

Cardiac vagal regulation differentiates among children at risk for behavior problems

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Abstract

A sample of 335 five-year-old children participating in an ongoing longitudinal study was the focus of a study on the effects of emotional and behavioral challenge on cardiac activity in children with different patterns of early childhood behavior problems. The children were placed in one of three behavior problem groups (low behavior problems, risk for externalizing problems, risk for mixed externalizing/internalizing problems) based on their scores on the Child Behavior Checklist for 4–18-year-olds [Achenbach, T.M., 1991. Integrative guide for the 1991 CBCL/4-18, YSR & TRF profiles. University of Vermont Department of Psychiatry, Burlington, VT], completed by their mothers. To assess cardiac vagal regulation, resting measures of respiratory sinus arrhythmia (RSA) and RSA change (vagal withdrawal) to five emotionally and behaviorally challenging tasks were derived. In addition, heart period (HP) and heart period change (HR acceleration) was examined. Results indicated that the behavior problem groups did not differ in terms of resting measures of either RSA or HP. Analyses of the challenge tasks indicated that the children at risk for mixed problems displayed greater cardiac vagal withdrawal across the five tasks than did the other two groups of children. There was a trend for the children at risk for externalizing problems to display less vagal withdrawal than the control group. In addition, the children at risk for mixed problems displayed greater heart rate acceleration to the tasks than did the other two groups of children. Follow-up analyses indicated that the greater cardiac acceleration observed in the mixed group was largely a function of greater vagal withdrawal. These findings are discussed in terms of the emotion regulatory function of cardiac vagal regulation, and its implications for patterns of risk for behavior problems in young children. © 2006 Elsevier B.V. All rights reserved.

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Recent work in both developmental and clinical psychology has identified the construct of emotion regulation as one that is critical to understanding adaptive functioning (Baumeister and Vohs, 2004; Calkins and Dedmon, 2000; Calkins and Fox, 2002; Keenan, 2000; Shaw et al., 1997). The ability to exercise self-control over the expression of emotion, particularly negative emotions, and emotion-related behavior, develops over the first years of life and has particular importance for the development of appropriate and adaptive social behavior during the preschool and school years (Calkins, 1994, in press; Kopp, 1982; Eisenberg et al., 1995, 1996; Thompson, 1994). Moreover, the lack of adequate development of control over emotion, including overcontrol of emotion, and behavior may be a precursor to the development of psychopathology,

particularly early problems characterized by aggression, hyperactivity, and anxiety (Keenan and Shaw, 2003; Nigg and Huang-Pollock, 2003).

Research in the area of early emotion regulation has focused on both intrinsic (biological) and extrinsic (familial) contributors to both normative development and individual differences in emotion regulation (Fox and Calkins, 2003). Biological substrates of emotion regulation have been the focus of both theoretical (Calkins, 1994; Fox, 1994) and empirical work (Blair, 2003; Calkins and Dedmon, 2000; Calkins and Keane, 2004). Theories of emotion 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 that is observed across childhood. Fox (1989, 1994), for example, has 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 notes that maturation of the frontal cortex

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provides a mechanism for the more sophisticated and planful regulatory behaviors of older children versus infants. Porges' Polyvagal theory (Porges et al., 1994; Porges, 1996, 2001, 2003) also describes 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 notes that individual differences in nervous system functioning might mediate the expression and regulation of emotion and, by extension, be important elements of the system that supports appropriate social engagement (Porges et al., 1994; Porges, 2001, 2003). Porges and others have found that parasympathetic nervous system functioning, as reflected in heart rate variability influenced by the vagal system, is related to the control of attention, emotion, and behavior (Calkins, 1997; Calkins and Dedmon, 2000; DeGangi et al., 1991; Huffman et al., 1998; Porges et al., 1996).

Although there are multiple ways to measure this variability, Porges (1985, 1991, 1996) and colleagues developed a method that measures the amplitude and period of the oscillations associated with inhalation and exhalation. This measure refers to the variability in heart rate that occurs at the frequency of breathing (respiratory sinus arrhythmia, RSA) and is thought to reflect the parasympathetic influence on heart rate variability via the vagus nerve. Porges has termed this measure of heart rate variability vagal tone (Vna; Porges and Byrne, 1992; Porges, 1996). 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 and Fox, 1990) and good attentional ability (Richards, 1985, 1987; Suess et al., 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 (Hoffheimer et al., 1995; Richards and Cameron, 1989).

Porges' theory further suggests that one particular measure of cardiac activity that may be more directly related to the kinds of regulatory behaviors children begin to display in toddlerhood and early childhood is vagal regulation of the heart as indexed by a decrease in RSA (vagal withdrawal) during situations where coping or emotional and behavioral regulation is required (Porges, 2001, 2003). Vagal regulation in the form of decreases in 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, vagal withdrawal 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 and Gottman, 1996), and that results in greater cardiac output in the form of HR acceleration.

Considerable research indicates that greater vagal withdrawal 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 and Dedmon, 2000; Calkins and Keane, 2004; Porges et al., 1996), and sustained attention in school-age children (Suess et al., 1994). Moreover, recent research comparing the magnitude of RSA response to different types of challenges indicates that children display significantly greater decreases in RSA when provided with parental support during a task than when confronted with a challenge independent of support (Calkins and Keane, 2004), and that the magnitude of this response is an individual difference that is moderately stable across early development and that predicts a range of indicators of adaptive functioning (Calkins and Keane, 2004; El-Sheik, 2005). The extension of these research findings is that while vagal withdrawal may be related to complex responses involving the regulation of attention and behavior, a deficiency in this ability may be related to early adjustment problems, particularly problems characterized by a lack of behavioral and emotional regulation (Calkins and Dedmon, 2000; Porges, 1996; Wilson and Gottman, 1996).

Lack of behavioral and emotional control is considered a core deficit for children with externalizing-type behavior problems (Gilliom and Shaw, 2004; Keenan and Shaw, 2003). Children with externalizing problems display patterns of aggressive, destructive, undercontrolled behavior that remains stable from preschool to middle childhood (Gilliom and Shaw, 2004) and that often results in more severe conduct problems in adolescence and young adulthood (Olweus, 1979). Given that such problems are believed to have both biological and socialization origins (Moffitt, 1993), one question that may be asked is whether these children display a pattern of physiological dysregulation that impairs their ability to generate and engage appropriate regulatory strategies in situations that are emotionally or behaviorally challenging. A small number of studies have addressed this question. Pine et al. (1998) reported that 11-year-old boys with externalizing symptoms had lower heart period variability. Mezzacappa et al. (1997) report similar findings among adolescent males. Both researchers conclude that such relations may occur because of parasympathetic links to regulatory abilities involving attentional and behavioral control.

These early seminal studies of RSA and externalizing problems are limited in their focus on adolescent male samples. More recent work has addressed the question of whether such findings may be observed in sample of younger girls and boys. In one study, children at high risk for the development of aggressive behavior problems were identified at age 2 years and assessed in a number of challenging tasks (Calkins and Dedmon, 2000). These children displayed significantly lower RSA suppression (less vagal withdrawal) across these tasks than did children at low risk for behavior problems. In a follow-up of these same children, continued behavioral difficulties, including social problems and difficulties with emotion regulation, were characteristic of the children who displayed, across the preschool period, a stable pattern of physiological

dysregulation, in the form of lower vagal withdrawal to challenge (Calkins and Keane, 2004). Interestingly, children who displayed a pattern of lower withdrawal at age 2 years, but who displayed a decrease in RSA (indicating vagal withdrawal) at age 4 years had continued behavioral difficulties, suggesting that the early pattern of cardiac vagal regulation may have constrained the acquisition of regulatory skill that affected behavior later in the preschool period.

These limited findings suggest that there may be a physiological profile of poorer vagal regulation of HR activity that may be characteristic of children at risk for early externalizing problems. However, one challenge to the study of physiological regulation among children with behavior problems characterized by aggression is that these problems often present with comorbid internalizing symptoms (anxiety, withdrawal) (Achenbach et al., 1991; Gilliom and Shaw, 2004). These comorbid problems are often ignored, either because they are thought to be a consequence of single-reporter bias, or because the sample sizes in most studies of children's behavior problems are too small to allow for separate consideration of pure versus comorbid problems (Calkins and Dedmon, 2000). However, in a recent large-scale study of early externalizing behavior problems, researchers identified differential behavioral and environmental correlates and predictors of pure versus mixed patterns of externalizing behavior problems (Keiley et al., 2003). Clearly, it is important to examine whether these different behavioral patterns may be distinguished by cardiac vagal regulation in the form of RSA decreases to emotional and behavioral challenges. One hypothesis is that the comorbid anxiety symptoms, which may associated with overcontrol of emotion, may indicate less severe behavior problems (Lilienfeld, 2003) and may be reflected in greater cardiac vagal regulation compared to children with pure externalizing problems. However, excessive vagal withdrawal may also be a marker of emotional lability and a flight/fight response on the part of the child with anxiety symptoms (Beauchaine, 2001). Another possibility is that comorbid problems may be considered more severe than pure internalizing or externalizing problems (Hinshaw et al., 1993), and may result in significantly poorer cardiac vagal regulation compared to children with pure externalizing problems.

Although there is a clear rationale for examining cardiac vagal regulation as an indicator of emotional and behavioral regulation, and for hypothesizing that children at risk for behavior problems characterized by a lack of emotional and behavioral regulation would display poorer cardiac vagal regulation, other cardiac measures may also be related to behavior problems in young children. In the adult personality and psychopathology literature, a number of studies suggest links between aggressive and antisocial behavior and autonomic functioning using such indicators as heart rate and skin conductance (see Lahey et al., 1993, and Raine, 1996, for reviews). One conclusion to be drawn from this literature is that underarousal of the autonomic nervous system as reflected in low heart rate (HR) in particular may be a core characteristic of aggressive behavior in adolescents and adults (Lahey et al., 1993; Raine et al., 1990; Raine, 1996).

Raine and colleagues have also linked low resting heart rate to behavior problems in late childhood (Raine and Jones, 1987; Raine et al., 1997) and have found that low resting HR in adolescence is predictive of criminal behavior in adulthood. Raine has suggested that low autonomic nervous system (ANS) arousal may be a genetic marker for aggressive behavior (Raine et al., 1990). However, this finding has not been widely replicated in the developmental literature, though the studies examining relations between resting measures of heart rate and aggression in children are few and the behavior of the children tested is typically not as extreme as in studies of adolescent or adult aggression. For example, Eisenberg et al. (1996) examined relations between resting HR in normal school-age children and parent report of behavior problems and found modest relations between low resting HR and the incidence of problem behavior. Zahn-Waxler et al. (1995) found no association between problem behavior in preschoolers and resting heart rate or between early childhood measures of resting HR and behavior problems at age 7 years. Using a sample at subclinical risk for behavior problems, Calkins (Calkins and Dedmon, 2000) found no relation between resting HR and toddler behavior problems or preschool social and behavioral functioning (Calkins and Keane, 2004). Clearly more data on the relation between childhood behavior problems, and risk for behavior problems, and resting HR are needed.

HR reactivity has also been examined as a correlate of aggressive behavior in children. Eisenberg et al. (1996) found an association between boys' problem behavior and changes in HR during distressing film stimuli, but argued that this relation was due to the lower resting HR measure observed in boys as opposed to any independent change in HR. Wilson and Gottman (1996) hypothesized that excessive heart rate reactivity may interfere with the effective allocation of attentional abilities to meet task demands. Given that resting measures of cardiac activity and response measures have been shown to be related in children (Calkins, 1997; Suess et al., 1994), and that these measures are influenced both sympathetically and parasympathetically, it would be important to examine these effects independently in a sample of children with behavior problems.

The aims of the present study were to examine multiple measures of cardiac functioning in a large sample of male and female children, to try to address several gaps in the current literature. First, the study was designed to look at resting measures of cardiac activity and changes in cardiac activity, across several emotional and behaviorally challenging tasks. As a way of validating prior psychophysiological studies of older children and males, and to test Porges' Polyvagal theory that parasympathetic functioning, in particular, is related to more adaptive regulatory behavior in young children. A large community sample, overselected for externalizing problems, was chosen as the appropriate group in which to test the theory as this group would have sufficient numbers of boys and girls displaying both mixed and pure patterns of externalizing problems indicative of different patterns of emotion regulation and adaptation. Children were classified as at risk for externalizing problems, at risk for mixed problems or low in problem behavior using borderline clinical cut-offs on a

widely-used measure of childhood behavior problems. Such an approach is less stringent than using clinical cut-offs or clinical-referred children, but may be appropriate in longitudinal studies of young children given that considerable discontinuity in behavioral adaptation is observed across early development (NICHD SECC, 2004). Examining children at risk for problems provides a window on interactions between children and their environments as factors in behavioral change across time.

Several questions were addressed in the present study. The first question was whether there would be differences in resting measures of RSA and HP among groups of children displaying different patterns of behavior problems. It was hypothesized that there would be differences in the RSA measure as this measure has been found in numerous studies to index emotional reactivity (cf. Calkins, 1997). No difference was predicted among the groups in terms of resting HP. Although some researchers speculate that low resting HR (high resting HP) is an index of low arousal that is characteristic of children with conduct problems, little evidence of such a phenomenon exists in community samples of young children or in children at lower risk for behavior problems. Moreover, in this sample, conduct problems were likely to be low occurring. Sex was also examined as part of this question as sex differences have been observed in both levels of behavior problems and in measures of resting HR (Eisenberg et al., 1996). The second question addressed in the study was whether there would be behavior problem group differences in RSA change across tasks. It was hypothesized that the children with behavior problems would display lower vagal withdrawal (smaller decreases in RSA) than the children in the low problem group, as children with behavior problems display significant difficulties in the regulation of affect and behavior (Calkins and Dedmon, 2000). It was unclear whether the mixed children would show the smallest decrease in RSA since they are considered to have a higher level of problem behavior, or whether the anxiety symptoms these children display would result in excessive vagal regulation, which might manifest in a greater degree of RSA suppression (Beauchaine, 2001). The third question addressed in this study was whether there would be behavior problem group differences in HP change across challenge tasks. It was hypothesized that the behavior problem groups would not differ on measures of HP change. Again, although there has been some data to suggest that behavior problems characterized by conduct problems versus anxiety might lead to differences in HP response to challenge, these changes may in fact be a function of differences in the ability to suppress RSA, as opposed to other non-parasympathetic influences on HR (such as sympathetic, homeostatic, or hormonal).

1. Method

1.1. Participants

Participants for this study were recruited as part of an ongoing longitudinal study that began when children were 2 years old. At the original 2-year assessment, 447 families participated (215 males). Because the original study was designed to the trajectories of early externalizing behavior problems, the

original sample was overselected for externalizing problems, with 37% of the sample displaying elevated externalizing symptoms at age 2 years. Further details about the original sample recruitment strategy may be found in Calkins and Keane (2004), Smith et al. (2004), and Calkins and Dedmon (2000). Assessments at age 2 years and each follow-up age (4 and 5 years) consisted of multiple assessments in the home, school, and laboratory. Parents were compensated for their participation in each assessment.

At the 5-year assessment that is the focus of the current study, 335 children (156 males, 179 females, mean age = 66 months, S.D. = 3.2 months) participated in the laboratory portion of the study that included the collection of cardiac data. Attrition from age 2 to 5 years was due to refusal (approximately 6%, as many of the original participants were not told that there would be follow-up as continued funding was unknown at the time), movement from the area (7%) or movement within the area to an unknown address (11%). Of the 335 families participating in this follow-up, 67% were Caucasian, and the remaining families were African American (30%) or mixed race (3%). Sixty-four percent of the children were from intact families. Fifty-six percent of the parents of the children had college degrees, 30% had attended some college, and 12% had a high school education. Socioeconomic status of the participants ranged from lower to upper-middle class, with mean Hollingshead (1975) score = 43, S.D. = 10.5. There were no differences between children who completed the 5-year assessment and those who did not on any demographic or behavior problem measure collected at age 2 years.

1.2. Procedures

1.2.1. Overview

Mothers accompanied their children to the laboratory for this assessment. In the laboratory, a number of individual child tasks and mother–child tasks were conducted. Following informed consent, each child had his or her weight and height measured. Then, the child and the mother were observed in a series of individual and dyadic tasks. Several of these tasks were conducted while collecting psychophysiological data from the children. The six tasks that were conducted with the child observed independently of the mother are the focus of the present report. Parents also completed questionnaires concerning their child's adjustment at preschool. 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).

1.2.2. Laboratory assessment

Parents who had participated in prior assessments when their children were 4 years old were contacted to schedule a laboratory assessment. Mothers were asked to accompany their children to the laboratory where the children were assessed in a laboratory playroom during several procedures. First, the experimenter placed three disposable pediatric electrodes in an inverted triangle pattern on the child's chest while the child 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 heart rate (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 multipisode sequence that was derived from the Laboratory Temperament Assessment Battery (LAB-TAB; Goldsmith and Rothbart, 1993) and prior work (Calkins, 1997; Calkins and Johnson, 1998; Calkins and Keane, 2004; Kochanska et al., 1997). The *baseline* episode consisted of a 5-min segment of the videotape "Spot," a short story about a puppy that explores its neighborhood. While this episode was not a true baseline given that the child's attention was engaged in an external stimulus, it was sufficient to keep the child sitting quietly and showing little affect. Given the ages of the participants, such stimulus was necessary in order 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 and end 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. In the first episode, an *effortful control* task was designed to assess the child's ability to slow down gross and fine motor activity. The child was asked to draw some shapes (circles and stars) between boundary lines at varying speeds (regular, slow, and fast). This episode lasted 6 min. The next episode was a second *effortful control* task similar to a Stroop task. The child was presented with large pictures representing large shapes (animals, geometric figures). Within the larger pictures, smaller shapes were depicted. In half of the trials the small shapes were consistent with the large shape (e.g. a large cat was made up of identical smaller cats), and in the other half the shapes were inconsistent (e.g. large circle made up of small squares). The child was asked to recognize only the smaller shapes in the pictures presented and were instructed to answer as fast as they could. This episode lasted for 4 min. The next episode was an *attentional persistence* task, during which the child was asked to sort a large number of beads by color and place them in a container. This episode lasted 3 min. The *positive* episode that followed consisted of a 4-min segment in which the child was surprised with a pop up snake and then was instructed to surprise his/her mother. Lastly, a *frustration* episode consisted of a 4-min segment in which a second experimenter presented the experimenter and child with candy to be evenly divided. The experimenter proceeded to share the candy unevenly, eating some of the child's candy, and slowly taking all the candy away from the child while preventing the child from eating any of it.

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 (and in particular, remaining seated 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 carry-over 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, only the initial baseline measure was considered for analyses involving contrasts with the challenge episodes.

1.2.3. Questionnaires

Mothers were given a packet of questionnaires to complete at this assessment. Of interest for this report was *The Child Behavior Checklist for 4–18 year olds* (CBCL; Achenbach, 1991). This measure has been widely used by researchers studying early social adjustment and has adequate reliability and validity.

1.3. Measures

1.3.1. Cardiac measures

Two types of physiological measures were derived from the laboratory assessments. These were: cardiac vagal regulation measures (RSA and RSA change), and heart period measures (HP and HP change). 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). 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 heart period (HP) data. The algorithm uses a moving 21-point polynomial to detrend periodicities in HP slower than RSA. Then, a band-pass filter extracts the variance of HP within the frequency band of spontaneous respiration in young children, .24–1.04 Hz. Although lower frequency bands may be studied, research with young children has consistently examined this band and identified associations to child functioning (Porges et al., 1996; Stifter and Fox, 1990; Huffman et al., 1998). The estimate of RSA is derived by calculating the natural log of this variance and is reported in units of $\ln(\text{ms})^2$. Heart period and RSA were calculated every 30 s for the 5-min baseline period and for each of the challenge episodes. These epoch durations are typical for studies of short

Table 1

Descriptive statistics for RSA, RSA change, HP, HP change

	<i>M</i>	<i>S.D.</i>	<i>Min</i>	<i>Max</i>	<i>n</i>
Age 5 RSA					
Baseline RSA	6.08	1.15	3.28	9.42	296
Effortful control 1 RSA	6.09	1.13	3.09	9.09	293
Effortful control 2 RSA	5.87	1.18	3.01	8.80	291
Attention RSA	5.57	1.13	2.72	8.85	288
Positive RSA	6.02	1.01	2.99	8.44	280
Frustration RSA	5.81	1.11	2.68	9.41	287
Age 5 RSA change					
Effortful control 1	−.02	.55	−2.88	2.05	293
Effortful control 2	.20 ^a	.77	−3.47	3.34	290
Attention	.49	.78	−3.02	3.24	287
Positive	.06	.75	−2.44	2.27	279
Frustration	.25	.72	−2.66	2.50	286
Age 5 HP					
Baseline HP	642.82	70.88	501.90	913.56	296
Effortful control 1 HP	626.62	66.94	487.45	893.86	293
Effortful attention 2 HP	621.84	64.46	489.89	862.02	291
Attention HP	595.75	59.75	473.35	798.23	288
Positive HP	603.56	59.59	453.32	833.66	280
Frustration HP	614.50	62.75	491.67	847.91	287
Age 5 HP change					
Effortful control 1	15.95	25.00	−53.60	133.82	293
Effortful control 2	20.04	35.07	−75.39	176.32	287
Attention	46.05	35.93	−54.30	195.11	287
Positive	38.34	41.43	−60.10	220.88	279
Frustration	27.25	37.44	−74.80	223.44	286

RSA, respiratory sinus arrhythmia; HP, heart period.

^a Positive change scores indicate greater decrease from baseline to task.

duration tasks (Huffman et al., 1998; Doussard-Roosevelt et al., 2003). The mean RSA of the epochs within each episode was used in subsequent analyses. If the standard deviation 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 indicates, the data files of some children were not included in some of the analyses. Several situations led to missing data across all six tasks. A few children would not allow the experimenter to apply the HR electrodes (7% of missing). In addition, the HR data collection equipment failed on several occasions (72% of missing). A third explanation for missing data was that the child pulled on, or touched, the HR leads from the beginning of the collection procedure (21%). Individual trials may have also been compromised due to excessive movement artifact affecting greater than 5% of the data in the HR file. A comparison of children with complete missing HR data from those without missing data revealed that these children did not differ in terms of behavior problem group status.

Change scores were computed for each challenge episode by subtracting the challenge episode RSA from the baseline RSA, and by subtracting the challenge HP from the baseline HP. These change scores appear in Table 1. High or positive change scores for RSA indicated that the child displayed a decrease in RSA (vagal withdrawal) from baseline to task. High or positive scores for HP indicated that the child displayed a decrease in HP (or HR acceleration) from baseline to task.

1.3.2. Child behavior problems

The CBCL completed by the parent was used to generate groups of children with different behavior problem profiles that might map onto different patterns of emotion regulation. Two broadband scales, representing externalizing behavior problems (attention, aggression, destructive behavior problems) and internalizing behavior problems (withdrawal, anxiety, and depression) were

Table 2
CBCL descriptive statistics for problem groups

	Low problem			Externalizing			Mixed		
	<i>M</i>	S.D.	<i>N</i>	<i>M</i>	S.D.	<i>N</i>	<i>M</i>	S.D.	<i>N</i>
Internalizing <i>t</i> -score	43.51	6.80	240	50.19	6.11	47	65.69	4.94	28
Externalizing <i>t</i> -score	47.22	7.32	240	64.36	4.40	47	68.07	5.87	28
Withdrawn <i>t</i> -score	51.14	2.86	240	52.23	3.53	47	60.69	7.02	28
Somatic complaints <i>t</i> -score	51.94	3.53	240	53.79	5.01	47	60.97	9.10	28
Anxious/depressed <i>t</i> -score	50.78	2.10	240	53.32	3.71	47	65.10	6.71	28
Social problems <i>t</i> -score	51.52	3.56	240	55.51	6.06	47	60.97	8.92	28
Thought problems <i>t</i> -score	52.24	4.62	240	55.91	6.89	47	61.24	9.17	28
Attention problems <i>t</i> -score	52.41	4.50	240	58.60	6.74	47	65.79	9.05	28
Delinquent behavior <i>t</i> -score	52.36	3.90	240	60.11	5.96	47	62.17	6.50	28
Aggressive behavior <i>t</i> -score	51.83	2.91	240	65.17	6.29	47	69.93	8.42	28

CBCL, Child Behavior Checklist (Achenbach, 1991).

the focus of the study. Children were selected for the “low problem” group if their *t*-scores on the two scales were below 60 ($n = 249$, 111 males), which is considered the borderline clinical cut-off (Achenbach, 1991); children who score at or above this cut-off are 10 times more likely to be referred for clinical services than children who score below the cut-off (Achenbach, 1991). Children were selected for the “Risk for Externalizing Problems” group if their externalizing *t*-score was at or above 60 and their internalizing *t*-score was below 60 ($n = 47$, 21 males, 14 above the clinical cut-off of 70). Children were selected for the “Risk for Mixed Problems” group if their *t*-scores on both the externalizing and internalizing scales were at or above 60 ($n = 29$, 13 males, 4 above the clinical cut-off of 70 on both scales). Because externalizing behavior problems were the focus of the study and children were not originally included in the sample at age 2 years if their *t*-scores on the internalizing scale was high, this “Risk for Internalizing Problems” group ($n = 13$, 10 males, 2 above the clinical cut-off of 70) was not considered representative of children at age 5 years with internalizing problems and was not included in the analyses. In addition, seven mothers failed to complete the CBCL and these children were not included in the analyses.

Descriptive statistics for the CBCL subscales and the broadband measures of child internalizing and externalizing behavior problems appear in Table 2.

These data were analyzed using an ANOVA comparing the three groups on the two broadband subscales. The analysis indicated significant group differences on both scales, $F(2,314) = 146.72$, $p < .001$ for internalizing and $F(2,314) = 208.90$, $p < .001$ for externalizing. Follow-up post hoc tests comparing the three groups indicated that the children in the low problem group were rated by their mothers as lower in externalizing symptoms than both the risk for externalizing group and the risk for mixed problems group (Tukey’s HSD, $p < .001$ for both contrasts), but that the two behavior problem groups did not differ in terms of externalizing score. The three groups differed from each other in terms of internalizing score, with the low problem group receiving the lowest internalizing score and the mixed group receiving the highest (Tukey’s HSD, $p < .001$ for each contrast). Additional analyses indicated that the three groups differed from each other on every subscale ($p < .001$ for all contrasts, Tukey’s HSD) except the withdrawn subscale, in which the mixed problem group was significantly higher ($p < .001$ for all contrasts, Tukey’s HSD) than both the low problem group and the externalizing group, who did not differ from each other.

2. Results

2.1. Preliminary analyses

Preliminary analyses examined whether there were any relations between sex, race, age, height, weight, or SES and the physiological measures and behavior problem groups. The behavior problem groups did not differ on any of these measures. The physiological measures of baseline RSA and HP and task RSA and HP were unrelated to all the measures

except sex. Across all five tasks, boys displayed higher HP (lower HR) than did girls, $F(1,259) = 4.09$, $p < .04$. Subsequent analyses of HP and HP change incorporated both sex and behavior problem group.

2.2. Behavior problem group differences in resting RSA and HP

To examine whether the behavior problem groups differed in terms of resting RSA and resting HP, two ANOVA’s were conducted with RSA and HP as the dependent measures and sex and behavior problem group as the independent variables. Group means for this analysis are presented in Table 3.

The first ANOVA analysis indicated that there was no difference between girls and boys or among the behavior problem groups in terms of resting RSA. Nor was there an interaction of sex and behavior problem group. The second analysis indicated that there was an effect of sex on HP, $F(1,280) = 5.73$, $p < .02$. Boys displayed significantly higher resting HP, lower HR, than did girls. No effect of behavior problem group and no interaction of sex and behavior problem group were found.

2.3. Behavior problem group differences in challenge RSA

To examine whether the behavior problem groups differed in terms of RSA change to the five challenge tasks, a repeated measures ANOVA was conducted with the three behavior problem groups. Sex was not examined as no sex differences were found in any of the measures of RSA. In addition,

Table 3
Descriptive statistics for baseline RSA and HP for problem groups by gender

	Low problem		Externalizing		Mixed	
	Male	Female	Male	Female	Male	Female
5-year baseline RSA	6.05	6.03	6.18	6.13	6.68	6.16
5-year baseline HP	647.61	636.50	656.25	639.50	687.40	624.44

RSA, respiratory sinus arrhythmia; HP, heart period.

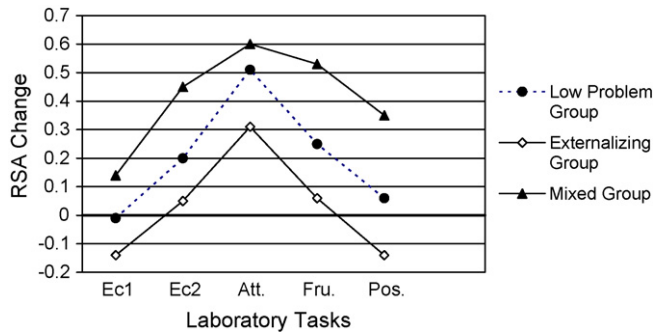


Fig. 1. RSA change scores for problem groups. RSA: respiratory sinus arrhythmia, positive change scores indicate greater decrease from baseline to task or vagal withdrawal. Ec1: effortful control task #1; Ec2: effortful control task #2; Att.: attention task; Fru.: frustration task; Pos.: positive task.

although initial levels of RSA are predictive of change scores of RSA, these initial levels did not differ across behavior problem groups, and were not covaried in this analysis. Group means for this analysis are presented in Fig. 1.

This analysis revealed a main effect of behavior problem group on the measures of RSA change, $F(2,260) = 3.91$, $p < .02$, partial eta-squared = .03. No interaction of task and behavior problem group was found. Across all five challenge tasks, the behavior problem groups differed in the measures of RSA change. Follow-up contrast tests, repeated measures ANOVA comparing each of the two groups revealed that the mixed group differed from the externalizing group, $F(1,58) = 5.44$, $p < .02$. Children in the mixed group displayed significantly greater RSA decreases (greater vagal withdrawal) across tasks than did children in the externalizing only group. The analysis comparing the mixed group and the low problem group indicated a trend toward a significant difference, $F(1,226) = 3.13$, $p = .08$. Similarly, a trend toward a significant difference emerged between the externalizing group and the low problem group $F(1,232) = 2.69$, $p = .10$. Children in the mixed problem group displayed the greatest decrease in RSA (greater vagal withdrawal) and children in the externalizing only group displayed the smallest decrease, with the low problem children in the middle of these two groups.

2.4. Behavior problem group differences in HP change

To examine whether the behavior problem groups differed in terms of HP change to the five challenge tasks, a repeated measures ANOVA was conducted with the three behavior problem groups. Sex was examined because sex differences were found across all of the HP measures. However, because there was a sex difference in terms of resting HP, which is used to compute the HP change score, resting HP was used as a covariate in this analysis. Descriptive statistics for this analysis are presented in Table 4.

This analysis revealed that after controlling for the effects of resting HP, which was a significant predictor of HP change, $p < .001$, there was a main effect of behavior problem group on the measures of HP change, $F(1,260) = 4.41$, $p < .01$, partial eta-squared = .04, no effect of sex, and no interaction of sex and behavior problem group. There were no interactions involving

Table 4

Heart period change scores for problem groups by gender

	Low problem		Externalizing		Mixed	
	Male	Female	Male	Female	Male	Female
Effortful control 1	16.61 ^a	16.47	12.97	11.64	24.27	19.82
Effortful control 2	21.30	18.84	13.80	9.42	43.20	33.57
Attention	44.21	49.64	38.10	33.06	53.34	47.47
Positive	39.15	37.02	31.94	30.15	60.74	45.31
Frustration	28.76	25.78	25.91	18.00	49.45	30.96

^a Positive change scores indicate greater decrease from baseline to task, heart period change scores adjusted for baseline heart period.

tasks. Across all five challenge tasks, the behavior problem groups differed in the measures of HP change. Follow-up contrast tests, repeated measures ANOVA, comparing each pair of the problem groups revealed that the mixed group differed from the externalizing group, $F(1,58) = 5.18$, $p < .03$. Children in the mixed group displayed significantly greater HP change (HR acceleration) across tasks than did children in the externalizing only group. The analysis comparing the mixed group and the low problem group also indicated a significant difference in terms of HP change, $F(1,226) = 4.98$, $p = .03$. No significant difference in HP change was found between the externalizing group and the low problem group. Children in the mixed problem group displayed the highest level of HP change across the five challenge tasks.

To examine whether the HP change difference that was observed among the three problem groups was a function of the group difference in RSA withdrawal that was observed, individual ANOVA's were conducted comparing the three groups on HP change in each of the five tasks, controlling for RSA change scores for each of the five tasks. In each case, the covariate RSA change variable accounted for a significant portion of the variance in HP change, $p < .001$ for each analysis. However, after controlling for the effects of RSA suppression, the behavior problem groups no longer differed in terms of HP change.

3. Discussion

One broad goal of this study was to understand the patterns of cardiac activity and regulation that may be observed in young children at risk for different patterns of externalizing behavior problems. Although these children are thought to have significant deficits in the regulation of behavior and emotion (Keenan and Shaw, 2003), prior work on the physiological indicators of such problems has been limited in its focus on older boys with little research conducted on younger samples of boys and girls. Moreover, prior work has not sought to disentangle physiological profiles of children with only externalizing problems from those of children experiencing both externalizing and internalizing symptoms. Our focus on the early childhood period, and on children at borderline risk for behavior problems, was motivated by the observation in other research that considerable development occurs in the domain of emotion regulation during this period, that behavior problems are becoming relatively stable by this time, and by the

fact 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 would be differences in resting measures of RSA and HP among groups of children at risk for different patterns of behavior problems. It was hypothesized that there would be differences in the resting RSA measure as such differences have been found in numerous studies of emotional reactivity (cf. Calkins, 1997), with children displaying greater negative emotion also displaying higher resting RSA (Calkins et al., 2002). However, this hypothesis was not confirmed. One explanation for the null finding is that children with different patterns of behavior problems may experience and express different patterns of negative emotion. Fear, frustration, and sadness are all negative emotions. However, these three emotions have not been examined separately in studies of RSA. It may be the case that different negative emotions are each differentially influenced by parasympathetic functioning. Given that externalizing and comorbid externalizing and internalizing behavior problems may be characterized by different patterns of these negative emotions, it may be difficult to differentiate among them with a single physiological measure.

The analysis of resting HP (the inverse of HR) also indicated that the behavior problem groups did not differ from one another or from the control group. The findings of the present study replicate a number of null findings (Calkins and Dedmon, 2000; Calkins and Keane, 2004; Zahn-Waxler et al., 1995; Van Hulle et al., 2000) that suggest that early aggression is likely determined by socialization and biological factors that are quite complex. Moreover, as the current body of literature clearly demonstrates, HR is multiply determined by sympathetic, parasympathetic, homeostatic, and hormonal processes. Finally, children at risk early in development, or those coping with mild regulatory challenges, may not develop serious conduct problems (i.e., the kind that have been associated with lower resting HR) later in development. Although behavior problems can be highly stable throughout childhood and adolescence, increases in language development, cognitive abilities, and self-regulation during toddlerhood should allow children to learn to control early normative noncompliant, aggressive, and impulsive tendencies, leading to a decline in serious and debilitating problem behavior (Campbell, 2002).

A second question addressed in this study was whether children with different patterns of behavior problems would display different patterns of RSA response to environmental challenges. Such a question follows directly from Porges' Polyvagal theory (2001, 2003), which notes that vagal regulation of cardiac activity is likely to be implicated in a variety of conditions characterized by deficits in emotional and social functioning. Moreover, numerous studies document that RSA does change under conditions in which the individual must generate a response to emotional, cognitive, and behavioral challenges (e.g. Calkins and Dedmon, 2000; El-Sheik, 2005). And, young children who display symptoms of early behavior problems are presumed to have difficulty regulating their emotions and their behaviors (Keenan and Shaw, 2003).

Presumably, such behavioral difficulties would be reflected in the fundamental ability to regulate cardiac activity under conditions of challenge. Five 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 and Dedmon, 2000). Because no study to date had examined whether the RSA response would vary as a function of early behavior problem subtypes, multiple hypotheses were proposed. Given the comorbid anxiety, withdrawal, and depression symptoms of the mixed group, one hypothesis was children with both externalizing and internalizing symptoms would exhibit greater vagal withdrawal, indicative of either better physiological regulation, or perhaps excessive physiological regulation. Alternatively, it was hypothesized that these children would display a pattern of less vagal withdrawal, indicative of poorer regulation, because of the pattern of multiple behavior problem symptoms with which they present. The data supported the first hypothesis. Children at risk for a mixed profile of externalizing and internalizing behavior problems displayed the greatest cardiac vagal regulation whereas children with a pure externalizing profile displayed the least regulation. This pattern of findings is suggestive of support for Beauchaine's (2001) hypothesis that there may be an optimal or moderate level of vagal regulation (in this case displayed by the low problem group) that is associated with both preparedness to respond to, and constructive engagement with, environmental challenge. And, moreover, that excessive vagal withdrawal in response to challenge (in this case displayed by the mixed problem group) reflects greater emotional lability, which is a likely characteristic of the children with a mixed behavior problem profile.

From a developmental point of view, it would be important for future research to identify which pattern of symptoms, internalizing or externalizing, if either, emerge first. Perhaps a child's initial internalizing symptoms impact his or her ability to effectively communicate with parents and/or peers, which may lead a child to feel more frustrated during social interactions and eventually react in a more impulsive, blunt, or aggressive manner. On the other hand, a child's initial externalizing symptoms may also impact his or her ability to effectively communicate with parents and/or peers which may lead that child to being rejected at school and potentially experiencing internalizing symptoms. The cross-sectional nature of this data set precludes answering these questions, although, we know that because this sample was overselected for externalizing problems, in all likelihood, for many of the children, these symptoms emerged first.

A third issue addressed in this study concerned the HP change in response to challenge. The data indicated that sex differences in HP response were largely a function of sex difference in resting HP. In addition to this sex difference, there was a behavior problem group difference, with the mixed group displaying significantly greater HP change (decrease, indicative of greater HR acceleration) than the other two groups of children. Such a difference might indicate greater sympathetic activation which is thought to be characteristic of children with anxiety. However, because RSA suppression is thought to

facilitate HR increases under conditions of challenge, it was important to control for these parasympathetic influences prior to concluding that HR differences might reflect sympathetic influences. In individual ANOVA's examining HP change in each of the five tasks, controlling for the parasympathetic influences measured by RSA suppression, there were no differences observed among the three behavior problem groups. Thus, the group differences in HP change (HR acceleration) appeared to have been largely a function of parasympathetic influence, in the form of vagal withdrawal, on HR.

The data from this study suggest that children at risk for different patterns of behavior problems, patterns that may reflect lack of control of emotion and aggression versus aggression with anxious symptomatology, also display a distinct pattern of parasympathetic nervous system functioning that has been linked in past research to the regulation of attention, affect, and behavior (Calkins, 1997; Calkins and Dedmon, 2000; Calkins and Keane, 2004). Differentiating among subtypes at the behavioral as well as physiological level is critical, as such differentiation may suggest sources of these behavioral differences as well as factors that influence the outcomes of these behavioral patterns. Future research must determine whether the parasympathetic processes precede the behavioral pattern or are a consequence of it. Moreover future research should also examine whether the greater cardiac vagal regulation of the anxious/aggressive group might be indicative of a more severe form of behavioral and physiological dysfunction.

This study has several limitations that must be acknowledged. First, the data were collected in one brief laboratory session. Questions about whether such a brief observation period allow for adequate characterization of children's responding are unanswered. Second, the effects sizes for the behavior problem group differences were quite modest. Third, the sample itself was not comparable to many other samples of children with more serious levels of conduct problems. Finally, 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. Nevertheless, the data from this study demonstrate that there are physiological differences among children with different patterns of behavior problems, and provide support for Polyvagal theory (Porges, 2001, 2003). The extent to which these differing patterns influence subsequent function, and may be influenced by numerous environmental factors, are important questions for future research.

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