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Vagal Reactivity and Affective Adjustment in Infants during Interaction Challenges

Olga V. Bazhenova, Oxana Plonskaia, and Stephen W. Porges

Respiratory sinus arrhythmia (RSA) and heart period were evaluated in 5-month-old infants ($N = 40$) during interaction challenges requiring affective adjustment. The paradigm consisted of four 2-min experimental conditions designed to elicit behavioral and autonomic responses to object-mediated (Picture Attention and Toy Attention) and person-mediated (Still Face and Social Interaction) engagement. The data demonstrated that autonomic state systematically changed during engagement and disengagement with the environment. During the object-mediated challenge, increases in RSA were uniquely related to positive engagement. During the person-mediated challenge, there was a more complex integration of autonomic and behavioral responses characterized by concordant increases and decreases in RSA, heart period, positive engagement, negative affect, and motor activity. When participants were partitioned into two groups, based on their RSA response pattern during the person-mediated challenge, only participants who exhibited a pattern of RSA decrease from Toy Attention to Still Face followed by a rapid recovery during Social Interaction demonstrated regulation of behavioral activity, including concordant recovery from stress. These findings provide additional empirical support for the role of vagal regulation of the heart in the modulation of affective adjustment and engagement behavior.

INTRODUCTION

The ability to maintain contingent engagement and interactions with the environment is a critical determinant of a young child's mental development (e.g., Bruner, 1975; Vygotsky, 1962). As with any complex mental activity, infant engagement has attentional and emotional components. The emotional component (i.e., interest, pleasant or unpleasant feelings, intentions and motives) can influence the attentional component by supporting or disrupting an infant's engagement with objects or people. To successfully adapt to a changing and challenging environment, the infant's emotional response repertoire needs to be flexible. Successful adjustment requires an ability to respond and recover rapidly from the inevitable stresses associated with environmental interactions. In addition, the strategies of affective adjustment required for engagement depend on a supportive visceral state regulated by the autonomic nervous system (e.g., Porges, 1992, 1995). Therefore, behaviors of engagement must be interrelated with affective adjustment, including the regulation of visceral state, although this relation has not been a research focus in developmental psychology.

The Polyvagal Theory (Porges, 1995, 1997, 1998) emphasizes the role of the myelinated motor pathways traveling through the vagus (Xth cranial nerve). The Polyvagal Theory proposes that vagal pathways may mediate affect by reducing cardiac output to promote calm states or by increasing cardiac output to promote mobilization behaviors. According to the Polyvagal Theory, autonomic state is not a correlate of affective state, but an integral component of a Social Engagement System, which has both expressive behavioral features and autonomic functions to adjust physiological state. Specifically, the Social Engagement System includes the myelinated vagus as a visceromotor (autonomic) component to complement the somatomotor component (i.e., the neural regulation of the striated muscles of the face and head). During social engagement, the neural structures in the medulla that regulate the visceromotor and somatomotor components interact.

The visceromotor component functions as a brake and regulates the rate of the beating heart. Withdrawal of the *vagal brake* (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996) can rapidly modulate heart rate to provide short-term increases in cardiac output to support metabolically costly behavior. For example, when affective states shift from pleasurable to the more "activated" states associated with greater mental demand and attention, potentially along a flight–flight dimension, the *vagal brake* would be removed to provide cardiac output necessary to mobilize the individual. Thus, the Polyvagal Theory postulates that the visceromotor component of engagement is primarily reflected in changes in vagal tone to the heart.

Developmental research has embraced measures of cardiac vagal tone in investigations of autonomic correlates of various infant behaviors (Calkins, 1997; Huffman et al., 1998; Richards, 1985a; for a review see Porges, Doussard-Roosevelt, & Maiti, 1994), or predictors of developmental outcome (Doussard-Roosevelt, Porges, & McClenny, 2001). However, despite this interest in measuring the neural regulation of the autonomic nervous system, there has been little concern about the dynamic nature of this response system and the dependence of this system on other behavioral systems (e.g., motor).

Infant Vagal Tone and Vagal Brake Research

Infant research measures of vagal tone and / or vagal brake regulation have been quantified and studied as two global (and often highly correlated) variables (i.e., baseline measures and change measures during challenge). In these studies, vagal tone has been indexed by evaluating the amplitude of respiratory sinus arrhythmia (RSA), which is derived from the beat-to-beat heart rate pattern (e.g., Fouad, Tarazi, Ferrario, Fighaly, & Alicandro, 1984; Katona & Jih, 1975; Porges, McCabe, & Yongue, 1982). Infant research from several independent laboratories has consistently demonstrated task-related changes in RSA amplitude in response to both objects and people (Bornstein & Suess, 2000; DiPietro, Porges, & Uhly, 1992; Huffman et al., 1998; Richards & Gibson, 1997; Stifter & Fox, 1990; Weinberg & Tronick, 1996). These studies have addressed the relation between RSA and either attentional or emotional components of engagement. In general, experimental paradigms have contrasted RSA during baseline with RSA during specific tasks that were considered to elicit affective or attentional response. Interactions among various components (i.e., autonomic, affective, attentional, and motor) during engagement have not been studied.

RSA and attentional component of engagement. Porges (1992) argued that the influence of sustained attention on autonomic processes is similar to a partial parasympathetic blockade. During sustained attention there is a marked withdrawal of vagal tone to the periphery. As proposed in the Polyvagal Theory, vagal withdrawal shifts the neurophysiological regulation of the heart to provide the cardiac output necessary to promote behavioral mobilization. Porges (1974) has reported that infants with greater heart rate variability stabilized heart rate (i.e., decreased heart rate variability) during states of sustained attention that were elicited by simple auditory or visual stimuli presentation. Other studies of infant sustained attention focused on the physiological significance of baseline measures of cardiac vagal tone, that is, heart rate variability and RSA (Richards, 1985a, 1985b, 1987).

RSA and affective component of engagement. In a second line of research, both person-mediated and object-mediated conditions have been used to elicit affective responses while monitoring RSA in infants. According to the Polyvagal Theory, decreases in RSA and increases in heart rate reflect autonomic support for mobilization and strong negative affect such as that reported during pain (e.g., circumcision; Porter, Porges, & Marshall, 1988) and frustration tasks (Stifter & Fox, 1990; Stifter & Jain, 1996). Although research with infants has demonstrated a relation between negative affect and RSA, a possible confound with motor activity is present in all studies, because, in general, infants increase motor activity during states of negative affect. Thus, it remains unclear if RSA measures, obtained in these studies, index affective processes or the metabolic cost of increased motor activity.

Little is known about how RSA relates to the positive affective component of engagement in infants. However, the Social Engagement System model would predict enhanced parasympathetic regulation (i.e., increased vagal tone) during behaviorally calm states such as engagement. Although there are no studies testing this assumption, some indirect support is found in the DiPietro, Porges, and Uhly (1992) study of autonomic reactivity to a surprising stimulus (i.e., Jack-in-the-Box presentation). In their study, infants who responded with increases in RSA during the presentation of the surprising stimulus showed longer engagement (i.e., examining) in contrast to infants who responded with decreases in RSA. The authors speculated that in infants there is an association between heightened attentiveness and vagal augmentation.

In the Weinberg and Tronick (1996) study that used Tronick's Still Face paradigm, no differences in RSA levels were observed between Play and Reunion episodes, although there was an increase in RSA during the Reunion episode relative to the Still Face episode. The affective component of infant behavior during the three episodes of the Still Face paradigm did not always correspond with the changes in RSA. Specifically, despite the lack of difference in RSA between Play and Reunion episodes, the latter was characterized by significant increases in both positive and negative affective displays in contrast to the Play episode.

The Present Study

The literature does not provide clear evidence on the relation between autonomic and emotional components of engagement. An understanding of the early ontogeny of the autonomic component of engagement and disengagement behaviors would contribute to developmental theories related to emotional regulation, sustained attention, and social engagement strategies. The current research provided a direct evaluation of whether the regulation of the vagal brake in infants, which has been reported in previous research, is related to engagement behaviors. In addition, this research evaluated whether individual differences in "vagal" regulation were related to behavioral engagement strategies. The present study tested hypotheses derived from the Social Engagement System described in the Polyvagal Theory (Porges, 1998). It was hypothesized that engagement behaviors in infants would be enhanced by increased vagal influence on the heart. To test these hypotheses, the study employed a paradigm that allowed for the monitoring of vagal influences to the heart and behavior during several sequential engagement challenges (i.e., Baseline, Picture Attention, Toy Attention, Still Face, and Social Interaction). During the initial Baseline, the infants were not engaged in any particular activity. During the Picture Attention and Toy Attention conditions, the infants were engaged in looking at objects. During the Still Face condition, the infants were challenged to engage or to disengage with the nonresponsive still face of the experimenter. In addition, individual differences in vagal-response profiles were investigated to determine whether there were behavioral differences between individuals with "poor" and "efficient" vagal regulation. The amplitude of RSA was taken as an index of the visceromotor component of the Social Engagement System during both object-mediated and person-mediated interactions. The proportion of looking time at an object or person without negative signaling indexed behavioral engagement. The proportion of time-negative signaling indexed negative affective state. Because of the known relation among heart rate, RSA, and motor activity, motor activity was measured.

Infants were tested at 5 months of age, because infants younger than 5 months have difficulty maintaining a state of alertness and engagement in a laboratory context for at least 30 min (Tautermannova, 1983; Tautermannova & Vonderacek, 1984). The covariation between autonomic activity and engagement behavior might be different in older infants due to the rapid maturation of the executive cortical function after 6 to 7 months of age (Diamond, 1990). Thus, 5-month-old infants were selected as a starting point in the study of the biobehavioral aspects of affect adjustment during engagement behaviors.

METHOD

Participants

Participants were selected from a commercial mailing list generated by the birth date for newborns in suburban Washington, DC. To recruit participants, approximately 500 letters were sent to families with 3-month-old infants. Forty-seven families volunteered for the study. Data were collected from 41 infants (17 female and 24 male) at approximately 5 months of age ($M = 19.2$ weeks). Data from 1 male participant were lost due to technical reasons. Infants were tested in an alert state at least 10 min after a nap and feeding. The sample consisted of 38 term and 3 preterm infants (35 weeks gestational age). All infants tested within the normal range on the Bayley Scales of Infant Development (Bayley, 1993). Parents of participants were predominantly middle to upper class. Most were Caucasian. Parents received a gift for participation.

Procedure

Laboratory procedures. After arriving at the laboratory, the experimental procedures were explained to the parent(s) and informed consent was obtained. Three disposable Ag/AgCl ECG electrodes were placed on the infant's back, and the infant was then seated in an infant seat. Following approximately 3 min of adaptation to the electrodes, the laboratory environment, and the experimenter, the experiment was started. Physiological data were collected throughout the adaptation and experimental periods. After the experimental procedures, developmental level was assessed with the Bayley Scales of Infant Development (BSID-II; Bayley, 1993). Additional data not relevant to the goals of the current study were collected (i.e., parent questionnaires and physiological assessment during the administration of the BSID-II). The entire session was videotaped unobtrusively.

The experiment consisted of six sequential conditions (2 min each) that were designed to manipulate engagement behaviors: (1) Baseline: infants were placed in a baby seat, no attempts were made to attract their attention to anything, one or both parents were present in the room out of infant view; (2) Picture Attention: black-and-white pictures with graphic patterns were presented in a slow-moving mode and changed when the infant looked away; (3) Toy Attention: a toy with a Mickey Mouse face was presented for 5-sec sequences in view and out of view on alternate sides of a 4-inch screen; (4) Still Face: the researcher looked at infants with a blank face—not talking, not touching, not smiling, not making gestures, but with minor head movements; (5) Social Interaction: the researcher interacted with infants (talked, cooed, smiled, and so forth; touch was not allowed); (6) Picture Attention: a repeat of procedure outlined in (2) above. The Picture Attention condition was repeated to provide evaluation of possible time-related effects.

ECG was collected during the entire experiment. The ECG signal was amplified and output to a Vagal Tone Monitor (VTM; Delta Biometrics Inc.) for R-wave detection. The VTM timed the interval between heart beats (heart period) to the nearest msec and output the data to a personal computer for storage. (A value of a heart period is inversely related to heart rate; a slowing of a heart rate is reflected in an increase in heart period duration.) Heart period data were edited off-line with MXedit software (Delta-Biometrics Inc). Editing consisted of visual detection of outlier points followed by integer division or summation. Heart period and RSA were calculated with MXedit according to a patented procedure developed by Porges (1985). ECG data from one participant for the Picture Attention condition were lost due to equipment problems.

Methods of quantification. Heart period patterns are composed typically of rhythmic activity superimposed on a complex baseline trend. In many situations the slowly changing trend accounts for most of the variance of the physiological process. During most situations, the trend is related to metabolic activity. This observation is supported by reports of strong relations between average heart period and oxygen consumption in infants (Woodson, Field, & Greenberg, 1983). Of more direct interest to the current study was the evaluation of the rapid heart period oscillations of neural origin mediated by the nucleus ambiguus vagal system. This rhythmic activity is superimposed on the trend. Vagal influences to the heart, which originate in the nucleus ambiguus, have a characteristic respiratory rhythm (Richter & Spyer, 1990) known as RSA. The greater the vagal influence from the nucleus ambiguus, the greater the amplitude of these rhythmic changes in heart period. Thus, the amplitude of RSA provides an accurate, noninvasive measure of cardiac vagal tone (Fouad et al., 1984; Katona & Jih, 1975; Porges, McCabe, & Yongue, 1982).

To quantify cardiac vagal tone, a time series of heart periods was generated by timing the intervals between sequential heart beats to the nearest msec. Heart periods were converted into equal time estimates every 250 msec. A third-order 21-point moving polynomial was fitted to the data to remove the aperiodic and slow trends. A bandpass filter was used to extract the variance of the heart period pattern in the frequency band associated with spontaneous breathing from the residual time series. For infants, a frequency band defined from .24 to 1.04 Hz (i.e., approximately 15 to 60 breaths per min) was used. The natural logarithm of the extracted variance for successive 30-sec intervals defined the cardiac vagal tone index. The cardiac vagal tone index was calculated by summing the variances across the band of frequencies associated with spontaneous respiration. This method is statistically equivalent to the sum of the spectral densities across a similar frequency band, if proper detrending methods are employed (e.g., Porges & Bohrer, 1990).

Behavioral recording, coding, and reliability. The experimental session was videotaped unobtrusively using a stationary video camera. The video camera was concealed in the ceiling approximately 5 m distal from the infant's face. All behaviors were coded using standardized procedures to provide indices of motor and affective state (see Appendix). In the current study, affect was assumed to be a psychobiological process that depends on internal experiences and provides both positive engagement (manifested in sustained attention, active interaction, and possibly positive signaling) and disengagement (manifested in overall behavioral stress and negative affect signaling). Behavioral indices were computed for mutually exclusive positive engagement and negative signaling, and separately for four mutually exclusive motor categories: quiet, slow movements; moderate movements; and pronounced motor efforts (body turns). The behavioral coding quantified the percentage of time within each condition in which the participant was in one of four motor states and two affective states: Positive Engagement (relaxed and engaged: looking at an object of interest without corresponding negative signaling) and Negative Signaling (upset, fussy, or disorganized).

All behaviors were coded from the videotape by the primary investigator (35% of data) and an assistant (65% of data), with the latter being blind to the hypotheses of the study. At the time of coding, both coders were blind to the physiological data. Reliability among behavioral measures was established across a random subset of participants (20% of data). Those instances in which both coders agreed that a behavior did not occur were not taken into account. Agreement was defined as both coders scoring the same behavior code in the same 1-s interval. Cohen's κ (Cicchetti & Feinstein, 1990; Cohen, 1960), a statistic that corrects for chance agreement, was calculated for each behavioral category (i.e., affective states and motor) with mutually exclusive codes. Mean κs for engagement were .73 and for motor were .79. Behavioral data from 3 participants for the last Picture Attention condition could not be obtained due to technical problems.

Statistical analyses. Repeated-measures ANOVAs were performed to evaluate the response patterns across the six within-experiment conditions for each physiological (Heart Period, RSA) and behavioral

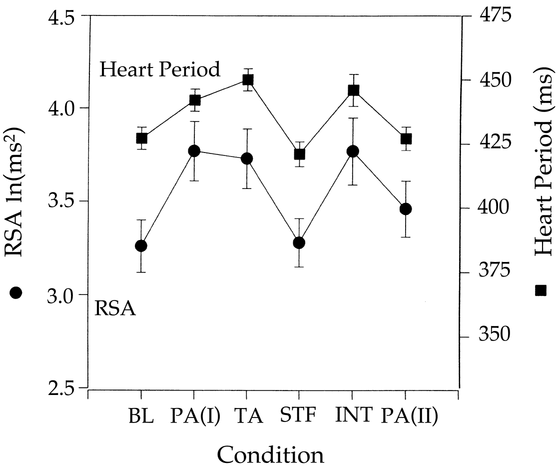

Figure 1 **Means (±*SE*) for Vagal Tone (respiratory sinus arrhythmia; RSA) and Heart Period during Baseline (BL), Picture Attention (PA), Toy Attention (TA), Still Face (STF), and Social Interaction (INT) test conditions.**

(Positive Engagement, Negative Signaling, Quiet Motor) variable. Specific hypotheses of this study were that with infants, RSA would increase and heart rate would decrease during the Picture Attention and Toy Attention conditions. During these conditions there would be an increase in the proportion of time the infant would spend positively engaged. In contrast, during Still Face, a condition characterized by extreme uncertainty, we expected withdrawal of the vagal brake (i.e., a decrease in RSA) to facilitate mobilization and fight-or-flight behaviors. Finally, during Social Interaction following Still Face, we expected a recovery of RSA to pre-Still Face levels and a parallel increase in Positive Engagement. The parallel changes of motor activity and negative affect were evaluated. The motor activity and negative affect were expected to increase during Still Face and decrease during Social Interaction. Specific hypotheses regarding the regulation of the vagal brake and behavioral engagement strategies were tested with planned comparisons. In addition, to evaluate the effect of time across the entire experiment, the Picture Attention conditions were contrasted. The level of statistical significance was set at $p < .05$.

RESULTS

Heart Period and RSA

Repeated-measures ANOVAs indicated a significant condition effect for RSA, $F(5, 190) = 9.0$, $p < .001$, power = 1.0; and Heart Period, $F(5, 190) = 13.0$, $p < .001$, power = 1.0. As illustrated in Figure 1 (see also Tables 1 and 2), the patterns of RSA and Heart Period were similar, with parallel increases and decreases across the various conditions. Planned comparisons (see Table 2) identified significant differences in RSA and Heart Period from Baseline to Picture Attention, from Toy Attention to Still Face, from Still Face to Social Interaction, and from Social Interaction to Picture Attention. In addition, there was a significant increase in Heart Period from Picture Attention to Toy Attention.

Behavioral Data

Repeated-measures ANOVAs indicated a significant condition effect for Positive Engagement, $F(5, 180) = 21.5$, $p < .001$, power = 1.0; Negative Signaling, $F(5, 180) = 14.8$, $p < .001$, power = 1.0; and Quiet Motor, $F(5, 180) = 5.4$, $p < .001$, power = .99. As illustrated in Figure 2 (see also Tables 1 and 2), the patterns of Negative Signaling and Quiet Motor were virtually reciprocal. Similarly, Positive Engagement tracked the pattern of Quiet Motor during social stimulation (the pattern across Toy Attention, Still Face, and Social Interaction conditions).

The response pattern for Positive Engagement during the cognitive-attentive conditions (Baseline, Picture Attention, and Toy Attention conditions) was unique. Planned comparisons (see Table 2) identified significant differences from Baseline to Picture Attention only for the physiological measures and Positive

Table 1 **Mean of Physiological and Behavioral Measures for Test Conditions**

	RSA ln(msec^2)	Heart Period (msec)	Positive Engagement (% of time)	Negative Signaling (% of time)	Quiet Motor (% of time)
Baseline	3.26 (.9)	427 (27)	25.43 (25)	7.28 (13)	42.01 (25)
Picture Attention	3.77 (1)	442 (27)	62.15 (22)	4.70 (12)	43.82 (24)
Toy Attention	3.73 (1)	450 (28)	63.62 (25)	5.61 (15)	51.52 (29)
Still Face	3.28 (.8)	421 (30)	30.68 (25)	30.48 (29)	27.81 (21)
Social Interaction	3.77 (1)	446 (40)	71.21 (32)	16.73 (29)	49.06 (29)

Note: Numbers in parentheses are standard deviations.

Table 2 Planned Comparisons of Physiological and Behavioral Variables between Experimental Conditions

	Respiratory Sinus Arrhythmia	Heart Period	Positive Engagement	Negative Affect	Quiet Motor
Paired comparisons for Baseline and each experimental condition					
Picture Attention	****	****	****	*ns*	*ns*
Toy Attention	****	****	****	*ns*	*ns*
Still Face	*ns*	*ns*	*ns*	****	***
Social Interaction	****	***	****	*ns*	*ns*
Paired comparisons for consecutive conditions					
Picture Attention versus Toy Attention	*ns*	*	*ns*	*ns*	*ns*
Toy Attention versus Still Face	****	****	****	****	****
Still Face versus Social Interaction	****	****	****	*	****

Note: Degrees of freedom for all comparisons: *df*(1, 39).
$^{*}p < .05$; $^{***}p < .005$; $^{****}p < .001$; *ns* = nonsignificant.

Engagement. However, the social stimulation elicited significant differences for all variables with changes from Toy Attention to Still Face and from Still Face to Social Interaction.

Time Effect

To evaluate the effect of time on the physiological and behavioral response pattern, the response patterns to the two identical Picture Attention conditions were contrasted (conditions were 6 min apart). Significant differences were observed over the time course of the experiment in all parameters: (1) lower RSA: $F(1, 36) = 7.8, p < .05$, power .73; (2) shorter Heart Period: $F(1, 36) = 13.0, p < .005$, power = .91; (3) reduced Quiet Motor: $F(1, 36) = 4.5, p < .05$, power = .52; (4) reduced Positive Engagement: $F(1, 36) = 5.8, p < .05$, power = .57; and (5) increased Negative Signaling: $F(1, 36) = 23.3, p < .001$, power = 1.

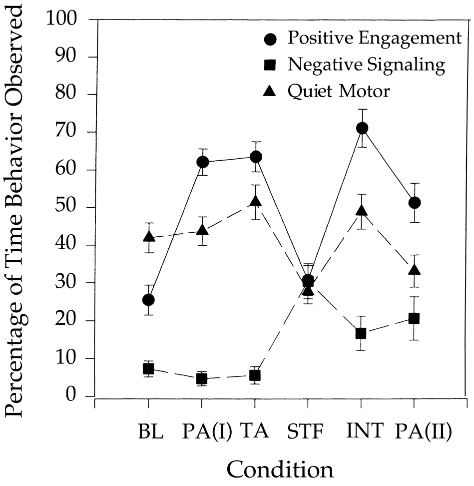

Figure 2 Mean percentage of time (±*SE*) coded behaviors were expressed during Baseline (BL), Picture Attention (PA), Toy Attention (TA), Still Face (STF), and Social Interaction (INT) test conditions.

Summary of Condition Effects

Theoretically, in this design the conditions following Baseline could be partitioned into two engagement contexts: (1) object-mediated engagement (the Picture Attention and Toy Attention conditions), and (2) person-mediated engagement (the Still Face and Social Interaction conditions). Analyses were conducted to compare physiological and behavioral measures in the object-mediated conditions to Baseline, and in the Still Face and Social Interaction conditions to the Toy Attention condition. In Figure 3, Baseline is included in object-mediated engagement and Toy Attention in person-mediated engagement merely as reference points from which to examine relative changes. The data are pooled within each context and transformed into *z* scores. By pooling across conditions within each context, it is possible to illustrate the relative changes in standardized units (i.e., *z* scores) of each variable across conditions. Pooling preserves the dynamic pattern of each variable on a constant scale. If the data were standardized within each condition, because of the nature of the *z*-transform, all conditions for all variables would have a mean of zero.

To illustrate how the physiological and behavioral variables change during the task demands, all vari-

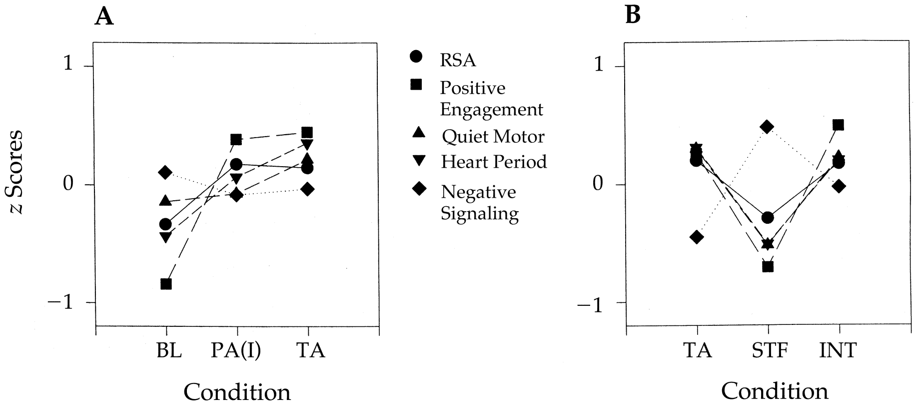

Figure 3 Changes in behavioral and physiological responses within (A) object-mediated and (B) person-mediated contexts. BL = Baseline; PA = Picture Attention; TA = Toy Attention; STF = Still Face; INT = Social Interaction.

ables were *z* transformed independently within each of the two contextual subsets (object-mediated and person-mediated engagement). The mean *z* scores for each condition were plotted. As illustrated in Figure 3 and supported by the planned comparisons of the original data in Table 2, the object-mediated engagement challenge did not elicit a convergent response profile across the behavioral and physiological variables. In response to the object-mediated engagement challenge, there were significant increases from Baseline to Picture Attention for Positive Engagement, Heart Period, and RSA. However, Negative Signaling and Quiet Motor activity did not change. Moreover, from Picture Attention to Toy Attention only Heart Period increased. In contrast to the relative independence of these variables to the object-mediated engagement challenge, the response profile to the person-mediated engagement challenge was strikingly integrated.

As illustrated in Figure 3, during the person-mediated engagement challenge, there was a consistent pattern of reactivity illustrated by the convergent changes in RSA, Heart Period, Quiet Motor, and Positive Engagement and reciprocal changes in Negative Signaling. These analyses demonstrated that during person-mediated social and emotional challenges, the autonomic (RSA and Heart Period) and social-affective behaviors (Positive Engagement, Negative Signaling, and motor responses) monitored in this study might be parts of an integrated response system. The integration of physiological, affective, and motor behaviors was not as tight during the object-mediated engagement challenge.

Group Analyses

Although the patterns of RSA and Heart Period during the person-mediated challenge (illustrated in Figure 3), reflected large statistical effects when the raw data were analyzed, not all participants exhibited this pattern. To evaluate whether individual differences in the ability to regulate the vagal brake in response to the person-mediated engagement challenge were paralleled by an ability to sooth and calm, the participants were divided into two groups. All infants who exhibited an RSA pattern similar to the group average, defined by the occurrence of a decrease in RSA from Toy Attention to Still Face and an increase in RSA from Still Face to Social Interaction (as illustrated in Figure 3), were categorized as Group 1 ($n = 22$) and the remaining infants were categorized as Group 2 ($n = 18$). The two groups defined by vagal brake strategy were evaluated for RSA, Heart Period, Positive Engagement, Negative Signaling, and Quiet Motor in two repeated-measures analyses, one for the person-mediated engagement challenge (i.e., from Toy Attention to Still Face and Social Interaction) and the other for the object-mediated engagement challenge (i.e., from Baseline to Picture Attention and Toy Attention; see Table 3). The groups were compared during the object-mediated challenge to evaluate possible baseline RSA differences and explore Group × Condition differences.

Person-mediated engagement context. The question of interest was if, in Group 1, RSA decrease and recovery elicited by social challenge were paralleled by corresponding changes through other response modalities and what the nature of systemic response, if any, was in Group 2.

There was a Group × Condition interaction for Positive Engagement, $F(2, 76) = 7.0, p < .005$, power = .920; and Negative Signaling, $F(1, 21) = 31.8, p < .001$, power = 1. Figure 4 illustrates, in standard scores, the pattern of reactivity for each group. Both

Table 3 Simple ANOVAs of Group Differences in Positive Engagement and Negative Signaling during Test Conditions

		M		
Variable	Condition	Group 1	Group 2	*F*(1, 38)
Positive Engagement	Baseline	22.36 (24)	29.17 (26)	.729
	Picture Attention	63.00 (20)	61.11 (25)	.071
	Toy Attention	72.18 (23)	53.15 (25)	6.357*
	Still Face	28.41 (27)	33.44 (24)	.393
	Social Interaction	87.14 (19)	51.75 (34)	17.459****
Negative Signaling	Baseline	4.55 (9)	10.61 (17)	2.104
	Picture Attention	3.05 (7)	6.72 (16)	.943
	Toy Attention	5.26 (15)	6.03 (15)	.028
	Still Face	30.91 (30)	29.94 (29)	.010
	Social Interaction	5.55 (13)	30.39 (36)	8.902**

Note: Numbers in parentheses are standard deviations.
$^{*}p < .05$; $^{**}p < .01$; $^{****}p < .001$.

groups decreased Positive Engagement and increased Negative Signaling during Still Face. Groups differed only in recovery of behavioral measures during Social Interaction compared with Still Face. Group 1 demonstrated significant recovery of both behavioral measures during Social Interaction to their levels during the reference condition (i.e., Toy Attention). Group 2 did not calm down and neither decreased Negative Signaling, nor increased Positive Engagement from Still Face to Social Interaction. For Heart Period and Quiet Motor there was no Group × Condition interaction.

Object-mediated engagement context. For RSA and Positive Engagement, the analyses identified a Group × Condition interaction, for RSA: $F(2, 76) = 4.7$, $p < .05$, power = .77; for Positive Engagement: $F(2, 76) = 3.3$, $p < .05$, power = .61. Groups differed in RSA and Positive Engagement reactivity from baseline to both object-mediated conditions. Only Group 1 responded with reliable RSA and Positive Engagement during the object-mediated context. As illustrated in Figure 5, Group 1 demonstrated a significant increase of RSA level during Picture Attention and maintained this level at a higher than baseline RSA level during Toy Attention. In addition, Positive Engagement behaviors paralleled the increase in RSA from Baseline to Picture Attention and Toy Attention. There was no Group × Condition interaction for Heart Period, Negative Signaling, or Quiet Motor.

DISCUSSION

General Response Patterns

The current experiment provides new findings that describe the integration of autonomic and behav-

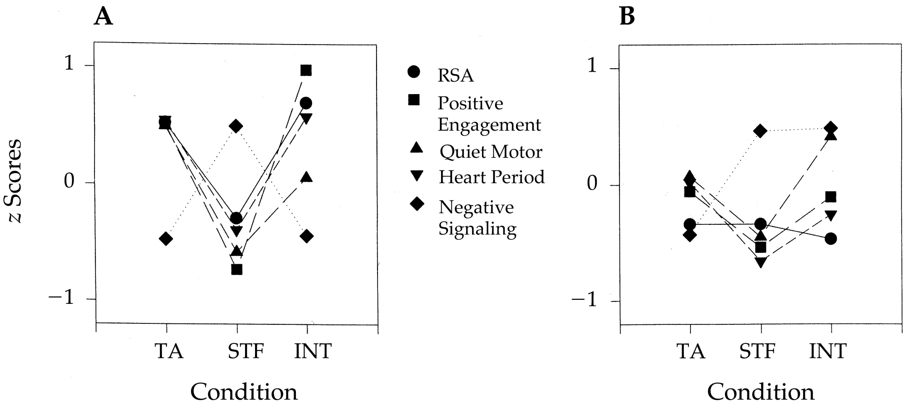

Figure 4 Differences between (A) Group 1 and (B) Group 2 during person-mediated context. TA = Toy Attention; STF = Still Face; INT = Social Interaction.

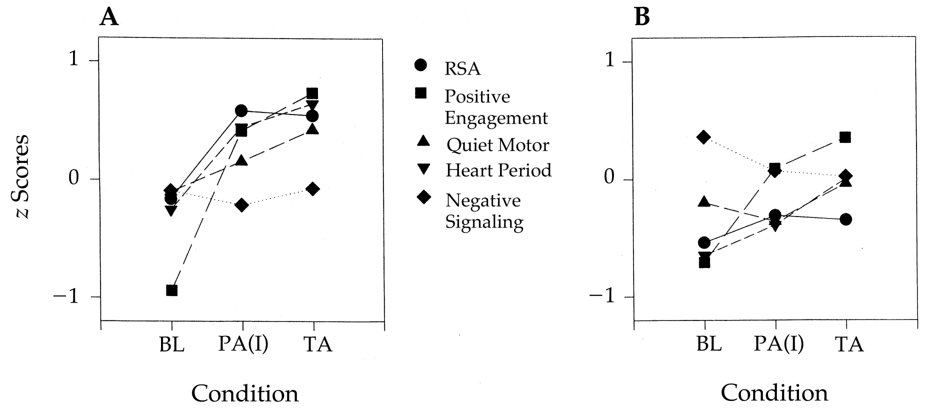

Figure 5 **Differences between (A) Group 1 and (B) Group 2 during object-mediated context. BL = Baseline; PA = Picture Attention; TA = Toy Attention.**

ioral responses during engagement of young infants with objects and people. The study demonstrated that during infancy, when cortical control of behavioral regulation remains immature, behavioral engagement and disengagement depend on autonomic control and covary with the functional impact of the mammalian vagus on the heart (i.e., activation and deactivation of the vagal brake). As predicted by the Polyvagal Theory, parallel changes in RSA amplitude and behavioral engagement were observed during both object- and person-mediated engagement contexts. Moreover, during person-mediated contexts, a functional integration of the physiological and behavioral components of the Social Engagement System was demonstrated.

RSA, negative affect, and metabolic demands. Analyses of infant behaviors during the person-mediated contexts (i.e., Still Face, and Social Interaction) revealed a response profile that reflected an expanded neurobehavioral integration with concordant changes in all components of the Social Engagement System: motor activity, affective state, autonomic output (i.e., heart rate), and neural tone to the heart (i.e., RSA). The findings of RSA decreases concordant with displays of negative affect are consistent with previous reports of RSA decreases in infants during stressful contexts such as difficult or frustrating tasks, maternal noncontingency, noncompliance to electrode placement, and arm restriction (e.g., Fracasso, Perges, Lamb, & Rosenberg, 1994; Stifter & Fox, 1990; Stifter & Jain, 1996; Weinberg & Tronick, 1996). In addition, the data illustrated that inhibition of the vagal brake (decreased RSA and increased heart rate) supported the metabolic demand of disengagement behaviors during the person-mediated stressful context (i.e., the Still Face condition).

In this study, RSA decreased and motor activity increased during the Still Face condition. This increase in motor activity was associated with physiological and behavioral components of a mobilization or stress response and was paralleled by an increase in negative affect commonly reported during Still Face (Gusella, Muir, & Tronick, 1988; Toda & Fogel, 1993; Trevarthen, 1977; Tronick, Als, Adamsen, Wise, & Brazelton, 1978). Research with adult participants reflects a similar parallel between RSA suppression and heart rate increases (i.e., decreases in heart period) during exercise (Hatfield et al., 1998; Obrist, 1981; Rowell, 1993). The decreased RSA observed during Still Face is easily understood within a metabolic cost model. Consistent with the Polyvagal Theory, the stress of the Still Face condition, observed in 5-month-old infants, is clearly mapped into a withdrawal of the vagal brake to potentiate sympathetic expression, increased cardiac output (i.e., increased heart rate), and the associated adaptive responses of increased motor activity and the expression of negative affect (see Figures 2 and 3). Thus, the decreased RSA observed during the Still Face condition in 5-month-old infants appears to be a nonspecific physiological response associated with increases in metabolic demand, and not uniquely associated with states of negative affect as has been suggested by Weinberg and Tronick (1996).

RSA, positive engagement, and metabolic cost model. This study demonstrated increased RSA during object-mediated engagement and positive social engagement following the negative affective state associated with the Still Face condition (see Figure 1). Because reduction of RSA appears to reflect the increased metabolic cost of motor activity, do increases in vagal activity reflect reduced motor activity, or, is the modulation of vagal activity part of a global response system associated with both object-mediated and person-mediated engagement strategies, which do not necessarily require changes in motor activity? RSA recovered during the Social Interaction from the low levels observed during Still Face. The levels observed during the Social Interaction were similar to the levels observed during the more neutral affective states associated with the object-mediated engagement conditions. This increase in RSA from Still Face to Social Interaction may be due, in part, to a decrease in motor activity (see Figures 2 and 3). Thus, the parallel between motor activity and RSA observed in the Still Face and Social Interaction conditions provides strong support for a metabolic cost explanation. However, this parsimonious explanation does not explain the observed differences between Baseline and object-mediated engagement.

As illustrated in Figure 2, during the object-mediated context, there were parallel increases in Positive Engagement, Heart Period, and RSA and no change in negative affect and motor activity relative to the low baseline levels. Although the metabolic cost model provides a plausible explanation of how autonomic state supports increased motor activity, the metabolic cost model is unable to explain the mechanisms enabling an RSA increase independent of reductions in motor activity. These increases in RSA may be a component of a physiological state that functionally supports positive engagement strategies, independent of whether the condition elicits a decrease in motor activity.

RSA and engagement. In response to the object-mediated contexts (i.e., Picture Attention and Toy Attention), the autonomic measures of vagal activity (i.e., RSA and Heart Period) covaried only with the measure of Positive Engagement. Increases in RSA were observed to parallel increases in Positive Engagement. This finding suggests that in infants, attention processes may be mediated not only by decreased parasympathetic activity as seen in older children and adults (Porges & Raskin, 1969; Suess, Newlin, & Porges, 1997; Weber, van der Molen, & Molenaar, 1994), but also by increased parasympathetic activity.

How can this finding of increased RSA during attention be reconciled with the prevalent reports of vagal withdrawal observed during tasks requiring sustained attention in older children and adults? A plausible explanation for this apparent discrepancy may be derived from a theoretical position that integrates emotional and cognitive processes (e.g., Cicchetti & Hesse, 1983; Sroufe & Waters, 1976; Vygotsky, 1983). For example, Vygotsky (1983) emphasized direct dependency of intellectual functions on affect during the early stages of cognitive development. In older children and adults this dependency diminishes. In a model that integrates emotion and cognition in young infants, the direction and magnitude of RSA changes might be mediated by the affective state occurring during information processing. In our study, the variable Positive Engagement may have captured this composite, because this variable reflected the percent of time spent looking at the person or object integrated with an affective component that signaled the absence of negative affect.

Sustained looking by infants may be viewed as a complex mental activity that includes coordination of visual orienting, visual search, visual attention, visual processing, and visual memory. In infancy these processes would be integrated with a sensory or organismic need to regulate state by maintaining or disrupting looking behavior. Possibly, the satisfaction of an underlying need might elicit a concordant pleasurable state with or without overt positive affect expression. The presence of pleasurable experience may not always be observed but could be indirectly conveyed in the fact that an infant continues to maintain looking. In support of this speculation, there are reports that infants use gaze aversion to regulate negative affect (e.g., Mangelsdorf, Shapiro, & Marzolf, 1995). The absence of negative affect, expressed during positive engagement, signals that there are no “emotional obstacles” in maintaining the mental activity. Thus, the current affective state may buffer or override negative affect.

The current data from 5-month-old infants reflect an important developmental stage when emotional and attentional processes are integrated into engagement behavior. It appears that in infancy, autonomic processes mediate this integration. We propose that the disinhibition of the vagal brake (i.e., increased RSA) observed in 5-month-old infants during the object-mediated condition is part of a response strategy that integrates affective state with the cognitive processes required to attend to objects and persons (i.e., positive engagement).

Thus, the data clearly indicated that during engagement challenges 5-month-old infants demonstrated autonomic mediation of the behavioral response. However, analysis of the general pattern of behavioral and autonomic responses did not provide information on whether autonomic mediation is necessary for engagement. What happens when infants do not demonstrate efficient vagal regulation? In the following section of this article we will discuss the relevant findings.

Individual Differences

Based on the individual infant's RSA response profile during the person-mediated context, infants were assigned to either a "poor" or an "efficient" vagal regulation group. Infants who did not exhibit a dynamic RSA response (i.e., decreases of RSA from Toy Attention to Still Face and increases of RSA from Still Face to Social Interaction) exhibited a less-coupled response profile (see Group 2 in Figures 4 and 5) and did not calm down behaviorally during the Social Interaction condition. Infants in Group 2 displayed decreased Heart Period and Positive Engagement and increased Negative Signaling and decreased Quiet Motor without concordant changes in RSA during Still Face. In addition, infants in this group demonstrated difficulties in reinstating the vagal brake. They did not override the increased heart rate following Still Face with an increase in vagal tone to the heart, which is physiologically necessary to self-sooth and to engage during the Social Interaction condition (see Figure 4). In contrast, infants with efficient vagal regulation (Group 1) inhibited the vagal brake during the Still Face Condition and disinhibited the vagal brake during the Social Interaction Condition to support behavioral and physiological calming. This was illustrated by the rapid recovery of positive engagement convergent with RSA and Heart Period immediately after the stressful Still Face condition. Interestingly, the infants in Group 2 compared to infants in Group 1 had similar baseline levels of RSA, and lower levels of both RSA and positive engagement during the object-mediated context.

As stated in the Polyvagal Theory, the rapid recovery of RSA creates a physiological state that calms the infant and promotes the positive social behavior associated with positive engagement. Functionally, this occurs because at the level of the heart, sympathetic influences are attenuated by the vagal system. The infants with poor regulation of the vagal system are not able to attenuate the naturally occurring sympathetic reactivity to the stressful challenge. In infants who are poor vagal regulators, the sympathetic influences to the heart remain unchecked and, as reported, negative affect will not decrease, positive engagement will not be supported, and behavior will be less organized. It is plausible that infants with a well-regulated vagal system may pay a lower biological or metabolic "price" for emotional adjustment, as evidenced by a quick recovery in RSA and the concordant lowering of heart rate. Thus, the efficient vagal regulators would dynamically reduce and recover positive engagement in response to environmental challenges, whereas the inefficient vagal regulators would be less flexible and effective in coping.

The present study demonstrated that, in 5-month-old infants, vagal reactivity (measured by the changing amplitude of RSA) is a component of an integrated biobehavioral engagement system. Moreover, the inhibition and disinhibition of the vagal brake appears to index the basic neurophysiological state required to engage or disengage with the environment. Increased vagal action on the heart reduces cardiac output and creates a physiological state that promotes the calm behavioral profile necessary to sustain interactions with people and objects. In addition, efficient vagal regulation appears to be related to positive engagement strategies and to facilitate coping with stress.

Based on our observations, we propose that during infancy the bidirectional responsivity of RSA may not only indicate the changes in autonomic state required for motor activity, but also reflect an emotional aspect of positive engagement. Thus, during positive engagement there may be a convergent affective process associated with pleasure, curiosity, interest, or sensory need satisfaction. If so, we would assume that RSA would increase during tasks that elicit positive states or feelings, and vary from one experimental context to another, depending on the individual's affective experience. This may be true not only for young infants, but for children and older individuals as well. However, because older individuals compared with infants possess more complex mediators of behavioral regulation (e.g., via speech, attitude, or thought) that are difficult to control, identifying a reliable autonomic mediator of engagement in older children and adults is a more difficult task.

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ADDRESSES AND AFFILIATIONS

Corresponding author: Olga V. Bazhenova, Department of Psychiatry, The Psychiatric Institute (MC 912), 1601 W. Taylor Street, Chicago, IL 60612; e-mail: obazhenova@psych.uic.edu. Oxana Plonskaia is at the University of Maryland at College Park. Stephen W. Porges is also at the University of Illinois.

APPENDIX

Category	Behavioral Coding
Engagement	
Positive Engagement	Looking at an object or person with no negative affect displays.
Negative Signaling	Facial grimaces with a negative accent; or whining and screaming with pauses in between; or crying, disorganized behavior and temper tantrums.
None of the above	Any other behavior displayed while not looking at an object or person.
Motor	
Quiet motor	No or almost no motor activity (possible finger movements).
Slow motor	Slow movements of head, hands, and/or legs. Limbs are not lifted.
Mild movements	Movements of lifted limbs, mild bodily turns from side to side.
Pronounced movements	Fast, forceful bodily movements and/or back arching.

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