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Cardiac Reactivity is Associated with Changes in Negative Emotion in 24-Month-Olds

ABSTRACT: *Despite the call for multilevel observation of negative affect, including multiple physiological systems, too little empirical research has been conducted in infants and young children, and physiology–affect associations are not consistently reported. We examined changes in heart rate, respiratory sinus arrhythmia, and preejection period in 24-month-olds across four increasingly challenging, emotion-eliciting tasks. We predicted that changes in cardiac reactivity would be systematically related to changes in negative affect. Results largely support the predictions with one important exception. With increasing distress across the tasks, HR increased and RSA decreased. However, no significant changes in PEP were observed. HR was associated with negative affect during all tasks, and changes in HR were related to changes in negative affect. PEP and negative affect were associated, but only marginally so. Within-subject analyses confirmed the predicted associations. Finally, the associations between physiology and negative affect were different for boys and girls. We discuss these results in the context of implications for future research on cardiac–affect associations in young children.* © *2005 Wiley Periodicals, Inc.* Dev Psychobiol 46: 118–132, 2005.

Keywords: *negative affect; physiology; heart rate; respiratory sinus arrhythmia; preejection period; autonomic nervous system; stress*

Interest in examining both behavioral and biological systems of affective behavior has recently surged. Multiple neural and physiological systems are implicated in affective behavior (Davidson, Jackson, & Kalin, 2000), and several theorists suggest that physiological measures are necessary to fully capture individual differences (e.g., Davidson, 2001). Examination of multiple dimensions of physiology in addition to examination of affect at different levels of analysis should provide a more complete picture of the phenomena of interest. It has been proposed that dysregulation of physiological systems is common in children with both internalizing and externalizing disorders (Bauer, Quas, & Boyce, 2002). Given this findings of dysregulated physiology and affective behavior problem, we argue that it is also important to consider the relation between physiological reactivity and individual differences across multiple negative affective states. Despite the call for multilevel observations, too little empirical research has adopted this approach in infants and young children. To this end, the current study examined cardiac reactivity and regulation of both the parasympathetic and sympathetic branches of the autonomic nervous system (ANS) in 24-month-old children during increasingly challenging, negative emotion-eliciting tasks. We asked two questions: (a) How does cardiac activity vary as a function of affective task demands, and (b) do individual differences in these negative affective states relate to individual differences in cardiac reactivity?

Historically, it was believed that physiological reactivity to aversive stimuli, which likely elicit negative affect, primarily resulted from sympathetic (SNS) activation (Cannon, 1928) whereas physiological reactivity to pleasant stimuli primarily resulted from parasympathetic (PNS) activation (Schneirla, 1959); however, the extant

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literature does not support this simplistic distinction. For example, research suggests that although heart rate (HR) in response to high-intensity aversive stimulus is higher than HR to a low-intensity stimulus, this difference in HR reactivity is due to the PNS and not the SNS (Quigley & Berntson, 1990). Research investigating affect–physiology associations also has been informed by investigation of the stress response (Mason, 1968) and the developmental psychobiological literature. It has been suggested that the development of the stress response and regulation of these complex systems are central to our understanding of individual differences in affective behavior (e.g., Gunnar, 1992; Kagan, Reznick, & Snidman, 1987). One physiological system that is critical to the stress response is the sympathetic–adrenal–medullary (SAM). This stress response system is predictive of negative affect, temperament, and behavior problems; however, it also has been proposed that the PNS branch plays an important role in physiological regulation of stress (Porges, 1995, 1996).

AFFECTIVE BEHAVIOR AND PNS ACTIVITY

Although a number of noninvasive measures of cardiac activity exist, only two have been the primary focus in developmental psychobiological research: heart rate and heart rate variability. Heart rate variability has typically been measured using respiratory sinus arrhythmia (RSA), often referred to as vagal tone. RSA reflects activity of the PNS such that increases in PNS influence on the heart results in increases in RSA. RSA can be measured noninvasively from the electrocardiogram (ECG), therefore making it a popular measure in studies of young children. RSA has become an important index of the interaction between cardiovascular activity and behavior such as sustained attention, emotion, and stress (e.g., Porges, 1986), and much of this research has focused on negative affect. Temperamentally fearful children have higher and less variable HR than their nonfearful counterparts (Kagan et al., 1987; Kagan, Reznick, & Snidman, 1988; Kagan, Reznick, Snidman, Gibbons, & Johnson, 1988; Reznick et al., 1986). Infants with high resting RSA were less fearful, approached a stranger more often, and were more active than infants with low RSA (Stifter, Fox, & Porges, 1989). Higher baseline RSA also has been associated with negative reactivity to a pacifier removal and mother report of frustration at 5 months (Stifter & Fox, 1990). In addition, 18-month-olds who regulated distress in frustrating situations had higher RSA (Stifter & Jain, 1996). Higher baseline RSA and expected decreases in RSA were associated with less aggressive behaviors (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996) and lower risk for aggression problems in toddlers (Calkins & Dedmon, 2000). Moreover, individual differences in baseline and task RSA under psychosocial stress have been shown to be relatively stable throughout childhood (Bornstein & Suess, 2000). RSA was found to increase from 2 months to 5 years, and individual differences were stable despite mean level changes.

Regulation of PNS (i.e., vagal) influence on the heart also may mediate the regulation of affective behavior. Reduction in cardiac output with increased vagal influence may result in calm and contentment while an increase in cardiac output with vagal withdrawal may result in affective behaviors associated with increased attention and mobilization. The ability to withdraw vagal influence on the heart is important for engagement with the environment (Porges, 1995, 1996, 1998). Considerable research has demonstrated the expected association between RSA regulation and task demands such as attention (Porges, 1974; Richards & Gibson, 1997), language and play (Bornstein & Suess, 2000), developmental competence (DiPietro, Porges, & Uhly, 1992), competition (Donzella, Gunnar, Krueger, & Alwin, 2000), negative affective reactions (Weinberg & Tronick, 1996), and temperament (Huffman et al., 1998). A recent report tested the hypothesis that vagal regulation and engagement behaviors are dynamically related (Bazhenova, Plonskaia, & Porges, 2001). Infants whose RSA decreased across two interaction challenges and increased with a positive social interaction displayed behavioral activity consistent with this pattern (e.g., shorter latency to recover from distress) compared to infants who did not show the expected RSA pattern. Thus, there is strong evidence that the regulation of RSA with environmental demands is linked to the regulation of affective behaviors.

Not all studies of cardiovascular reactivity and behavior have shown the expected association. Children rated as high in behavioral inhibition by their mothers did not differ from uninhibited children on measures of change in HR and RSA (Marshall & Stevenson-Hinde, 1998). Quas, Hong, Alkon, and Boyce (2000) reported dissociations between changes in cardiac measures, such as HR, BP, and RSA, and facial expressions of positive and negative affect in children 2 to 6 years of age. This dissociation remained present even when extreme groups and within-subjects analyses were conducted. Low base rates of emotional expressions, however, could aid the explanation of this dissociation. In fact, none of the tasks were specifically designed to elicit emotion reactions.

AFFECTIVE BEHAVIORS AND SNS ACTIVITY

Despite strong theoretical support for the role of SNS in negative affect behaviors (e.g., Kagan et al., 1987), there has been less research on cardiac activity related to SNS,

specifically using preejection period (PEP) compared to PNS cardiac measures. The sympathetic branch of the ANS modulates PEP (Berntson, Cacioppo, & Quigley, 1994) such that increased sympathetic influence on the heart results in faster PEP. Heart rate, per se, does not influence PEP unless changes in heart rate are associated with increased contractility (Lewis, Leighton, Forester, & Weissler, 1974). Recently, PEP measured in children ages 8 to 11 years of age using impendence cardiography had been shown to be highly correlated across time and tasks (McGrath & O'Brien, 2001), making it a highly reliable and consistent measure of SNS activity in children. High test-retest reliability for younger children (ages 3–8 years) also has been reported (Alkon et al., 2003).

There have been few studies of affective behavior and PEP associations in children. Children with externalizing symptoms exhibited greater decreases in PEP to tasks compared to children with other symptoms or no symptoms (Boyce et al., 2001). A 15-min protocol (including a number recall, interview, and affective video clips) produced significant decreases in PEP from a resting period in 3- to 8-year-olds; however, these changes were less dramatic than changes in HR and RSA during the same tasks (Alkon et al., 2003). Finally, faster resting PEP levels were related to task-specific freezing behavior in 24-month-old toddlers measured 1 week earlier, which was believed to be an index of fearful temperament (Buss, Davidson, Kalin, & Goldsmith, 2004).

PNS AND SNS INTERACTIONS AND PREDICTION TO AFFECTIVE BEHAVIOR

Cacioppo and colleagues (e.g., Berntson, Cacioppo, & Quigley, 1991, 1993) argued that heart rate reactivity can be divided into multiple modes of autonomic control. They argued that reliable individual differences exist in global HR reactivity, in SNS cardiac reactivity, and in PNS cardiac reactivity. Therefore, SNS and PNS activity may predict individual differences in HR reactivity under different circumstance; however, they may be only weakly correlated. As a test of this theory, they demonstrated that stressed-induced changes in PEP were negatively correlated with HR (Cacioppo, Uchino, & Berntson, 1994). This is consistent with the notion that SNS cardiac activation shortens PEP and elevates HR. Furthermore, stressed-induced changes in RSA were negatively correlated with HR, reflecting the inverse effects of increased PSA activity on HR. As expected, the correlation between RSA and PEP reactivity was not significant, suggesting that these indices do not consistently covary.

Including both sympathetic and parasympathetic measures of cardiovascular reactivity may change our understanding of behavior–physiology associations in children. For instance, individual cardiac response patterns have been identified in children and adolescents (Salomon, Matthews, & Allen, 2000). Children with a consistent pattern of PEP decreases and RSA increases were least likely to report family conflict compared to children with other PEP/RSA patterns. In a recent study, children with internalizing versus externalizing behavior problems showed dramatically different autonomic reactivity profiles (Boyce et al., 2001). The children classified as high internalizers showed the highest levels of parasympathetic withdrawal whereas children classified as high externalizers showed an overall diminished reactivity of both the parasympathetic and sympathetic systems.

WITHIN-SUBJECT COMPARISONS AND INTERACTIONS WITH GENDER

To this point, we have focused the review on between-subject or group-level comparisons of behavior–cardiac associations. Cacioppo et al. (1992) hypothesized that the associations between physiology and affective behavior would be stronger for within-subject comparisons than the typically used between-subject comparisons, and they provided support for this using adult facial expressions and sympathetic activation. This approach also has been investigated with young children aged 3 to 6 years (Quas et al., 2000). One advantage of this approach is the ability to capture within-group variation that is ignored, by design, with group-level statistics.

This method has been adapted by researchers interested in the influence of gender on the relation between behavior and cardiac physiology (e.g., Quas et al., 2000; Quigley, Feldman Barrett, & Weinstein, 2002). Although gender differences in affect are often reported (e.g., Maccoby, Snow, & Jacklin, 1984; Malatesta-Magai, Leak, Tesman, & Shepard, 1994), these effects are not always reported, especially when examining mean differences in the temperament literature (Buss et al., 2004; Kagan, Reznick, Clarke, Snidman, & Garcia-Coll, 1984; Rothbart & Bates, 1998). In addition, mean levels of cardiac reactivity rarely differ for boys and girls (e.g., Alkon et al., 2003; Boyce et al., 2001); however, there has been increasing evidence that the *association* between cardiac measures and emotional behaviors may differ for boys and girls. Kagan (1998) reported a significant difference in 2-year HR for low-reactive boys (i.e., boys classified as low reactive to stimuli at 4 months and classified as uninhibited at 4½ years; Kagan, 1997). These boys had the lowest HR levels as compared to other boys and low-reactive girls. Although not a consistent finding, the relation between cardiac reactivity and negative affect was present for only one gender. In the study described earlier, Quas et al. (2000) reported a moderate association

between cardiac reactivity and facial expressions of negative affect in girls, but not in boys. Although not specific to emotional reactions, other studies have reported gender differences in the relation between cardiac measures and behavior. Task-to-task changes in vagal tone, for 20-month-olds, predicted play performance in girls and language performance in boys (Suess & Bornstein, 2000).

THE CURRENT STUDY

The current study was designed to address some limitations of the previous research. First, despite the fact that cardiac activity is under control of the PNS and the SNS, few studies have attempted to disentangle SNS and PNS effects on cardiac reactivity in children. Second, the bulk of the work in the developmental literature has focused on affective behavior as it relates to HR and RSA while relatively few published studies address PEP. Children in the current study participated in three tasks, following a baseline period, while HR, RSA, and PEP were measured. The sequence of the tasks was designed to elicit increasing amounts of challenge and/or stress for the children, with the last two tasks designed to elicit emotional reactions. We investigated the dynamic changes in cardiac reactivity from baseline through the three tasks asking three questions: (a) Do the different tasks elicit changes in the cardiac measures? We predicted that HR would increase across the tasks and that both RSA and PEP would decrease. These changes in cardiac reactivity would be the result of both parasympathetic withdrawal and sympathetic activation as the challenge and the stress of the visit increased. (b) How much variance do PNS and SNS systems account for in the observed changes in heart rate across the visit? We predicted that as the tasks become more stressful, the variance in heart rate accounted for by PEP should increase whereas the RSA variance should decrease. (c) How are the cardiovascular measures related? Stressed-induced changes in PEP and in RSA should be negatively correlated with HR. Finally, we investigated the dynamics of cardiac reactivity in relation to changes in negative affect. We, along with others, have argued that examination of the associations between specific negative affect responses and physiological reactivity may be informative in identification of temperamentally vulnerable children (Buss et al., 2004; Buss et al., 2003; Davidson, 1998; Kagan, Snidman, McManis, Woodward, & Hardway, 2002). Therefore, we identified individual differences in the pattern of cardiac activity and examined the consequences for task-relevant negative affect. The cardiac–negative affect associations were investigated using both traditional between-subjects and within-subjects analyses (Cacioppo et al., 1992), and influence of gender on this relationship were examined.

METHOD

Participants

Participants were sixty-eight 24-month-old children (33 girls) recruited from local public birth-announcement records. Participants and families were not selected for any behavior or characteristic. Most participants were Caucasian (64 Caucasian, 1 African American, 1 Asian, 1 Hispanic, 1 Native American) and were from intact, middle-class families ($M = 48.66$ on Hollingshead index). Visits were scheduled within 1 month of the child's second birthday ($M = 24.50$, $SD = .40$, range = 23.03–25.57).

General Procedure

Data presented in this article were from a 1- to 2-hr laboratory assessment, which was preceded by a prior visit 1 week earlier that was related to different issues. The focal visit involved the recording of ECG and impedance cardiography (ZCG). Baseline recordings were taken for 5 min followed by recording during a series of tasks (a Cognitive Challenge) and two emotion-eliciting episodes representing the fear dimension (Stranger Approach) and the frustration/anger dimension (Toy Removal).

Behavioral Task Procedures

We designed the visit with consideration to the level of stress or challenge presented to the children. The order of tasks was designed to increase the level of stress/challenge and resultant negative affect. For all tasks, the child was seated in a highchair in front of a table which contained a hidden camera in a speaker. The mother was seated to the left of and slightly behind the child.

Task Descriptions. During baseline recording, children sat quietly for 5 min while watching a video, ''Baby Mugs.'' This video consists of a series of images of infants playing and smiling set to light music. We referred to the second task as Cognitive Challenge and used the Bayley Scales of Infant Development (BSID-II; Bayley, 1993), an individually administered examination that assesses the current developmental functioning of infants and children. This task lasted approximately 10 min. A portion of the Mental Scale served as a mild behavioral and cardiovascular stress task and was not intended to assess the children's developmental functioning. The task consisted of a series of problems that required the child to sit still, attend, and concentrate. To make the task more challenging, we chose items for 36-month-old children. The increasing difficulty of the items was intended to mirror the increasing difficulty of tasks, such as mental arithmetic tasks, that are often used to observe cardiovascular reactivity in the adult psychophysiological literature (e.g., Light & Obrist, 1983; Mills et al., 1993; Obrist, 1981).

The next tasks were designed to elicit negative affect (one fear, one anger). The first was called Stranger Approach. A male

stranger entered the room and paused at least 8 ft away from the child, then slowly approached the child from the right, and finally stared at the child for up to 2 min. The episode lasted for 2½ to 3 min. The second distress task was called Toy Removal. The goal of this task was to evoke the child's socially directed anger. This was achieved by having the parent deny the child a desired toy. After the experimenter demonstrated and allowed the child to play with the toy for a few minutes, the parent took the toy away saying, ''I don't want you to play with this anymore.'' For this task, the mother stood up and placed the toy on top of a shelf directly in front of the child and then sat back down in her chair. This separation from the toy lasted 30 s, after which time the parent returned the toy to the child. The episode lasted approximately 60 s.

Behavioral Scoring. From the videotapes, we scored the frequency of several affective behaviors during each task. For the Baseline and Cognitive Challenge tasks, we scored the videotapes for frequency of fussing/crying, negative facial expressions (e.g., sadness, anger, & fear), and neutral and positive expressions. Neutral expressions were most common, occurring more than 90% of the time. For Stranger Approach, we divided the episode in 5-s epochs and scored the following behaviors on a scale from 0 (*not present*) to 3 (*highest intensity*): facial fear, facial sadness, bodily fear, bodily sadness, vocal distress (crying), and escape/avoidance. The same 5-s, 4-point intensity scoring procedure was used for scoring Toy Removal. The following behaviors were coded during the 30 s that the child was unable to get the toy: crying, facial anger, bodily anger, facial sadness, and bodily sadness. For facial affect, we used the AFFEX system (Izard, Dougherty, & Hembree, 1983) to differentiate fear, sadness, and anger facial expressions. Coders recorded the maximum intensity of each expression ranging from 0 = expression not present; 1 = expression barely present or fleeting typically reflected in only one facial region; 2 = clear expression, present in one facial region strongly or in more than one facial region; to 3 = clear and strong expression, present in at least two facial regions. Distress facial expressions were differentiated from each other by examining changes in the brows/eyes, cheeks, and mouth in the following ways. Anger was scored when brows were pulled in and down, eye lids tensed, and/or eyes narrowed. Anger in the mouth involved an open and squared mouth or lips pressed tightly and tensed. Sadness was scored when brows were pulled in and up, eyes drooped at outside corners. A sad mouth was scored when corners were pulled down and lower lip resulted in a pout. It is important to note that sadness was not scored if the child was crying or about to cry because the cry or pre-cry mouth often resembles sadness. Fear was scored when brows were raised but not pulled together, lids were raised, and eyes were widened. Fear in the mouth was scored when lips were pulled back straight, often pulling checks back but neither up nor down. All coders were trained by the first author and were blind to study hypotheses. Coders needed to reach and maintain reliability for at least 20% of the tapes. Reliabilities on type and intensity of affect for each episode were very good, with agreement ranging from 83 to 96% and kappas ranging from .73 to .81. We recoded each behavior to reflect the frequency of occurrence rather than the intensity across the epochs and then transformed them into proportions since the length of episodes varied. All behavioral intensities scored higher than 1 were considered present and used in the frequency count. Note that if the child cried for more than 20 s, the episode and recording were terminated.

Cardiovascular Recording

Measures of cardiac output were collected and scored using the CIC-1000 Impedance Cardiograph software, Version 7.2 (SORBA Medical Systems, 1997). ZCG gives estimates of volumetric changes, changes in stroke volume and cardiac output, and systolic time intervals such as preejection period and left-ventricular ejection time (Kubicek, Karnegis, Patterson, Witsoe, & Mattson, 1966). The raw ECG signal was collected from this system for calculation of RSA. Pre-gelled, low-impedance, ultra-stable ICE-100 electrodes specifically designed for the CIC-1000 were used in the standard configuration using four spot electrodes (Sherwood, Royal, Hutcheson, & Turner, 1992). The children's height, weight, and distance (in.) from the two middle electrodes were entered into the system for accurate calculation of the cardiac indices. Note that we found no gender differences in these measures.

A 500 uA, 40-kHz oscillating current was generated between the two outer current electrodes. The ECG, basal thoracic impedance (Zo), change in impedance (ΔZ), and the first derivative of pulsatile changes in transthoracic impedance (dZ-dt) were recorded on separate channels from the two inner voltage electrodes. An 8 input, 12-bit, 100-kHz analog-to-digital converter, with analog output and 7 bits of digital I/O, and a Toshiba 6400 computer were used to sample the ECG, Zo, ΔZ, and dZ-dt signals at a rate of 500 Hz per channel.

The software derived and displayed an ensemble-averaged waveform for each 10- to 30-s consecutive interval. For baseline and the cognitive challenge, a 30-s average was used; a 20-s average was used for the Stranger Approach and Toy Removal episodes. Four artifact-free waveforms were required to make the ensemble average ECG and dZ/dt waveforms. The following points on the ensemble composite dZ/dt were automatically scored and marked on the displayed waveform: (a) the dZ/dt B-point, which represented the onset of left-ventricular ejection of blood into the aorta, (b) the dZ/dt_{max} (DZDT), which represented peak left-ventricular ejection velocity, and (c) the dZ/dt X-point, which represented the completion of the left-ventricular ejection. The beginning of the QRS complex on the ensemble ECG waveform also was marked. Ensemble averaging techniques provide a reliable measure of myocardial activity (Kelsey & Guethlein, 1990).

From the ensemble average waveforms, several derivations were produced at each interval. (a) HR was calculated from a QRS detection algorithm from the ECG waveform, and (b) systolic time intervals were calculated from the ECG and the dZ/dt waveforms during each interval. Preejection period was calculated as the time between the onset of the Q-wave of the ECG and the B-point of the dZ/dt wave. Although these derivations are produced during ongoing data collection, the waveforms were reexamined and derivations were recalculated or deleted, if necessary. Fewer than 5% of the collected intervals were discarded.

The Sorba system collected and processed the ECG signal into heart rate; however, this measure violates the rule of stationarity because it was collected from the 20- to 30-s ensemble averages. Therefore, the raw ECG signal was collected from the Sorba output system. This signal was then bandpass filtered at 30 and 100 Hz, amplified 20K, and sampled at a rate of 500 ms. The raw ECG signal was transformed into a file containing interbeat intervals (IBIs) obtained from a program that used a threshold to detect R-waves. These IBI files were then entered into MXedit (Porges, 1989) to identify and edit artifacts. RSA was computed using a moving polynomial filter to detrend the data prior to analysis according to the procedures described by Porges and Bohrer (1990). We used 30-s epochs to calculate RSA.

Cardiac data for the analyses were HR, RSA, and PEP for baseline and each task. We also calculated reactivity scores by subtracting baseline values from each task value (Llabre, Spitzer, Saab, Ironson, & Schneiderman, 1991). These delta reactivity scores are inherently related to the baseline measure. To address this concern, we also calculated residualized change scores. Delta change and residualized change were highly correlated ($rs > .85$) for all tasks. Given recommendations in Llabre et al. (1991), we opted to use the delta scores because we were interested in generalizing the magnitude of change across the different tasks. Note also that baseline and reactivity scores were only modestly correlated (Table 3). Moreover, delta scores from the different tasks were not significantly correlated, with most of the variance unique to each task. Another related concern is ''the law of initial values;'' however, the law of initial values is most relevant when considering within-subject effects rather than between-subject effects (Myrtek & Foerster, 1986), which is why we used the delta scores for the between-subject analyses.

We addressed the issue of the amount of missing cardiac data. We edited cardiac data for 75% of the sample ($n = 51$, 25 girls), leaving 17 children with unedited cardiac data. This missing data was due to a combination of equipment failure or sensor removal (82%) and extreme movement artifact (e.g., child bent over or struggling, 18%); however, note that not all 51 children had usable data for each task (Table 1). We asked whether these two groups of children differed from each other in behavior across the visit. There were no significant differences in behavior in any of the four tasks. Turning to missing PEP data, recall that PEP was calculated using 20 to 30 ensemble averages. If there was movement during any portion of the recording time, that average was not calculated. For stranger approach, only 36 children had enough ensemble averages to calculate PEP. There was considerable loss of data due to movement artifact for the Toy Removal episode. Only 10 children had enough ensemble-averaged ZCG data for the toy removal task, precluding report of PEP values for that task.

Turning to the ECG signal, we calculated the seconds and proportions of artifact-free ECG data for each task ($M = 276.80$, $SD = 15.20$, 92%; $M = 580.82$, $SD = 131.47$, 97%; $M = 142.66$; $SD = 28.90$, 95%; $M = 36.87$, $SD = 2.36$, 92%, for Baseline, Cognitive Challenge, Stranger Approach, and Toy Removal, respectively).

Preliminary Analysis

We verified our assumption that the behavioral tasks would increase stress for children by scoring distress and negative-affect behaviors for all four tasks. We compared the frequency of distress behaviors across the four tasks. Note that we considered fear responses to be distress for Stranger Approach and that anger responses were distress for Toy Removal. Recall that the tasks varied in duration and thus the frequency counts, so we created proportion scores within each episode. Results were consistent with our prediction. Presence of crying increased across the tasks, $F(3, 156) = 15.44$, $p < .0001$ ($M = .21$, $SD = .41$; $M = .32$, $SD = .47$; $M = .36$, $SD = .48$; $M = .74$, $SD = .45$, for Baseline, Cognitive Challenge, Stranger Approach, and Toy Removal, respectively). Presence of facial distress increased across the tasks, $F(3, 153) = 29.51$, $p < .0001$ ($M = .21$, $SD = .40$; $M = .33$, $SD = .47$; $M = .71$, $SD = .46$; $M = .89$, $SD = .32$, for Baseline, Cognitive Challenge, Stranger Approach, and Toy Removal, respectively). Thus, we were confident that the visit became more stressful with each subsequent task. We created distress composites by averaging across discrete behaviors within each task because they were moderately to strongly correlated ($rs = .19–.85$). Note we only formed composites with distress behaviors (e.g., crying, escape, facial distress) and not positive behaviors.

RESULTS

Effects of Task on HR, RSA, and PEP

To determine the effects of each task on cardiac reactivity, we conducted repeated measures ANOVAs for each cardiac variable to identify significant changes across the episodes. HR and RSA significantly changed across the visit, but PEP did not (Table 1). HR differed across the

Table 1. Means and *SD*s for Cardiac Measures

	Baseline ($n = 46$)	Cognitive ($n = 48$)	Stranger ($n = 48$)	Toy Removal ($n = 43$)	*F*
HR	119.03 (8.53)	119.95 (8.85)	122.75 (9.27)	126.98 (14.46)	15.05***
RSA	5.06 (.95)	4.74 (.92)	4.71 (1.05)	4.58 (1.37)	3.81**
PEP	61.60 (1.15)	63.30 (1.25)	60.00 (1.22)[a]	n/a	1.15

Note. [a]$n = 36$. **$p < .01$. ***$p < .001$. Cognitive = Cognitive Challenge. HR is represented as beats/min. RSA is represented as *ln* HP variance from .24 to 1.04 Hz. PEP is represented in ms.

episodes. Post hoc comparisons revealed that HR from the Toy Removal task was significantly higher than HR from the Stranger Approach ($p < .05$), the Cognitive Challenge ($p < .0001$), and Baseline ($p < .0001$). Stranger Approach HR also was significantly higher than the Cognitive Challenge ($p < .01$) and Baseline HR ($p < .001$). RSA also differed across the episodes. Post hoc comparisons revealed that RSA decreased significantly across the visit from Baseline to the Cognitive Challenge ($p < .001$), from Baseline to Stranger Approach ($p < .0001$), and from Baseline to Toy Removal ($p < .02$). Post hoc comparisons between the Cognitive Challenge, Stranger, and Toy Removal were not significant for RSA. Contrary to expectations, there was no significant change in PEP across the visit.

We also examined whether cardiac reactivity changed across the visits. We conducted repeated measures ANOVA with each cardiac change score. Changes in HR from Baseline to Cognitive Challenge ($M = 1.22$, $SD = 5.16$) and from Baseline to Stranger Approach ($M = 4.37$, $SD = 6.51$) were significantly smaller than changes in HR from Baseline to Toy Removal ($M = 8.30$, $SD = 10.20$), $F(2, 74) = 12.64$, $p < .0001$. In contrast, changes in RSA from Baseline to Cognitive Challenge ($M = -.31$, $SD = .50$), from Baseline to Stranger Approach ($M = -.37$, $SD = .57$), and from Baseline to Toy Removal ($M = -.46$, $SD = 1.13$) were not significantly different ($F = .43$). Finally, there was no difference for PEP change from Baseline to Cognitive Challenge ($M = .001$, $SD = .005$) or Baseline to Stranger Approach ($M = -.001$, $SD = .009$).

Relations among HR, RSA, and PEP. We analyzed the bivariate associations between the different cardiac measures. We predicted an inverse association between HR and RSA, and between HR and PEP. In addition, RSA and PEP were expected to be uncorrelated. As expected, HR and RSA were negatively correlated during Baseline ($r = -.64$, $p < .001$), Cognitive Challenge ($r = -.64$, $p < .001$), Stranger Approach ($r = -.51$, $p < .01$), and Toy Removal ($r = -.36$, $p < .02$). Contrary to predictions, there was no association between HR and PEP. Finally, as expected, RSA and PEP were uncorrelated ($rs = -.08 - .05$).

Predicting HR from RSA and PEP. The correlations among the different cardiac measures suggest that there was little effect of the SNS on heart rate reactivity. To test this more directly, we performed stepwise regressions on HR using RSA and PEP as the predictors. Model 1 contained RSA, and Model 2 added PEP. Note that this analysis was not conducted for Toy Removal because of the missing PEP for this task. We repeated the regressions for each episode as well as for the change in HR between episodes. These results are presented in Table 2. These analyses also suggest that there was little influence of PEP on HR reactivity, and only RSA accounted for significant variance in task HR and HR reactivity.

Individual Differences and Cardiac Patterns

We now turn to analyses of individual differences. First, we found no main effect of gender for any of the cardiac and negative-affect variables.

Cross-Task Correlations of HR, RSA, and PEP. Correlations among the tasks for each cardiac measure revealed that individual differences were stable across the tasks (Table 3). We also calculated correlations between the episodes for the cardiac reactivity variables. These also are presented in Table 3 along with the correlations between task-specific and reactivity measures. Across all tasks, we found strong associations in task-specific HR, RSA, and PEP. There was less evidence for stability in the reactivity measures. Changes from Baseline for Cognitive Challenge, Stranger Approach, and Toy Removal were only modestly correlated.

Cross-Task Correlations of Negative Affect. Measures of negative affect for the four tasks were not significantly correlated, with one exception (Table 4). Baseline negative affect was associated with negative affect during Stranger Approach. Baseline negative affect was negatively correlated with the reactivity measures reflecting change from Baseline, indicating that children who showed less negative affect during Baseline had the greatest increases in negative affect during the tasks. The reactivity scores were positively correlated, which might reflect simply that a common baseline measure was a component of each reactivity score.

Associations between Cardiac Reactivity and Negative Affect

How were individual differences in cardiac activity and change related to negative affect during the tasks? To reduce the number of variables, we only considered concurrent relations between negative affect and the cardiac measures during each task (Table 5, Part 1). Looking only at the columns for the full sample, HR was associated with higher intensities of negative-affect behavior for Stranger Approach and Toy Removal. There was no association between negative affect and RSA, although correlations were in the expected direction. Finally, negative affect tended to associate with shorter PEP, but again not at a significant level.

We examined the association between change in negative affect and change in the cardiac measures for each

Table 2. Predicting Heart Rate from RSA and PEP

	Model			
	1		2	
	β	**ΔR^2**	β	ΔR^2
A. Dependent Variable = Baseline Heart Rate				
1. Baseline RSA	−.67	.45***	−.67	.45***
2. Baseline PEP			*−.00*	*.00*
Final Model R^2		**.45**		
B. Dependent Variable = Cognitive Challenge Heart Rate				
1. Cognitive RSA	−.75	.56***	−.75	.56***
2. Cognitive PEP			*−.07*	*.10*
Final Model R^2		**.56**		
C. Dependent Variable = Stranger Heart Rate				
1. Stranger RSA	−.57	.33**	*−.57*	.33**
2. Stranger PEP			*−.01*	*.01*
Final Model R^2		**.33**		
D. Dependent Variable = Cognitive Challenge−Baseline Heart Rate				
1. Cog−Base RSA	−.66	.43***	−.66	.43***
2. Cog−Base PEP			*.22*	*.28*
Final Model R^2		**.43**		
E. Dependent Variable = Stranger−Baseline Heart Rate				
1. Str−Base RSA	*−.20*	*.04*	*−.20*	*.04*
2. Str−Base PEP			*−.05*	*.05*
Final Model R^2		*.09*		

Note. $^{**}p < .01$. $^{***}p < .001$. Predictors in italics were dropped from the final regression equation. Abbreviations Cog−Base = Cognitive Challenge−Baseline. Str−Base = Stranger−Baseline.

task (Table 5, Part 2). Increases in negative affect were associated with increases in HR during the Cognitive Challenge and Stranger Approach tasks and in the expected direction for Toy Removal. Changes in negative affect were not associated with changes in RSA. Although not in the expected direction, increases in negative affect were associated with increases in PEP duration during the Cognitive Challenge. In contrast and as predicted, associations between increases in negative affect and decreases in PEP during the Stranger Approach were marginally significant.

Gender Differences in Cardiac Patterns. There has been increasing evidence in the literature that the association between cardiac measures and emotions may differ for girls and boys. We therefore computed separate negative affect−cardiac correlations for girls and boys (Table 5). First examining the correlations between task-specific cardiac and affect measures, we noted that the overall pattern of correlations was similar to the full sample. With the exception of one correlation for boys (Cognitive Challenge PEP and negative affect), all the significant associations between negative affect and cardiac measure were larger for girls than for boys (although not all were statistically significant due to the small sample sizes). The only exception to this pattern is the significant correlation between Cognitive Challenge PEP and negative affect for boys. More negative affect was associated with shorter PEP (i.e., greater sympathetic reactivity) for boys only. Contrary to predictions, increases in negative affect from Baseline to the Cognitive Challenge were associated with longer PEP during the Cognitive Challenge for boys and girls. Finally, increases in HR and negative affect from Baseline to Cognitive Challenge and Stranger Approach were significant for girls, but not for boys.

Within-Subject Associations. In a final set of analyses, we examined individual patterns of cardiac−negative affect associations to examine the amount of within-group variation (Cacioppo et al., 1992). For each child, correlations were computed between the cardiac measures and negative affect across the four tasks. Correlations are only reported for children with cardiac and affect data from at least three tasks. These correlations allowed us to examine whether task-to-task changes in cardiac measures are consistent with task-to-task changes in negative affect. These analyses supported the analyses presented earlier. Averaging across the individual correlations ($n = 46$), more negative affect was associated with higher HR

Table 3. Correlations for Cardiac Variables Across Tasks

Part I. Heart Rate Correlations

	1	2	3	4	5	6	7
1. Baseline	—						
2. Cognitive	.86***	—					
3. Stranger	.75***	.75***	—				
4. Toy Removal	.72***	.71***	.72***	—			
5. Cog-Base	−.38**	.14	−.09	−.12	—		
6. Str-Base	−.51***	−.29†	.19	−.18	.44**	—	
7. Toy-Base	−.01	.16	.22	.69***	.29†	.29†	—

Part II. RSA Correlations

	1	2	3	4	5	6	7
1. Baseline	—						
2. Cognitive	.87***	—					
3. Stranger	.84***	.80***	—				
4. Toy Removal	.54***	.53***	.59***	—			
5. Cog-Base	−.29†	.23	−.08	.02	—		
6. Str-Base	−.22	−.07	.35*	−.01	.29†	—	
7. Toy-Base	−.19	−.05	−.03	.72***	.25	.23	—

Part III. PEP Correlations

	1	2	3	4	5
1. Baseline	—				
2. Cognitive	.86***	—			
3. Stranger	.75***	.86***	—		
4. Cog-Base	−.36*	.16	−.10	—	
5. Str-Base	−.50**	−.35†	.19	.61**	—

Note. HR Listwise $n = 46$, RSA Listwise $n = 46$, PEP Listwise $n = 36$. †$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$. Abbreviations Cognitive = Cognitive Challenge, BASE = Baseline, COG = Cognitive Challenge, STR = Stranger Approach, TOY = Toy Removal.

($r = .51$, $p < .01$). The range of correlations, however, was quite broad (−.92–.98). Sixty-five percent of the children ($n = 30$) showed the expected association while only 17% ($n = 8$) showed the reverse pattern (i.e., a negative correlation between HR and negative affect). Eight children showed no association between negative affect and HR. We found evidence for a moderate association between negative affect and RSA. Averaging across the individual correlations ($n = 46$), more negative affect was associated with lower RSA ($r = -.20$, $p < 05$). Again, the range of correlations was broad (−.99–.53). Approximately half of the sample, 52% ($n = 24$), showed the expected negative correlation, a substantial minority of children (37%, $n = 17$) showed the opposite pattern, and 5 children failed to show an association between negative affect and RSA. We also found evidence for a moderate association

Table 4. Correlations for Negative Affect across Tasks

	1	2	3	4	5	6	7
1. Baseline	—						
2. Cognitive	.12	—					
3. Stranger	.30*	.14	—				
4. Toy Removal	.10	.09	.21†	—			
5. Cog-Base	−.62***	.70***	−.09	−.13	—		
6. Str-Base	−.66***	−.21	.68***	−.18	.36**	—	
7. Toy-Base	−.74***	−.05	−.22	.68***	.49***	.44**	—

Note. †$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$. Abbreviations Cognitive = Cognitive Challenge, BASE = Baseline, COG = Cognitive Challenge, STR = Stranger Approach, TOY = Toy Removal.

Table 5. Correlations between Negative Affect and Cardiac Measures within and between Tasks

Part I.

	Negative Affect by Task											
	Baseline			Cognitive			Stranger			Toy Removal		
	Full	F	M	Full	F	M	Full	F	M	Full	F	M
n	38	19	19	48	24	24	48	24	24	46	23	23
HR	.21	.44†	−.03	−.12	−.07	−.10	.46**	.51**	.37*	.31*	.39*	.19
RSA	−.04	−.23	.07	−.21	−.19	−.19	−.15	−.39†	.07	−.15	−.13	−.15
PEP	−.22	−.31	−.16	−.22	.01	−.45*	.04	−.08	.10		—	

Part II.

	Negative Affect Change–Task - Baseline								
	Cognitive			Stranger			Toy Removal		
	Full	F	M	Full	F	M	Full	F	M
n	36	18	18	36	18	18	30	15	15
HR	.39*	.55*	.21	.39*	.62**	.03	.30†	.24	.35
RSA	−.07	−.05	−.06	−.03	−.30	.28	−.18	−.27	.01
PEP	.40*	.41†	.44†	−.33†	−.50†	−.29		—	

Note. $^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$. Cognitive = Cognitive Challenge. Full = Full Sample. F = Girls. M = Boys.

between negative affect and PEP. Averaging across the individual correlations ($n = 23$), more negative affect was associated with shorter PEP ($r = -.29$, $p < .05$, range = −.99–.98). Approximately half of the sample, 52% ($n = 12$), showed the expected negative association, a large minority of children (41%, $n = 9$) showed the opposite pattern, and only 2 children failed to shown an association between negative affect and PEP. In contrast to the previous analyses, there was no evidence for gender differences.

DISCUSSION

The focus on examining multiple dimensions of physiology across contexts was the framework that motivated the current study. Given recent reports that the regulation of physiological systems is associated with affective behavior (Bauer et al., 2002; Weinberg & Tronick, 1996), we examined changes in three cardiac measures in four contexts and their respective associations with observed negative affect. We predicted that with increasing levels of stress and challenge, systematic changes in cardiac reactivity would be observed. These changes in cardiac reactivity were compared to changes in behavior to reveal predicted associations. We discuss the results of these predictions and the implications for the findings in the following sections.

Effects of Context on HR, RSA, and PEP

Tracking changes in cardiac activity across tasks revealed that HR and RSA changed significantly across the visit whereas PEP did not change. As predicted, HR increased during the two affect tasks over baseline levels. RSA decreased across the three tasks from baseline, which is consistent with Porges' theory of vagal regulation during environmental engagement (Porges, 1995, 1996, 1998); however, there was no change in PEP from baseline to the tasks. Overall, these results only partially support our prediction regarding the cardiac responses to the stressfulness of the tasks due to the lack of PEP response.

We also investigated the relations among these cardiac measures. An inverse association was predicted between HR and RSA and between HR and PEP. In addition, RSA and PEP were expected to be uncorrelated. As expected, HR and RSA were negatively correlated, and RSA and PEP were uncorrelated; however, there was no association between HR and PEP. The correlations among the different cardiac measures suggested that there was little effect of the SNS on PEP levels and heart rate reactivity. To test this more directly, regressions were performed on heart rate using RSA and PEP as the predictors. Regressions were repeated for each episode as well as for the change in heart rate between episodes. Results from these analyses also suggested that there was little influence of

the SNS as indexed by PEP on HR reactivity. Only RSA accounted for a significant amount of variance in HR during each task and change in HR. It is important to note that PEP reflects sympathetically mediated contractility on the heart (Lewis et al., 1974); therefore, these findings suggest that contractility was not associated with changes in HR for these tasks. Therefore, the lack of association between PEP and HR does not completely rule out the role of the SNS during these tasks because SNS mediated rate changes could have been elicited. Note that there was still unexplained variance in task HR and HR reactivity that RSA and PEP could not account for. These findings provide a framework for the interpretation of relations between the cardiac variables and negative affect during the tasks. Specifically, any failure to find an association between PEP and negative affect should be interpreted with caution given the low variability of PEP and its minimal influence on HR reactivity.

Cardiac Reactivity and Negative-Affect Associations

Several studies of examining physiological reactivity to laboratory stressors have shown that cardiac reactivity is associated with fearful temperament (Kagan et al., 1987; Kagan, Reznick, & Snidman, 1988), negative emotionality (Fox, 1989), and behavioral stress reactions (Porges et al., 1996). Not all research has revealed this association (Kagan, Reznick, Snidman, Gibbons, & Johnson, 1988). Others have suggested that the cardiac–behavior associations will be strongest when the eliciting events are the same for the cardiac and behavioral measures. However, Quas and colleagues (2000) failed to demonstrate an association between HR or BP and facial expression of distress during the same tasks in preschool age children.

In the current study, we found that state HR was associated with negative affect in three of the four contexts. Moreover, increases in HR from baseline were associated with increases in negative affect for baseline and the three tasks using both between- and within-subjects analyses. We found little evidence for significant associations between context-specific or reactive RSA and negative affect, although all the correlations were in the predicted direction. However, when examining the RSA–negative affect association using within-subject analyses, the expected association was significant, and most children showed the expected pattern. We argued in the introduction that examination of more specific measures of cardiac reactivity (e.g., PEP) would inform this question. Although there was suggestion that negative affect was associated with shorter PEP (i.e., greater sympathetic activity), these associations were not consistent using the between-subjects approach, perhaps due to sample size and loss of physiological data. Again, however, examining the association using within-subjects analyses revealed that half of the children showed the expected pattern. In sum, we found mixed evidence for the cardiac–negative affect association. We failed to find a consistent association between RSA or PEP and negative affect when using the traditional between-subjects analyses. In contrast, these associations were uncovered with the within-subjects analyses.

Finally, we found some evidence that the association between negative affect and cardiac reactivity was stronger for girls. Although consistent with other studies of gender in direction of effects (e.g., Quas et al., 2000), these differences were not always statistically significant. As discussed in the introduction, gender differences are not typically found for cardiac reactivity, and none were found in the current study, so we do not believe that there is a gender difference in underlying physiological processes. Rather, we suggest that these differences may be driven by gender differences in the regulation of emotion expression (e.g., display rules). For instance, it is possible that there was a dissociation between physiological and behavioral distress for boys such that boys did not express negative affect even when cardiac measures indicated stress.

Implications of Cardiac–Behavior Findings

There were two findings we would like to highlight: the lack of PEP change across tasks and the lack of consistent associations between PEP and negative affect. We address two possible reasons for this: the stressfulness of task and developmental effects. In the current study, we predicted that HR would increase, RSA would decrease, and PEP would decrease across the four tasks (i.e., as negative affect increased). The fact that PEP did not significantly decrease during the tasks suggests that the tasks were not stressful enough to elicit sympathetic reactivity, as might have been predicted from Porges' polyvagal theory (1995, 1996, 1998), where the individual's capacity to regulate physiological states with changing environmental demands is critical. According to the theory, the vagal system provides physiological regulation of arousal and reactivity to stimulation and is an underlying component of individual differences in self-regulation, temperament, and emotion reactivity. The vagal system regulates between homeostatic states and response states, which are driven by the PNS and SNS branches of the ANS, respectively. For instance, in response to environmental demands, homeostatic processes are compromised as the ANS supports increased output of energy by downregulating PNS function and often increasing SNS function. Thus, nonthreatening environmental challenges result in the withdrawal of inhibitory vagal influences on the heart, resulting in decreased RSA and HR increases; however, challenges involving threat also should result in changes

in PEP and cardiac output through increased SNS activation.

Applying this theory to the current results might suggest that our tasks were not threatening enough to elicit changes in PEP; however, note with adults and adolescents, changes in PEP are observed for fairly mild challenges (e.g., Kelsey et al., 1999). As discussed previously, however, absence of PEP reactivity alone does not mean that the SNS was not activated during these tasks. PEP only reflects SNS influence on contractility, so there may be other SNS influences on HR that we did not measure in the current study.

Despite mounting evidence that negative affect is linked to sympathetic activation, specifically PEP (e.g., Cacioppo et al., 1992), not all researchers have replicated this finding with children. Recall that Quas et al. (2000) failed to find an association between negative facial expressions and cardiac reactivity, perhaps because these tasks were not designed to elicit negative affect, per se. Moreover, the level of affect expressed was extremely low and did not increase significantly from baseline. Thus, we suggest that negative affect was not elicited with enough intensity to reveal associations with physiological measures; however, in the current study, we demonstrated an increase in negative affect across the tasks. Although we found little evidence for this association with between-subject analyses, the within-subject analysis revealed that half of the subjects showed the predicted association. Thus, it seems that the level of negative affect may be an important consideration when examining physiological reactivity to challenge.

Others have suggested additional task characteristics for eliciting a PEP response. The challenge should involve active coping, be rather novel, and/or involve a social evaluative component (Kelsey et al., 2000). Therefore, our suggestion that our tasks were not threatening enough to elicit PEP reactivity should be tempered. First, we know that a significant amount of negative affect was elicited. Second, it is difficult to assume that these tasks, especially the Stranger Approach, did not elicit active coping, especially given the presence of the mother. Finally, these tasks were designed to be fairly novel, which by their nature are threatening. Therefore, we are still left with mixed findings on the association between PEP and negative affect.

What else could account for the lack of change in PEP? Age-related changes in cardiac levels have been reported such that 3- to 4-year-old children had the highest HR ($M = 98.7$, $SD = 10.2$), lowest RSA levels ($M = 5.7$, $SD = 1.2$), and lowest PEP levels ($M = 77.5$, $SD = 6.6$) compared to 6- to 8-year-olds ($M = 89.8$, $SD = 11.3$; $M = 6.3$, $SD = 1.1$; $M = 81.4$, $SD = 9.5$, for HR, RSA, and PEP, respectively) (Alkon et al., 2003). In the current study (Table 1), 24-month-old PEP during baseline was lower and outside the confidence intervals of the 3- to 4-year-olds, as presented in the aforementioned study. This comparison along with the current results failing to find significant PEP reactivity to task demands raise the possibility that a developmental explanation of autonomic control is warranted. Note that the resting levels of PEP in the current study were at the lower limits of the measure while the HR levels were quite high. This might suggest a level of immaturity of the ANS. There are important developmental changes in autonomic control in infancy and early childhood. Specifically, it has been demonstrated that significant developmental age related changes in the sympathetic system (e.g., sympathetic control of blood pressure) occur across childhood to adolescence (Allen & Matthews, 1997; Galanter, Wasserman, Sloan, & Pine, 1999; Tanaka et al., 2000). Thus, it seems likely that immaturity in the SNS may account for the current findings with PEP. Finally, another question is whether we would expect age related changes in the *association* between PEP and negative affect. We did not, however, find evidence in the literature for the effects of age on the relation between negative affect and cardiac reactivity. Thus, a lack of consistent PEP–negative affect association remains a question for further study.

Limitations

The moderate sample size likely affected the statistical significance of our results and may have limited our ability to detect smaller effects; however, the magnitude of the bivariate associations was consistent with previous reports. Psychophysiological research with young children is a difficult enterprise. Dealing with missing data and low sample sizes is the rule. For instance, we were unable to collect data on the majority of children in the Toy Removal tasks, most likely due to movement artifact. Finally, we observed low variability in PEP, which may have limited our ability to detect individual differences in sympathetic reactivity. Reliability of ZCG may be called into question. While we cannot directly speak to the reliability of PEP in the current study, we have additional data from the ZCG signal which may shed light on this issue. The ZCG signal also produced measures of cardiac output, stroke volume, and left ventricular ejection time. We looked at those measures to address the potential issue of reliability of the PEP measure. Both cardiac output and stroke volume increased significantly across the three tasks, suggesting expected variability in those measures. Thus, there was no evidence that ZCG, and therefore PEP, was unreliable (see Dalton & Davidson, 1997, for reliability of Sorba ZCG system).

We suspect that the lack of variability and observed change in PEP was due both to developmental issues and to the level of stress experienced by the children. Although

dictated by ethical concerns and reducing movement artifact, the lack of a really strong stressor is a shortcoming of this study. In fact, average distress levels were moderate, and when a child did get extremely upset, the task was terminated. Despite these limitations, given the hypothesis driven nature of the findings and the challenges of physiological research with young children, the findings are quite robust.

Conclusion

Does the current study help to clarify the association between cardiac reactivity and negative affect? We believe it does. Moreover, we believe the design and results of the current study will help inform future research on the associations between physiology and behavior in infants and young children. Careful examination of the stress level of tasks, quantification of negative affect behaviors, and attention to developmental issues will have important implications for the relative contributions of parasympathetic and sympathetic cardiac regulation of negative affect. In sum, full understanding of cardiac reactivity–negative affect relations will depend on age, gender, stress level of tasks, and both PNS and SNS measures. We are a long way from filling in all these details. Even if future studies can address all of these components, there might be heterogeneity due to temperament within each component. Individual differences in temperament may obscure the effects of negative affect on physiological changes. For instance, physiology and negative affect may be strongly associated, but only for children with extreme characteristics. This effect has been eloquently demonstrated in children who are behaviorally inhibited (e.g., Kagan, Reznick, & Snidman, 1988) and has been demonstrated in adults with depression. Rottenberg, Wilhelm, Gross, and Gotlieb (2003) reported that patients with depression, compared to nondepressed controls, failed to exhibit RSA increases associated with the resolution of tearful crying. Given this literature as well as the current findings, we suggest that revealing physiology–affect associations may benefit from careful examination of extreme groups, gender, and within-subject variation.

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