagal tone measures, fit a neurophysiological explanation relating base level cardiac vagal tone to homeostatic processes and the regulation of the vagal brake to dynamic executive and prosocial behaviors.

With regard to the relations between different temperament measures, correlations between the laboratory-based BRP measures and the maternal report IBQ scales were not statistically significant. Although there have been reports of correlations between parental responses and laboratory assessments of temperament (e.g., Goldsmith & Campos, 1990; Gunnar, Mangelsdorf, Larson, & Hertzgaard, 1990; Wolk et al., 1992), there are few studies that have examined these relations in 3-month-olds (e.g., Crockenberg & Acredolo, 1983; Hagekull, Bohlin, & Lindhagen, 1984; Rothbart, 1986). In those few reports, the correlations have been modest. It has been proposed that such modest correlations could come, in part, from observers simply not seeing the behavior that parents based their reports on (Rothbart & Bates, *in press*).

Our results suggest that, in 3-month-old infants, laboratory assessment and maternal questionnaire are assessing different dimensions of temperament. In the laboratory setting, the infant is systematically challenged by a series of novel social and sensory events. The laboratory paradigm is an attempt to present a constant environmental challenge for all infants, independent of the infant's unique sensory threshold profile. Individual differences in underlying neurophysiology may predispose specific infants to have lower sensory thresholds and/or lower thresholds to behavioral state disorganization (i.e., become fussy, behaviorally disorganized, or cry). The laboratory paradigm does not take any of these potential individual differences into account. In contrast, the maternal reports are primarily based on maternal observations of infant behavior in a home environment that is usually more sensitive to the infant's unique behavioral and sensory profile. Thus, maternal reports would be less likely to observe state disorganization, if simple manipulations of the sensory environment associated with normal parenting would reduce fussy and difficult behaviors.

The laboratory paradigm, with its inherent insensitivity to individual differences in thresholds and vulnerabilities to behavioral state disorganization, may provide an efficient approach to identify vulnerabilities in the ability to maintain behavioral homeostasis. The maternal scales from the IBQ may have

been obtained in settings in which infant state regulation was optimized to encourage attention and prosocial activities such as positive facial expressions and sequences of contingent engagement-disengagement behaviors. Thus, the IBQ may provide useful profiles of the infant's prosocial strategies of awareness and interaction, when the individual differences in state vulnerability are minimized by appropriate and supportive parenting.

In conclusion, we support the proposal that there is an autonomic substrate to the temperament dimensions of reactivity and self-regulation. Consistent with the Polyvagal Theory, our data demonstrate that base level cardiac vagal tone is related to behavioral homeostasis, and the engagement of the vagal brake is related to prosocial behavior. Based on our findings, we propose that in research relating cardiac vagal tone to temperament, it is necessary to measure both baseline cardiac vagal tone and the regulation of the vagal brake (i.e., the direction and magnitude of cardiac vagal tone changes) during social and cognitive challenges.

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#### ADDRESSES AND AFFILIATIONS

Corresponding author: Lynne C. Huffman, Laboratory of Comparative Ethology (now at Stanford University School of Medicine, Department of Pediatrics and The Children's Health Council, 700 Sand Hill Road, Palo Alto, CA 94304); e-mail: lynne.huffman@stanford.edu. Yvonne E. Bryan is at Lehigh Valley Hospital; Rebecca del Carmen is at the National Institute of Mental Health; Jane A. Doussard-Roosevelt

and Stephen W. Porges are at the University of Maryland.

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