Susan D. Calkins
Susan P. Keane
Department of Psychology
University of North Carolina at Greensboro
Greensboro, NC 27402–6164
E-mail: sdcalkin@uncg.edu

Cardiac Vagal Regulation across the Preschool Period: Stability, Continuity, and Implications for Childhood Adjustment

ABSTRACT: *Stability and continuity of vagal regulation of the heart, operationalized as suppression of respiratory sinus arrhythmia (RSA) during challenge, was examined in a longitudinal study of preschoolers. A sample of 154 two-year-old children was recruited for participation in a study of the effects of emotional and behavioral challenge on cardiac activity and behavioral indices of adjustment and self-regulation. A total of 122 of these children were assessed again at age 4.5 years. At both ages, the children were assessed in a series of laboratory procedures that were intended to be emotionally and behaviorally challenging, during which time heart rate was recorded. To assess vagal regulation, resting measures of RSA and RSA suppression to the challenge task were derived from these procedures. To assess childhood adjustment and self-regulation, a number of parent-report measures were administered when the children were 4.5 years of age. Results indicated that there was high stability in RSA suppression across the challenge tasks within both ages, modest cross-age stability in RSA suppression, and a significant decrease in the magnitude of RSA suppression across age. Second, children who displayed a pattern of stable and high suppression across the preschool period were less emotionally negative, and had fewer behavior problems and better social skills than other children. © 2004 Wiley Periodicals, Inc.* Dev Psychobiol 45: 101–112, 2004.

Keywords: *respiratory sinus arrhythmia; vagal regulation; self-regulation; emotion*

In the developmental psychology literature, the construct of self-regulation and its role in successful adaptation has been examined quite extensively, particularly in the early childhood period. The capacity to exercise self-control over the expression of emotion (particularly negative emotions) and behavior develops over the first years of life and has particular importance for the unfolding of appropriate and adaptive social behavior during the preschool and school years (Calkins, 1994; Eisenberg et al., 1995, 1996; Kopp, 1982; Thompson, 1994). Furthermore, the lack of adequate development of control over emotion (as well as, in some instances, overcontrol of emotion) and behavior may be a precursor to the development of psychopathology (Calkins & Dedmon, 2000; Calkins & Fox, 2002; Keenan, 2000; Shaw, Keenan, Vondra, Delliquadri, & Giovannelli, 1997). By the time a child is ready to enter school, behavioral and emotional regulation patterns may be firmly established to the extent that they influence early personality and social-interaction skills and contribute to problematic patterns of behavior (Calkins, 1994; Cicchetti, Ganiban, & Barnett, 1991; Cole, Michel, & O'Donnell, 1994; Stifter, Spinrad, & Braungart-Rieker, 1999).

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Research in the area of early self-regulation has focused on both intrinsic (biological) and extrinsic (familial) contributors to both normative development and individual differences in self-regulation (Fox & Calkins, 2003). Biological substrates of self-regulation have been the focus of both theoretical (Fox, 1994) and empirical work (Blair, 2003; Calkins & Dedmon, 2000). Theories of self-regulation that focus on underlying biological components of regulation assume that maturation of different biological support systems lays the foundation for increasingly sophisticated emotional and behavioral regulation. For example, Fox (1989, 1994) noted that the frontal lobes of the brain are differentially specialized for approach versus avoidance, and that these tendencies influence the behaviors that children engage in when emotionally and behaviorally aroused. He further noted that maturation of the frontal cortex provides a mechanism for the more sophisticated and planful regulatory behaviors of older children versus infants. Porges (1996) and colleagues (Porges, Doussard-Roosevelt, & Maita, 1994) also described an important role for biological maturation: specifically, maturation of the parasympathetic nervous system that plays a key role in regulation of state, motor activity, and emotion. Moreover, Porges et al. (1994) noted that individual differences in nervous system functioning might mediate the expression and regulation of emotion. Porges and others (Calkins, 1997; Calkins & Dedmon, 2000; DeGangi, DiPietro, Greenspan, & Porges, 1991; Huffman et al., 1998; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996) found that parasympathetic nervous system functioning, as reflected in heart rate (HR) variability, is related to the control of attention, emotion, and behavior.

Although there are multiple ways to measure this variability, Porges (1985, 1991, 1996) developed a method that measures the amplitude and period of the oscillations associated with inhalation and exhalation. This measure refers to the variability in HR that occurs at the frequency of breathing (respiratory sinus arrythmia, RSA) and is thought to reflect the parasympathetic influence on HR variability via the vagus nerve. Porges (1996; Porges & Byrne, 1992) termed this measure of HR variability vagal tone (Vna). Although there are other components of HR variability, the RSA measure has been identified as suitable for the study of physiological links to multiple dimensions of behavioral functioning in young children (Huffman et al., 1998; Richards, 1985, 1987). For example, high resting RSA is one index of autonomic functioning that has been associated with appropriate emotional reactivity (Stifter & Fox, 1990) and good attentional ability (Richards, 1985, 1987; Suess, Porges, & Plude, 1994). Several studies have linked high RSA in newborns with good developmental outcomes, suggesting that it may be an important physiological component of appropriate engagement with the environment (Hofheimer, Wood, Porges, Pearson, & Lawson, 1995; Richards & Cameron, 1989).

A measure of cardiac activity that may be more directly related to the kinds of self-regulatory behaviors children begin to display in toddlerhood and early childhood is vagal regulation of the heart, as indexed by a decrease (suppression) in RSA during situations where coping or emotional and behavioral regulation is required. Vagal regulation in the form of suppression of RSA during demanding tasks may reflect physiological processes that allow the child to shift focus from internal homeostatic demands to demands that require internal processing or the generation of coping strategies to control affective or behavioral arousal. Thus, suppression of RSA is thought to be a physiological strategy that permits sustained attention and behaviors indicative of active coping that are mediated by the parasympathetic nervous system (Porges, 1991, 1996; Wilson & Gottman, 1996). Recent research has indicated that suppression of RSA during challenging situations is related to better state regulation, greater self-soothing, and more attentional control in infancy (DeGangi et al., 1991; Huffman et al., 1998), fewer behavior problems and more appropriate emotion regulation in preschool (Calkins, 1997; Calkins & Dedmon, 2000; Porges et al., 1996), and sustained attention in school-age children (Suess et al., 1994). The extension of these research findings is that while the ability to suppress RSA may be related to complex responses involving the regulation of attention and behavior, a deficiency in this ability may be related to early behavior problems, particularly problems characterized by a lack of behavioral and emotional control (Calkins & Dedmon, 2000; Porges, 1996; Wilson & Gottman, 1996). Thus, one issue addressed in the present study was whether children who displayed a pattern of better vagal regulation of the heart, as indexed by greater RSA suppression during an emotional or behavioral challenge, would display more positive developmental outcomes than children who did not display this pattern.

An interest in self-regulation and its role in adjustment in childhood may be informed by the study of vagal regulation in the form of changes or suppression of RSA; however, a number of fundamental questions remain about the nature of this response, particularly with respect to changes that may occur with development and the context in which such responses may be observed. For example, if one hypothesizes that RSA suppression indexes physiological regulation (Porges, 1996), then the magnitude of this response should increase over the course of infancy and preschool, as the child is developing a regulatory repertoire and gaining control over attentional and behavioral skills (Kopp, 1982). The only study to date that has addressed the issue of the development of cardiac responses to challenge examined changes from 2 months to 5 years of age (Bornstein & Suess, 2000). The findings revealed no changes in the magnitude of RSA response across this time period; however, a single assessment of cardiac response to a single task at such an early time point in infancy may not provide a sufficient test of the continuity or discontinuity of the response nor are the tasks that were used at the two ages equivalent in terms of the demands placed on the child. Thus, a test of the hypothesis of developmental change in RSA suppression is needed.

A second important issue yet to be resolved with respect to the use of RSA response measures has to do with the context under which the changes are elicited. There is a good deal of variability in terms of the kinds of tasks that are used to measure the child's capacity to physiologically self-regulate. In some studies, multiple types of elicitors are used (Calkins, 1997; Calkins & Dedmon, 2000) while in others, a single task is used (Bornstein & Suess, 2000; Huffman et al., 1998). Some of these tasks focus more on emotional stimuli as the primary elicitor (Calkins, 1997) while others place attentional or cognitive, but not emotional, demands on the child (Blair, 2003; Bornstein & Suess, 2000). Moreover, some studies explicitly test whether the RSA measures decrease significantly to the eliciting stimuli (Bornstein & Suess, 2000; Calkins, 1997; Doussard-Roosevelt, Montgomery, & Porges, 2003) while others do not (Huffman et al., 1998). The questions of whether different tasks are equivalent in terms of the demands placed on the child and whether a significant decrease from baseline is necessary to conclude that suppression has occurred have yet to be addressed in any systematic fashion. One might hypothesize, for example, that a more challenging task would elicit, on average, a greater suppression response. For example, a task that is frustrating might require greater suppression of RSA than one that is attention demanding because it requires the child to control an affective response to the task.

The third issue that has generated ambiguous findings has to do with the issue of stability of physiological responses. One might expect a fair degree of stability in measures of emotional or self-regulation, given that these are believed to be stable traits linked to temperament (Posner & Rothbart, 2000); however, one study of RSA suppression over time reported no stability (Bornstein & Suess, 2000). Again, though, the period of assessments were widely spaced and the tasks did not place similar demands on the child. A second study examined short-term stability of the RSA response to challenge in kindergarten children (Doussard-Roosevelt et al., 2003). This study found modest stability across one 2-week period, but not across the next 2-week period or across the 4-week period of the study; however, this study employed the same negative-affect elicitor over the three sessions, and it is not clear whether the children failed to respond to the task after the first two assessments. In addition, this study did not address continuity or stability across the preschool period, a time of rapid growth in the development of self-regulation.

The goal of the current study was to examine measures of cardiac vagal regulation, as indexed by RSA suppression longitudinally across the period of 2 to 4 years of age, and their relation to preschool indicators of self-regulation. The first question addressed was whether there would be age or task differences in RSA suppression. One hypothesis is that with age, children become better regulated behaviorally, which may be supported by better physiological regulation of the cardiac response. In addition, it was hypothesized that different kinds of tasks would require different degrees of physiological regulation. The second question addressed in this study was whether there would be stability of vagal regulation across tasks and across ages. Stability of response measures of RSA in children have not been examined across this period of development. It was hypothesized that modest stability would be observed, based on research indicating modest degrees of stability in resting measures of RSA (Bar-Haim, Marshall, & Fox, 2000); however, in this study, we controlled for the child's resting measure of RSA in our examination of RSA suppression across task and time. In this case, stable responses would indicate that the child may be displaying characteristic patterns of vagal regulation that might map onto characteristic patterns of behavioral regulation. Finally, relations between cardiac vagal regulation and child-adjustment outcomes including social skills, behavior problems, and emotion regulation at age 4.5 years were examined. It was hypothesized that those children displaying appropriate physiological regulation in the form of RSA suppression in preschool would display better self-regulation and psychological adjustment (fewer behavior problems, better social skills, and better emotion regulation) than children who did not display such a pattern.

METHOD

Participants

Participants for this study were recruited as part of an ongoing longitudinal study that began when children were 2 years old. A total of 154 two-year-old children (78 male, 76 female) and their mothers were initially recruited through child daycare centers, the County Health Department, and the local Women, Infants, and Children program. Children were recruited from a variety of sources to obtain a sample diverse in socioeconomic status (SES) and ethnicity. This sample of 2-year-olds was racially and economically diverse [65% European American, mean Hollingshead (Hollingshead, 1975) score = 39.2] and from primarily intact families (77%). Further details about the sample and recruitment may be found in Smith, Calkins, Keane, Anastopoulos, and Shelton (2004) and Calkins and Dedmon (2000).

Two years after the original assessment, the families were contacted by mail and telephone and were asked to participate in a follow-up study of the children. Of the original 154 mother–child dyads, 12 families moved from the county of recruitment, 8 families refused to continue in the study, and 9 families could not be located. A total of 125 families agreed to participate in the follow-up phase of the study. Three children had already entered kindergarten and were excluded from the study. The remaining children were enrolled in preschool. More families of boys discontinued participation in the study; however, there were no differences in race or SES between the subjects who continued participating in the study and those who did not, or between the boys who discontinued participation and those who did not. Children (58 males, 67 females) retained in the sample were 4.5 years old (mean age = 56 months; *SD* = 2.9 months) at the time of the preschool assessment. Thirty-seven percent of the participants at the age 4.5 visit were African American, and 63% were European American. The SES of the participants again ranged from lower to upper middle class, with mean Hollingshead = 39.6.

Procedures

Overview. Assessments were conducted in the laboratory at ages 2 and 4.5, with mothers accompanying their children to the laboratory. In the laboratory, individual child tasks and mother–child tasks were conducted. Several of these tasks were conducted while collecting psychophysiological data from the children. The five tasks that were similar across the two ages (baseline, attention, empathy, frustration, problem solving) will be the focus of the present report. Additional assessments included several mother–child interaction tasks including free-play, problem-solving, structured-play, and toy clean-up tasks (for more details, see Smith et al., 2004). In addition, parents completed questionnaires concerning their child's adjustment at preschool. At both ages, psychophysiological data were collected during the first half of the session. Sessions typically lasted between 90 and 120 min (including informed consent and completion of questionnaires by the mother). Because similar procedures were conducted at both ages, they will be described together, with procedural differences described where appropriate.

Laboratory Assessment. After subjects were selected for inclusion in the study, parents were contacted to schedule an assessment. Mothers were asked to accompany their children to the laboratory where the children were assessed in a playroom during several procedures. First, the experimenter placed three disposable pediatric electrodes in an inverted-triangle pattern on the child's chest while he or she was seated at a table next to the mother. The electrodes were connected to a preamplifier, the output of which was transmitted to a vagal tone monitor (VTM-I, Delta Biometrics, Inc., Bethesda, MD) for R-wave detection. The vagal tone monitor displayed ongoing HR, and computed and displayed RSA (vagal tone) every 30 s. A data file containing the interbeat intervals (IBIs) for the entire period of collection was transferred to a laptop computer for later artifact editing (resulting from child movement) and analysis.

While connected to the HR collection equipment, the child was observed during a multiepisode sequence that was derived from the Laboratory Temperament Assessment Battery (LAB-TAB; Goldsmith & Rothbart, 1993) and prior work (Calkins, 1997; Calkins & Johnson, 1998). In prior work with this and other samples, these tasks have reliably elicited differential emotional reactions in toddlers and preschoolers (Calkins, 1997; Calkins & Dedmon, 2000). The baseline episode consisted of a 5-min segment of the videotape "Spot," a short story about a puppy that explores his neighborhood. While this episode was not a true baseline given that the child's attention was engaged by an external stimulus, it was sufficient to keep the child sitting quietly and showing little affect. Given the ages of the subjects in this study, such a stimulus was necessary to keep the child seated at the table and to limit movement artifact in the HR data. Following the baseline episode, the child was observed in several situations designed to elicit physiological stress and coping. The onset of each challenge episode was marked on the computer file of the IBI data through the use of an electronic signal controlled by the experimenter. Minor adjustments were made to each type of task so that they would be appropriate for use with either 2- or 4-year-old children. These adjustments included using age-appropriate stimuli or lengthening the time of the task. These types of tasks are considered appropriate for use with young children and are typically employed to elicit measures of emotional and behavioral regulation in response to challenge or stress (cf. Calkins, 1997; Doussard-Roosevelt et al., 2003; LAB-TAB, Goldsmith & Rothbart, 1993; Grolnick, Bridges, & Connell, 1996). For each challenge episode, the mother sat nearby and was asked to respond normally to the child, but not to initiate interaction (except in the case of the problem-solving episode, where she was explicitly instructed to assist her child).

In the first episode, one experimenter presented a visual stimulus for 2 min directly to the child (age 2) and on a television screen (age 4.5) that was used to elicit the child's *attention*. The next episode was an *empathy* situation, during which the child looked at books for 2 min while the audiotape of a crying toddler was played just outside the playroom door (age 2) or the child was shown a 4-min videotape of a distressing film clip in which the main character, a young child, experiences the death of a pet (age 4.5). During the *frustration* episode at age 2, the experimenter asked the child whether she or he would like a snack. The experimenter placed on the table a clear-plastic container of cookies that the child was unable to open, and then left the room. The child was free to manipulate the container while the experimenter was out of the room. The mother was instructed not to open the container for her child. This episode lasted for 2 min. At age 4.5, the child was given a toy in a plastic box that was locked. The child was given a set of keys to try to open the box; however, the correct key was not on the key chain. This episode lasted for 4 min. In the next episode, *problem solving*, the child was presented with a difficult puzzle to solve, and the mother was asked to help the child piece the puzzle together during the 4-min period.

Each challenge episode was separated from the subsequent episode by a very brief (2–3 min) period during which the child was free to interact with the mother while the experimenter gathered materials for the next episode. This period was necessary because the children's tolerance for the HR collection (in particular, remaining seating for collection) was often low. In addition, this break was not considered to be an additional resting measure of cardiac activity with which to contrast the subsequent challenge episode given that the child was almost always engaged with the mother or moving around (or both). Moreover, there was some concern that there would be carryover effects from the episode to the break that would call into question the validity of using the break to derive resting measures. For these reasons, the initial baseline measure only was considered for analyses involving contrasts with the challenge episodes.

Questionnaires. Mothers were given a packet of questionnaires to complete at the age 4.5 assessment. Mothers completed the *Child Behavior Checklist for 4–18 year olds* (CBCL; Achenbach, 1991), the *Emotion Regulation Checklist* (Shields & Cicchetti, 1998), and the *Social Skills Rating System* (Gresham & Elliot, 1990). Each of these measures has been widely used by researchers studying early social adjustment, and each has adequate reliability and validity.

Measures

Two types of measures were derived from the laboratory assessments: cardiac vagal regulation (RSA and RSA suppression), and child-adjustment outcome (behavior problems, emotion regulation, and social skills).

Physiological Measures. To generate measures of cardiac activity from which to derive measures of RSA and RSA in response to challenge, the IBI files were edited and analyzed using MXEDIT software (Delta Biometrics, Bethesda, MD). Editing the files consisted of scanning the data for outlier points relative to adjacent data and replacing those points by dividing them or summing them so that they would be consistent with the surrounding data. Data files that required editing of more than 5% of the data were not included in the analyses.

Analysis of the IBI data consisted of applying the Porges (1985) method of calculating RSA. This method applies an algorithm to the sequential HP data. The algorithm uses a moving 21-point polynomial to detrend periodicities in HP slower than RSA. A band-pass filter then extracts the variance of HP within the frequency band of spontaneous respiration in young children, .24 to 1.04 Hz. Although lower frequency bands may be studied, research with young children has consistently examined this band and identified associations to child functioning (Huffman et al., 1998; Porges et al., 1996; Stifter & Fox, 1990). The estimate of RSA is derived by calculating the natural log of this variance and is reported in units of $\ln(\text{ms})^2$. HP and RSA were calculated every 30 s for the 5-min baseline period and every 15 s for the challenge episodes. These epoch durations are typical for studies of short-duration tasks (Doussard-Roosevelt et al., 2003; Huffman et al., 1998). The mean RSA of all epochs within each episode was used in subsequent analyses. If the *SD* across the epochs was greater than 1.00 for RSA (indicating a high degree of variability over the course of the episode and calling into question the validity of the mean RSA value), that episode was excluded from subsequent analyses. Descriptive statistics for RSA and HP for the baseline and challenge episodes are reported in Table 1. As the table

Table 1. Descriptive Statistics for RSA and HP at Ages 2 and 4.5

	M	*SD*	Min	Max	*n*
Age 2 RSA & HP					Total = 152
Baseline RSA	5.76	1.4	2.05	8.79	140
Attention RSA	5.26	1.19	2.15	8.93	135
Empathy RSA	5.26	1.25	2.14	8.30	137
Frustration RSA	5.02	1.24	2.45	8.57	135
Problem RSA	4.80	1.15	2.18	8.11	137
Baseline HP	549.91	54.94	426.90	721.18	140
Attention HP	523.69	43.59	433.86	652.86	135
Empathy HP	530.04	47.65	422.93	723.65	137
Frustration HP	518.28	48.75	396.64	694.20	135
Problem HP	518.39	44.29	425.55	691.96	137
Age 4.5 RSA & HP					Total = 122
Baseline RSA	5.95	1.35	2.89	10.20	118
Attention RSA	5.76	1.34	3.56	9.93	114
Empathy RSA	6.00	1.39	2.30	9.41	114
Frustration RSA	5.65	1.34	2.29	9.33	115
Problem RSA	5.32	1.27	2.39	9.06	113
Baseline HP	618.59	82.02	482.45	1028.0	118
Attention HP	600.71	82.62	471.66	1085.3	114
Empathy HP	612.34	75.66	467.14	845.87	114
Frustration HP	593.36	66.03	471.93	775.02	115
Problem HP	577.42	63.78	466.05	761.35	113

RSA, respiratory sinus arrhythmia; HP, heart period.

indicates, the data files of some children were not included in some of the analyses at each age. A few children would not allow the experimenter to apply the HR electrodes ($n = 3$ at age 2; $n = 2$ at age 4.5). In addition, the HR data-collection equipment failed on several occasions ($n = 6$ at age 2; $n = 2$ at age 4.5); however, the most common explanation for missing data was that the child pulled on the HR leads, which resulted in movement artifact affecting greater than 5% of the data in the HR file ($n = 8$ at age 2; $n = 5$ at age 4.5).

Child Adjustment Outcome Measures. The three questionnaires completed by the parent were used to generate measures of child adjustment. The CBCL (Achenbach, 1991) yields six subcales of child behavior and two broadband scales of externalizing and internalizing. Of interest for the present study was the broadband *Externalizing Scale*, which measures aggressive and destructive behavior. The *Emotion Regulation Checklist* (Shields & Cicchetti, 1998) is a 24-item questionnaire that was administered to parents to assess children's emotion regulation. Two subscales were created: a *Negativity/Lability* scale that contained 10 items (Cronbach's $\alpha = .77$) and an *Emotion Regulation* scale that contained 14 items (Cronbach's $\alpha = .68$). The two factors were correlated −.50. The *Negativity/Lability* subscale represents negative affect and mood lability. The Social Skills Rating System (Gresham & Elliot, 1990) is a behavior rating scale designed to assess social behavior in children. The form lists a variety of social behaviors, and raters indicate, using a scale of 0 (*never*), 1 (*sometimes*), or 2 (*very often*), the frequency with which the child engages in each behavior. Raters also are instructed to indicate how important each of these behaviors is for the child's development using a scale of 0 (*not important*), 1 (*important*), or 2 (*critical*). A *Social Skill Standard Problem Score* was derived from these items. Descriptive statistics for the measures of child adjustment appear in Table 2.

RESULTS

Preliminary analyses examined whether there were any gender, racial, or SES differences in terms of physiological measures. No such differences were found. Examination of the child-adjustment data indicated that maternal reports of emotion regulation and externalizing problems did differ by gender. Boys were reported to be significantly higher on externalizing and lower on emotion regulation at age 4.5 ($ps < .05$). Gender was used as a covariate in analyses involving these outcome measures.

Effects of Challenge Episodes

To examine whether there was an effect of the challenge episode on RSA, a repeated measures ANOVA was conducted with RSA from each of the five episodes (baseline, attention, empathy, frustration, and problem solving) at both ages. This analysis revealed a significant episode effect, $F(1, 4) = 66.54$, $p < .001$, a significant age effect, $F(1, 90) = 22.94$, $p < .001$, and a significant Age × Episode interaction effect, $F(360) = 6.86$, $p < .001$. Post hoc analyses (paired t tests) indicated that at age 2, all challenge-episode RSA values were significantly lower than the baseline episode ($ps < .01$ or greater for each contrast). At age 4.5, all challenge-episode RSA values, except the empathy-episode RSA, were significantly lower than the baseline episode ($ps < .01$ or greater for each contrast). Thus, with only one exception, the challenge episodes elicited on average a significant change (suppression) in RSA at both ages.

Post hoc analyses also revealed that with the exception of the age 2 attention-versus-empathy episode, all other episodes within each age differed significantly from one another ($p < .05$). Thus, the magnitude of the RSA suppression response differed depending on the type of challenge, with the problem-solving episode at both ages eliciting the largest decreases, the frustration episodes eliciting the next-largest decreases, and the attention and empathy episodes eliciting the smallest decreases.

Finally, the two age groups differed in terms of both baseline measures and episode measures of RSA, with the older children displaying significantly larger RSA values across all tasks. The next set of analyses used computed change scores to examine age differences in RSA suppression across the different tasks.

Age Difference in RSA Suppression

To address the question of whether children display increases in RSA suppression with age, change scores

Table 2. Descriptive Statistics for Age 4.5 Regulation Measures

	M	*SD*	Min	Max	*n*
Age 4.5 Regulation					Total = 122
Social Problems (SSRS)	97.76	11.9	84	135	110
Negativity (ERC)	1.69	.35	1.00	2.70	117
Regulation (ERC)	2.97	.31	2.21	3.86	117
Externalizing (CBCL)	54.07	10.00	30.00	74.00	120

SSRS, social skills rating system (Gresham & Elliot, 1990); ERC, emotion regulation checklist (Shields & Cicchetti, 1998); CBCL, child behavior checklist (Achenbach, 1991).

were computed for each challenge episode by subtracting the challenge episode RSA from the baseline RSA. These change scores appear in Table 3.

Although residualized change scores may be the most appropriate strategy for examining change given the significant and positive relation between baseline and episode measures ($r\text{s} = .44–.55$, $p < .001$ at age 2; $r\text{s} = .10–.34$, significant $p\text{s} < .05$ at age 4.5), they were not used in this analysis because across a given sample, the residualized change score has a mean = 0. The use of this kind of change score would make it impossible to detect age changes. A repeated measures ANOVA was therefore computed on the four-episode RSA change scores for the two ages. This analysis revealed a significant age effect, $F(1, 92) = 21.27$, $p < .001$. There was no interaction of age and episode. Across all episodes, the change scores for the challenge episode at 4.5 were lower than those for age 2. This finding is notable in view of the fact that the baseline measure of RSA was higher at age 4.5 than at age 2. Although the Law of Initial Values would predict that the change scores at age 4.5 would be higher than at age 2, this was not the case.

Stability of RSA Suppression Response (within Age)

To examine stability within age and over tasks, *controlling for the resting measure of RSA*, a residualized change score was computed by regressing each episode RSA values on the baseline RSA values. Thus, at each age, four residualized change scores were computed that took into account the baseline values of each child. These residualized change scores were used in subsequent analyses of stability. To examine whether the residualized RSA suppression scores were stable within age, cross-episode correlations were examined. These correlations are presented in Table 4. As the table indicates, there were significant relations within each age in terms of RSA suppression across episodes. Greater suppression to one challenging task predicted greater RSA suppression to other tasks, within each age.

Stability of RSA Baseline and Suppression across Ages

Examination of baseline RSA across ages revealed a significant relation over the 2-year period, $r = .57$, $p < .001$. Children with higher baseline measures of RSA also had higher baseline measures at age 4.5. To examine whether the residualized RSA change scores were stable across age, cross-episode correlations were examined. These correlations are presented in Table 5. As the table indicates, there were several significant relations across age in terms of RSA suppression across episodes. Greater suppression to several of the challenge tasks at age 2 predicted greater RSA suppression to the attention and problem-solving tasks at age 4.5, and greater suppression to the problem-solving task at age 2 predicted greater suppression to all but the attention task at age 4.5.

RSA Suppression Stability and Child Outcomes

To examine whether RSA suppression and stability of RSA suppression were related to child outcomes, two sets of analyses were conducted. First, simple correlations between the eight measures of suppression and the four outcome measures were examined. Of the 32 possible correlations, 3 were significant. RSA suppression during the attention task at age 2 was negatively related to negativity ($r = -.32$, $p < .001$) and externalizing problems at age 4.5 ($r = -.21$, $p < .05$). Higher RSA suppression at age 2 was related to lower levels of child negativity and fewer externalizing behavior problems at age 4.5. Next,

Table 3. Descriptive Statistics for RSA Change Scores

	M	*SD*	Min	Max	*n*
RSA Change (2)					Total = 152
Attention	.61[a]	.82	−1.07	3.22	135
Empathy	.53	.78	−1.22	2.88	137
Frustration	.79	.84	−1.37	3.10	135
Problem	.97	.81	−1.19	3.03	137
RSA Change (4.5)					Total = 122
Attention	.20	.47	−1.41	1.46	114
Empathy	−.01	.52	−1.28	2.01	114
Frustration	.30	.64	−1.45	1.96	115
Problem	.65	.70	−.81	2.37	113

RSA, respiratory sinus arrythmia.
[a]Positive change scores indicate greater decrease from baseline to task.

Table 4. Correlations Among RSA Residualized Change Scores Across Four Tasks, Within Age

	Attention	Empathy	Frustration	Problem
Attention	—	.40*	.35*	.58**
Empathy	.38*	—	.46**	.41*
Frustration	.40*	.29*	—	.44**
Problem	.31*	.33*	.61**	—

Note. Correlations among age two variables are above the diagonal; age 4.5 are below the diagonal. RSA, respiratory sinus arrythmia.
*$p < .01$.
**$p < .001$.

correlations between baseline measures of RSA at each age and the outcome measures were examined. No relation was found between baseline RSA and any of the outcome measures.

Given these findings and the high within-age stability but modest cross-age stability in RSA suppression, a second set of analyses was undertaken. Children were placed into one of three groups, using a k-means cluster analysis (SPSS, Version 10) and the raw RSA suppression scores. Children with complete data were included in the analyses. The groups emerged in seven iterations and consisted of children who were low in RSA suppression at age 2, but high at age 4.5 (referred to as the Change group, $n = 27$), children who were low on RSA suppression at both ages (referred to as the Stable Low group, $n = 46$), and children who were high on suppression at both ages (referred to as the Stable High group, $n = 28$). The remaining children could not be classified due to missing data at either age 2 or age 4.5. In addition, no group emerged that was high on RSA suppression at age 2 and low at age $4\frac{1}{2}$. Visual inspection of the data revealed that a small number ($n = 4$) of children showed a pattern of positive or high suppression scores at age 2 and a mixture of high and low scores at age 4.5. These children were classified by the analysis as Stable High.

There was no relation between stability group status and child gender, race, or SES. Next, these three groups were compared on the measures of child-adjustment outcomes using ANOVA and controlling for child gender. These analyses are depicted in Table 6. As the table indicates, there were several differences among the three groups of children. Across all analyses, the Stable High group (children who displayed higher degrees of RSA suppression in response to challenge at both 2 and 4.5 years of age) were rated by their mothers as more socially skilled, less negatively reactive, and less likely to display externalizing-type behavior problems than children who were consistently low in their RSA suppression response and, in the case of externalizing and negativity, than children whose RSA response changed from low to high across the preschool period.

DISCUSSION

This study had several goals. First, we were interested in the phenomena of cardiac vagal regulation across the preschool period—a time of considerable growth in self-regulation (Kopp, 1982). Prior research has indexed physiological regulation of cardiac activity by examining suppression or decreases in the magnitude of RSA. No data exist on the characteristics of this type of physiological regulation across this period of development, either in terms of stability or in terms of the kind of behavioral tasks that might elicit such a response. In addition, little is known about the developmental continuity or discontinuity of the response. Second, we were interested in whether the pattern of physiological responding over this period of development would be related to behavioral measures of self-regulation and psychological adjustment of the child. To address these questions, we examined data from an ongoing longitudinal study of early self-regulation. Our focus on the preschool period was motivated by the observation in other research that

Table 5. Correlations Between 2-Year and 4.5-Year Residualized RSA Change Scores Across Four Tasks

	Attention 4.5	Empathy 4.5	Frustration 4.5	Problem 4.5
Attention (2)	.17*	.04	.08	.11
Empathy (2)	.23**	.09	.10	.29***
Frustration (2)	.17*	.20*	.05	.23**
Problem (2)	.09	.21**	.25**	.33***

RSA, respiratory sinus arrythmia.
*$p < .10$.
**$p < .05$.
***$p < .01$.

considerable development occurs in the domain of self-regulation across this period, and that relatively few studies of physiological functioning have been conducted with children of this age.

The first issue examined in this study was whether there was a parasympathetic cardiac response, in the form of RSA suppression, to different types of challenge tasks. Four tasks were examined: attention-demanding, frustration, empathy-eliciting, and problem-solving tasks. These tasks were chosen for examination because they have been demonstrated in prior research to elicit a significant parasympathetic response and because they present clear emotional and behavioral challenges to the children (Calkins, 1997; Calkins & Dedmon, 2000). The analyses of these data demonstrate clearly that each of these tasks (with the exception of the empathy task at age 4.5) elicited, on average, a significant decrease in RSA from baseline, which should support cardiac output and behavioral regulation. In addition, there were differences among these four tasks within each age in terms of the magnitude of the RSA response. The problem-solving task and the frustration task elicited a greater suppression response than did the attention and the empathy tasks. It is likely that the attention and the empathy tasks were less challenging behaviorally and emotionally, and thus elicited less of a physiological response.

These findings are consistent with the notion that different kinds of challenges place different demands on the child and elicit different levels of self-regulation at the behavioral level. They also point to the need to consider the type of task that is used to index cardiac physiological regulation and the need to address whether the ''challenge'' task that is used is sufficient to elicit a regulatory response. Note that we did not examine the child's behavioral response to these tasks. The tasks have been used extensively in prior work and have been shown to elicit, on average, a behavioral response in toddlers and preschoolers (Calkins, 1997; Calkins & Dedmon, 2000); however, each task placed different demands on the child, making cross-task comparisons of behavior difficult. Moreover, it is unclear whether observed behavioral indicators would be sufficient to capture the child's regulatory efforts. Task differences in RSA response do suggest that the tasks are differentially challenging, and the similarity in the pattern of response at the two ages reinforces this conclusion. Based on prior work, it is likely that attentional control, which is critical to self-regulation (Ruff & Rothbart, 1996), is related to the suppression of RSA, and that these tasks may have differed in the attentional demands placed on the child (Calkins & Dedmon, 2000).

A second question addressed in this study was whether there are age differences in the magnitude of the RSA response across challenge tasks. The hypothesis regarding the development of RSA was that as children develop regulatory skills, cardiac physiological regulation would increase; however, analysis of the data across the preschool period indicated that there was actually a decrease in the RSA response over time. Moreover, the magnitude of the correlation between baseline and suppression scores was smaller at the older age. Multiple explanations for this finding must be considered. The first is that the tasks themselves were less challenging at 4.5 than they were at age 2. A second explanation is that as children become better regulated emotionally and behaviorally, they require less physiological regulation. Physiological regulation is considered a primitive regulation ability upon which other, more sophisticated skills depend (Porges et al., 1994). Alternative explanations may reflect the influence of maturation of other physiological systems or processes, which then become integrated into the response repertoire, providing the child with multiple modes of self-regulation. Thus, one unanswered question is whether the relations between physiological regulation and emotional or behavioral regulation that have been observed in younger children are less likely to be observed among older children.

Table 6. Child Adjustment Measures at Age 4.5 by RSA Suppression Group

	Change		Stable Low		Stable High	
Age 4.5 Regulation	*M*	*SD*	*M*	*SD*	*M*	*SD*
Social Problems (SSRS)	98.5	13.2	100.5	10.8	92.8	10.5**,a
Negativity (ERC)	1.75	.32	1.69	.35	1.53	.26*,b
Regulation (ERC)	2.9	.32	2.9	.31	3.0	.31
Externalizing (CBCL)	55.71	9.05	56.32	8.65	50.32	10.43*,b

SSRS, social skills rating system (Gresham & Elliot, 1990); ERC, emotion regulation checklist (Shields & Cicchetti, 1998); CBCL, child behavior checklist (Achenbach, 1991).

** $p < .01$.

* $p < .05$.

[a] Post hoc tests (LSD) indicate that Stable High group differs from Stable Low group.

[b] Post hoc tests (LSD) indicate that Stable High group differs from Stable Low group and Change group.

A third issue addressed in this study concerned the stability of the RSA response within and across time. Within-assessment analyses indicated that at both ages, after controlling for the level of baseline or resting RSA, the children tended to maintain their individual level of response to the challenge tasks. These data suggest that within a relatively short assessment period, children display a similar magnitude of response, independent of their characteristic level of RSA, to different types of challenges. Across age, there was modest stability as well, suggesting that physiological responding may be a characteristic of the child. Temperament theory as articulated by Derryberry and Rothbart (1985) suggests that both reactivity and regulation of physiological and behavioral systems are moderately stable over time. This is the first study to demonstrate that this stability exists over the preschool period.

The final set of analyses examined the relations between RSA response measures and children's adjustment. Simple correlations between individual measures of RSA regulation and adjustment revealed few significant findings. These null findings may reflect the fact that regulatory abilities that emerge during the preschool period are likely to be multiply determined. One factor that was not considered in the present study was the influence of the external environment. Considerable data suggest that external factors, such as the caregiving environment and caregiver behavior, influence the child's acquisition of self-regulatory skills (Calkins, 1994; Fox & Calkins, 2003; Kopp, 1982). A second reason for the null findings regarding RSA regulation and behavioral outcomes may be that early regulatory abilities affect the development of subsequent abilities. Given that these earlier abilities were not examined in the present study, one must consider the effects of earlier regulation on later behaviors. Thus, given the modest cross-age correlations in RSA regulation, a second set of analyses was conducted. This analysis examined three groups of children whose physiological response across the preschool period was characterized by stable versus unstable responding. These three groups were compared on a number of parent-report outcome measures that indexed behavior problems, social skills, and emotion regulation. The findings indicated that the children who displayed a pattern of stable high regulation across both ages also displayed the most positive outcomes. These children were rated by mothers as displaying lower levels of externalizing behavior problems, less negativity, and higher social skills. Thus, these data provide support for the notion that appropriate physiological regulation, in the form of RSA suppression, supports adaptive self-regulatory behavior and social functioning.

The other two groups of children showed more mixed behavioral profiles, with the stable low group apparently having more adjustment difficulties, although the Change group also displayed less positive outcomes on some measures. There are multiple ways to interpret these findings. First, these children, by virtue of their lower cardiac physiological regulation at age 2, may have experienced more behavioral adjustment difficulties (Calkins & Dedmon, 2000). Parents' perceptions of these children may not have changed over the 2-year period, and this is reflected in their assessments of the children's emotionality, social skills, and behavior problems. Alternatively, children's behavioral regulation skills may be more influenced by earlier physiological regulation, thus constraining the development of more mature skills during preschool. A closer examination of children's specific skills and skill deficits across the period would address this issue.

This study has several limitations that must be acknowledged. First, data were collected in two brief laboratory sessions. Questions about whether such brief observation periods allow for adequate characterization of children's responding are unanswered. Second, the stability group differences are clearly modest and suggest that there are probably children within each of these groups for whom the conclusions drawn are not warranted. Third, no effort was made in this report to examine possible moderating effects on early cardiac physiological regulation, such as parenting behavior. Such an analysis would likely shed more light on the multiple developmental processes implicated in the emergence of child regulation skills across the preschool period.

NOTES

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