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A comparative validation of sympathetic reactivity in children and adults

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Abstract

This study provides comparative data on cardiac reactivity to common laboratory tasks in preschool children (ages 4.5–5.5 years) and young adults. We used a series of tasks (an emotionally evocative video, interview, reaction time task, and cold forehead pressor) to examine whether pre-ejection period, a common estimate of sympathetic cardiac activity in adults, provides a comparable measure of sympathetic reactivity to these tasks in preschool children. Our results demonstrate that the cardiac reactivity (pre-ejection period, respiratory sinus arrhythmia, and heart period) to such tasks in children and young adults is similar, but with smaller sympathetic reactivity in children. The consistency of the reactivity across tasks within individuals and consistency of reactivity across children and young adults suggests that pre-ejection period is a reasonable estimate of sympathetic activity in children.

Descriptors: Pre-ejection period, Respiratory sinus arrhythmia, Heart period, Reaction time, Cold pressor, Stranger task, Emotional video

Measures of autonomic control of the heart have provided a window into the cognitive and affective capabilities of infants, children, and adults. The primary autonomic measure used in studies with infants and children has been respiratory sinus arrhythmia (RSA), which reflects central and peripheral parasympathetic effects on the heart. Measures of baseline RSA have been used to index regulatory abilities such as attention in young and older children (Richards, 1987; Stifter & Jain, 1996; Suess & Bornstein, 1994). Temperamental variation in emotion has also been linked to basal RSA. For example, high levels of both positive and negative emotionality, specifically anger, have been linked to higher levels of parasympathetic tone (Calkins, 1997; Stifter & Fox, 1990; Stifter, Fox, & Porges, 1989) whereas fearfulness was related to lower levels (Kagan & Snidman, 1991). RSA has also been shown to predict problem behavior in children with at-risk toddlers and older children, particularly males, exhibiting lower levels of RSA (Calkins & Dedmon, 2000; Pine et al., 1998).

Most recently, Porges, Doussard-Roosevelt, Portales, and Greenspan (1996) have proposed that the suppression of vagal output in response to external challenges, or the "vagal brake," reflects the organism's ability to engage and disengage flexibly with the environment and may promote the development of social behaviors. The inability to suppress vagal tone has been found to be related to more behavior problems at 3 years of age (Porges et al., 1996), whereas greater vagal suppression has been linked to better behavioral regulation (Calkins, 1997; Porges et al., 1996), social approach (Stifter & Corey, 2001), and greater reward sensitivity and on-task behavior (Blair, 2002).

Heart period is controlled autonomically by both the parasympathetic and sympathetic branches of the autonomic nervous system (Berntson, Cacioppo, & Quigley, 1991, 1993). It is well documented that the activity of both autonomic branches contributes to overall cardiac function; however, activity of the sympathetic branch has been much more difficult to measure noninvasively, which is especially important in studies with infants and children.

To date sympathetic activity in children has been predominantly measured using low-frequency heart period variability. Some investigators have used low-frequency heart period variability or the ratio of low to high frequency (or total) variability as an estimate of sympathetic activity (Mezzacappa, Kindlon,

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Saul, & Earls, 1998; Snidman, Kagan, Riordan, & Shannon, 1995). However, this parsing of the heart period variability does not produce a pure measure of sympathetic activity. The spectral power in the low-frequency portion of the heart period variability arises from both sympathetic and parasympathetic sources. Even the use of a ratio of low to high or low to total spectral power to estimate sympathetic activity is flawed because it assumes that the parasympathetic contribution to the low-frequency power is fixed or varies in some known way with changes in sympathetic activity, which may not occur because changes in the two autonomic branches can be independent of one another (Berntson et al., 1991).

Beyond putative measures of sympathetic activity in heart period variability, Kagan and colleagues measured other sympathetically mediated responses such as pupillary changes and levels of norepinephrine and cortisol in behaviorally inhibited and uninhibited children (Kagan, Reznick, & Snidman, 1987, 1988). These studies suggested that behaviorally inhibited children had greater sympathetic activity to cognitive challenge. Interestingly, the strongest correlations with behavioral inhibition were for heart rate and overall heart rate variability, both of which we now know to be predominantly parasympathetically mediated at rest. Thus, methodological problems of estimating sympathetic activity from cardiac measures has slowed research into the cognitive, affective, and behavioral correlates of sympathetic cardiac function in infants and children.

Recently, a measure of cardiac sympathetic function called pre-ejection period (PEP), which is an estimate of changes in sympathetic activity in adults, has been used in studies with children (Allen & Matthews, 1997; Boyce et al., 2001; Matthews, Salomon, Kenyon, & Allen, 2002; McGrath & O'Brien, 2001; Salomon, Matthews, & Allen, 2000). Pre-ejection period is the time between the electrical initiation of the heart beat and the time that blood is ejected into the aorta. Pre-ejection period has been shown to be a reasonable estimate of sympathetic activity in typical laboratory settings and under certain boundary conditions (Berntson et al., 1994). For example, PEP cannot be used as an unequivocal estimate of sympathetic activity in the presence of large changes in preload (e.g., venous return to the heart) or afterload (e.g., total peripheral resistance). However, when these changes are minimal, PEP is a viable estimate of cardiac sympathetic activity in adults.

For the most part, studies of PEP in childhood have examined responses to tasks with varying cognitive and affective demands, and the results suggest an age effect. For example, a small sample of toddlers who showed significant heart rate and RSA changes to emotionally challenging tasks showed no PEP changes (Buss, Davidson, Kalin, & Goldsmith, 2004). Similar results were found with children ages 3–8 years in response to stressor tasks (social interview, number recall, lemon juice on the tongue, and emotional videos; Alkon et al., 2003). By 8–10 years of age, however, children are able to mount a sympathetic response. In a longitudinal study of healthy school-aged children Allen, Matthews, and colleagues found that 8–10-year-old children exhibited significant changes in PEP to stressor tasks such as a social competency interview, a go/no-go reaction time task, a mirror tracing task, and a cold forehead pressor task (Allen & Matthews, 1997; Matthews et al., 2002). Importantly, they documented that despite smaller hemodynamic responses in 8–10-year-olds than adolescents (15–17 years of age), PEP responses varied by age only for the reaction time task, where adolescents showed a more potent sympathetic response (Allen & Matthews, 1997). Stability in PEP responses was also tested in two separate studies. Short-term stability and intertask consistency were observed in 8–11-year-old children (McGrath & O'Brien, 2001), whereas long-term (3 years) stability was observed in middle childhood and adolescence (Matthews et al., 2002).

Although there is an emerging literature on PEP in children, it has not been demonstrated that PEP is related to sympathetic activation in young children. PEP has not been validated using pharmacological blockades as it has been in adults. Because it is unlikely that it will be pharmacologically validated in healthy children, it is important to provide additional comparative validation of PEP in children. Only Matthews and colleagues have addressed this issue by comparing responses of 8–10-year-olds and 15–17-year-olds (Matthews et al., 2002; Salomon et al., 2000). We sought to determine whether PEP is similarly reactive to cognitive or affective tasks in children and adults by looking across a greater range of ages that would permit comparison between the growing literatures on both adult and early life autonomic cardiac measures. To enhance comparability with prior studies, we used common laboratory tasks with well-defined patterns of autonomic response where possible.

In the current study, we provide a comparative validation of PEP in 4.5–5.5-year-old children and young adults using tasks that could be completed by both age groups. The tasks were an emotionally evocative video (clips from *The Wizard of Oz*), an interview, a reaction time task, and a cold forehead pressor task. We wanted to compare reactivity in children and adults across these four tasks and assess intertask consistency in both groups. Our primary a priori hypotheses were that (1) on each of the four tasks, adults and children would show directionally similar PEP changes from baseline, and (2) individuals in both age groups would show similar intertask PEP reactivity such that individuals with higher PEP reactivity on one task would also show higher reactivity in another task, as was previously shown in older children (McGrath & O'Brien, 2001; Salomon et al., 2000). A secondary hypothesis was our prediction that PEP would shorten (increased sympathetic activation) in response to both the interview and reaction time tasks in the children and adults (Allen & Crowell, 1989; Berntson et al., 1994; McGrath & O'Brien, 2001; Salomon et al., 2000).

Method

Participants

Thirty-eight children ranging in age from 4 years 9 months to 5 years 8 months of age ($M = 5$ years 3 months, $SD = 3.25$ months; 16 girls; all white) participated in the present study. The children were recruited from an ongoing longitudinal study of children's socio-emotional behavior and physiology. The majority of children were from middle- and upper-middle-class families, with 92% of the children living with two parents and average parental education of 2 years of college ($M = 14.2$ years, $SD = 1.4$). A comparison group of 20 adults (ages 18–31; mean = 21, median = 20; 12 women) was recruited from the same college town where the children's families resided. The adults were all college students (70% white, 20% black, 5% Hispanic, 5% Asian Indian). The medications used by the adults were birth control pills ($N = 6$), antibiotics ($N = 2$), nonsedating allergy medications ($N = 2$), and over-the-counter pain medications ($N = 1$).

Due to methodological (electrical interference) and participant (movement or noncompliance) problems, some of the data for both children and adults were unusable. Thus, the number of subjects varies across tasks and across dependent measures (children: video *N*s = 36–37, interview *N*s = 35–38, reaction time *N*s = 32–37, cold pressor *N*s = 33–36; adults: video and interview *N*s = 18–20, reaction time *N*s = 14–18, cold pressor *N*s = 17–19).

Tasks

Video. The video task consisted of 12 min of video clips from the movie *The Wizard of Oz*. Emotionally evocative and neutral segments were appended together as follows: 1 min neutral, 2 min fear, 2 min happy, 2 min fear, 1 min neutral, 2 min anger, and 2 min happy. Undergraduate students rated these materials on their valence and the degree of experienced emotional intensity, and those segments with consistently high ratings for a particular emotional state were used to create the 12-min video. We chose this video because although it may not be equally familiar for children and young adults, it is one of the few films that is both emotionally potent across these two age groups and also appropriate for viewing by children.

Interview. The interview task that immediately followed the video consisted of an interview (with a novel person for the children and with the main experimenter for the adults) about the content and emotions evoked by the video clips. Interviewers followed a standard script and asked children and adults to indicate how specific sections of the video made them feel (children's ratings used a pictorial scale understandable to them). The interview also elicited information about the video to ensure that participants had watched and understood the video. All participants recalled specific content indicating that they had attended to the stimulus.

Reaction time. A computerized go/no-go reaction time task was presented for approximately 2 min. The task required identifying a specific picture (a rabbit) in a series of black-and-white animal drawings with pictures presented at increasing rates over the task period (children: 9 stimuli/1.5 s (practice), 9 stimuli/1.2 s, 9 stimuli/0.9 s, 9 stimuli/0.6 s; adults: 25 stimuli/1.3 s (practice), 25 stimuli/1.0 s, 24 stimuli/0.7 s, 21 stimuli/0.4 s). In each set of stimuli, targets (rabbits at 4/block for children or 11 or 9/block for adults) and distractors (elephant, frog, deer, kangaroo, and polar bear) were presented. Between pictures, a plus-sign fixation point was presented for 100 ms (child) or 300 ms (adult). Participants were instructed to press a key as quickly as possible when a rabbit was detected and to refrain from pressing any key when any other animal appeared. When a key was pressed, the stimulus disappeared from the screen. If no key was pressed, the stimulus disappeared when the stimulus presentation time had elapsed. A high-pitched beep indicated a correct detection (i.e., a key press to a rabbit) and a low-pitched beep signaled an error of commission or false alarm (i.e., a key press to an animal other than a rabbit).

Forehead cold pressor. A gel pack (18.5 cm $\times$ 10.5 cm) at 8–10°C was placed on the forehead for 1 min using an elasticized band and fabric holder. This temperature was determined in previous tests with adults (K.S. Quigley, unpubl. data) to evoke prominent cardiovascular responses while also minimizing the painful aspects of the stimulus.

Physiological Recordings and Data Reduction

We recorded the ECG and the impedance cardiogram with respiratory variables also derived from the impedance signal. The ECG was recorded using two spot electrodes in a modified Lead II configuration with active leads over the distal right collarbone and the lower left rib. Cardiac impedance was recorded using a four spot electrode configuration with electrodes placed over the C4 vertebrae (on the back of the neck), at the top of the sternum, over the xiphisternal junction, and on the back over the thoracic spine (Sherwood et al., 1990). The front two were recording electrodes and the back two electrodes passed the 4-mA, 100-kHz alternating current across the thorax. The outer current electrodes were a minimum of 3 vertical cm above and below the inner recording electrodes. Basal thoracic impedance (Z_0), the first derivative of the change in thoracic impedance (dZ/dt), and the ECG were measured by a Minnesota Impedance Cardiograph (Model 304B, Instrumentation for Medicine). The ECG and impedance signals were passed to a microcomputer with an A/D converter (12 bit) with ECG and dZ/dt sampled at 1000 Hz and Z_0 sampled at 500 Hz. ECG and dZ/dt were later decimated to 500 Hz for data processing. Digitized data were stored for off-line reduction and analysis.

Impedance-derived physiological measures were reduced using software providing visual inspection of impedance cardiographic waveforms and computer-aided event detection and ensemble averaging (ANS Suites; Mindware, Westerville, OH). ECG and ZCG data were inspected for movement artifact, and artifactual heart periods were interpolated to retain the time series. Artifacts affected less than 1% of the data. One-minute means were derived from the ensemble-averaged waveforms where fewer than 1% of ensemble averages were comprised of 45 or fewer heart beats. No ensemble averages were composed of fewer than 30 s of data. We calculated heart period, or the time between successive heart beats, because heart period has a more linear relationship with underlying autonomic changes that mediate short-term cardiac changes than heart rate (Berntson, Cacioppo, & Quigley, 1995). Thus, across different initial basal heart periods, equivalent changes in autonomic input to the heart will result in nearly equivalent changes in heart period, a relationship that does not hold for heart rate.

Pre-ejection period was taken as the time between the onset of the Q wave of the ECG and the B point of the dZ/dt waveform (beginning of ejection). It should be noted that PEP is a measure of changes in sympathetic effects on inotropic (contractility) function, rather than chronotropic (rate) function. However, a previous study using similar methods showed that task-induced changes in PEP were strongly related to sympathetically mediated changes in heart period in adults (Berntson et al., 1994). RSA was derived using the method of Porges and Bohrer (MXEdit, ver. 2.21, Delta Biometrics, Inc.) for each minute of heart period data. Respiration rate and relative depth was derived from the impedance signal using methods described by Ernst, Litvack, Lozano, Cacioppo, and Berntson (1999).

Procedures

Participants (and their accompanying parent in the case of the children) were greeted by an experimenter and escorted to the laboratory. For child participants, the child went to play a video game with an experimenter while the informed consent was explained to and completed by the parent. Parents also brought completed questionnaires about demographics of the family and the child's behavior (not reported here). Following informed consent and child assent, the experimenter placed electrodes as described above for the recording of ECG and ZCG. Children were then seated in a child-sized seat pulled up to a small wooden table. Parents were seated across the room within visual range of the children. Adult participants were seated in a comfortable chair in the same part of the laboratory as child participants. While the electrodes stabilized for a minimum of 10 min, the children completed a circle tracing task, the Peabody Picture Vocabulary Test (Dunn & Dunn, 1981), and a picture recognition game requiring the child to withhold a verbal response to some pictures and make a verbal response to others. Candy or goldfish cracker rewards were given. During the stabilization period for adults, the participant was asked to sit quietly and relax.

After stabilization, a 2-min baseline quiet period for children (where the experimenter spoke quietly to the child) and a 4-min quiet period for adults were recorded. Next, the participant watched the 12-min *Wizard of Oz* video followed immediately by the interview. All participants watched the video alone except for 1 child who would not allow her parent to leave the room with the experimenter. The parent returned with the novel experimenter for the interview. Next, the experimenter moved a computer next to the participant on which he or she completed the reaction time task. After the task, the computer was removed and the participant completed a handgrip task. We found that children could not consistently hold the handgrip as required, so these results were not analyzed. Finally, the experimenter placed the cold pack on the participant's forehead and recorded the physiological variables for 1 min.

For adult participants, 2-min baselines occurred before the reaction time, handgrip, and cold pressor tasks. To keep the preschoolers engaged with the tasks and sitting quietly, we chose to eliminate any intertask resting baselines. However, equipment was moved around between tasks for all participants, averaging 2 min between successive tasks (except between the video and the interview, where the interval was approximately 15 s). Because the small *N* precluded enough samples of each possible order of task presentation, we chose to present tasks all in the same order across all participants. And, as previous studies have shown aftereffects of the handgrip and cold pressor tasks, these tasks were presented last. After the cold pressor task, the electrodes were removed. Adults were thanked and reimbursed at this time. Children completed a few additional tasks that are not reported here, and then were thanked and reimbursed.

Data Analysis

Mean heart period, PEP, and RSA were calculated for each minute of the baseline and task periods. A measure of baseline physiological levels was computed by averaging the physiological recordings for the 2 min (children) or 4 min (adults) of the rest period immediately preceding the video task. Because preliminary analyses revealed few significant correlations between baseline and change scores (3 of 18), simple reactivity scores were computed for each task by calculating differences from baseline. Respiratory rate was examined to ensure that rates did not fall outside of the RSA frequency bands of interest (0.12–0.40 for adults and 0.24–1.04 for children; MXEdit manual, ver. 2.21, Delta Biometrics, Inc.), which they did not.

The shortest interview duration was 3.5 min, so the initial 3 min of each interview were used for all participants to ensure comparability across individuals, and because the initial minutes of the interview would be expected to be most evocative for the children with a novel interviewer.

To assess our hypothesis that children and adults would have directionally similar PEP responses, analyses of PEP, RSA, and heart period reactivity in children and adults were conducted using independent samples *t* tests for each task. To assess the hypothesis that individuals in both age groups would show similar intertask PEP reactivity, intertask consistency was assessed using Pearson's correlations with an alpha of .05 throughout. Effect sizes are reported using Cohen's *d*. Where Levene's test for equality of variances indicated departure from equality, *t*s were obtained from the test where equal variance was not assumed and thus, degrees of freedom in these cases are not integers.

Results

Basal Cardiac Function

Mean basal heart period, pre-ejection period, and respiratory sinus arrhythmia are reported in Table 1. As expected from previous research, preschool children had significantly shorter heart periods, $t(21.3) = 5.91$, $p < .0001$, and shorter pre-ejection periods, $t(22.2) = 7.68$, $p < .0001$, than young adults. There was no difference between the groups in basal RSA, $t(55) = 1.08$, n.s.

Cardiac Reactivity to Laboratory Tasks

The mean and standard errors for all cardiac variables are shown in Table 1 for the children and adults, and task-related change scores are shown in Figure 1.

Reactivity in children. Children showed significant RSA and heart period reactivity to the video, the interview, the reaction time task, and the cold pressor, and significant PEP reactivity to the video and interview as analyzed by testing the simple change scores against zero (ts > 2.00, ps $< .03$, ds ranged from 0.06 for PEP change to the interview to 1.79 for heart period change to the reaction time task, mean $d = 1.02$). The only reactivity scores not significantly different from zero were the PEP responses to the reaction time and cold pressor tasks (both ts ≤ 1.00, n.s.).

Reactivity in adults. Adults showed significant heart period reactivity to the video, $t(19) = 4.47$, $p < .0001$, $d = 0.99$, and

Table 1. *Means and Standard Errors for Children and Adults for All Baselines and Tasks*[a]

	Children	Adults
Baseline mean ± *SEM* (range)		
Heart period (ms)	582.9 ± 6.8 (518–674)	753.5 ± 28.0 (578–1101)
PEP (ms)	72.8 ± 1.3 (58–92)	101.1 ± 3.4 (69–120)
RSA (ln ms^2)	5.5 ± 0.1 (3.9–7.6)	5.8 ± 0.2 (4.0–8.1)
Wizard of Oz video mean ± *SEM*		
Heart period	613.8 ± 8.1	792.5 ± 31.5
PEP	74.4 ± 1.3	101.3 ± 3.7
RSA	6.1 ± 0.1	5.9 ± 0.3
Interview mean ± *SEM*		
Heart period	598.0 ± 8.3	739.1 ± 22.0
PEP	74.0 ± 1.4	101.4 ± 3.8
RSA	5.7 ± 0.2	6.0 ± 0.2
Reaction time mean ± *SEM*		
Heart period	643.4 ± 9.8	809.0 ± 28.7
PEP	73.2 ± 1.5	97.2 ± 3.5
RSA	6.5 ± 0.2	6.1 ± 0.3
Cold pressor mean ± *SEM*		
Heart period	632.8 ± 10.6	777.1 ± 27.0
PEP	71.8 ± 1.3	103.1 ± 3.9
RSA	6.4 ± 0.2	5.9 ± 0.3

[a]For baselines, the range is given in parentheses.

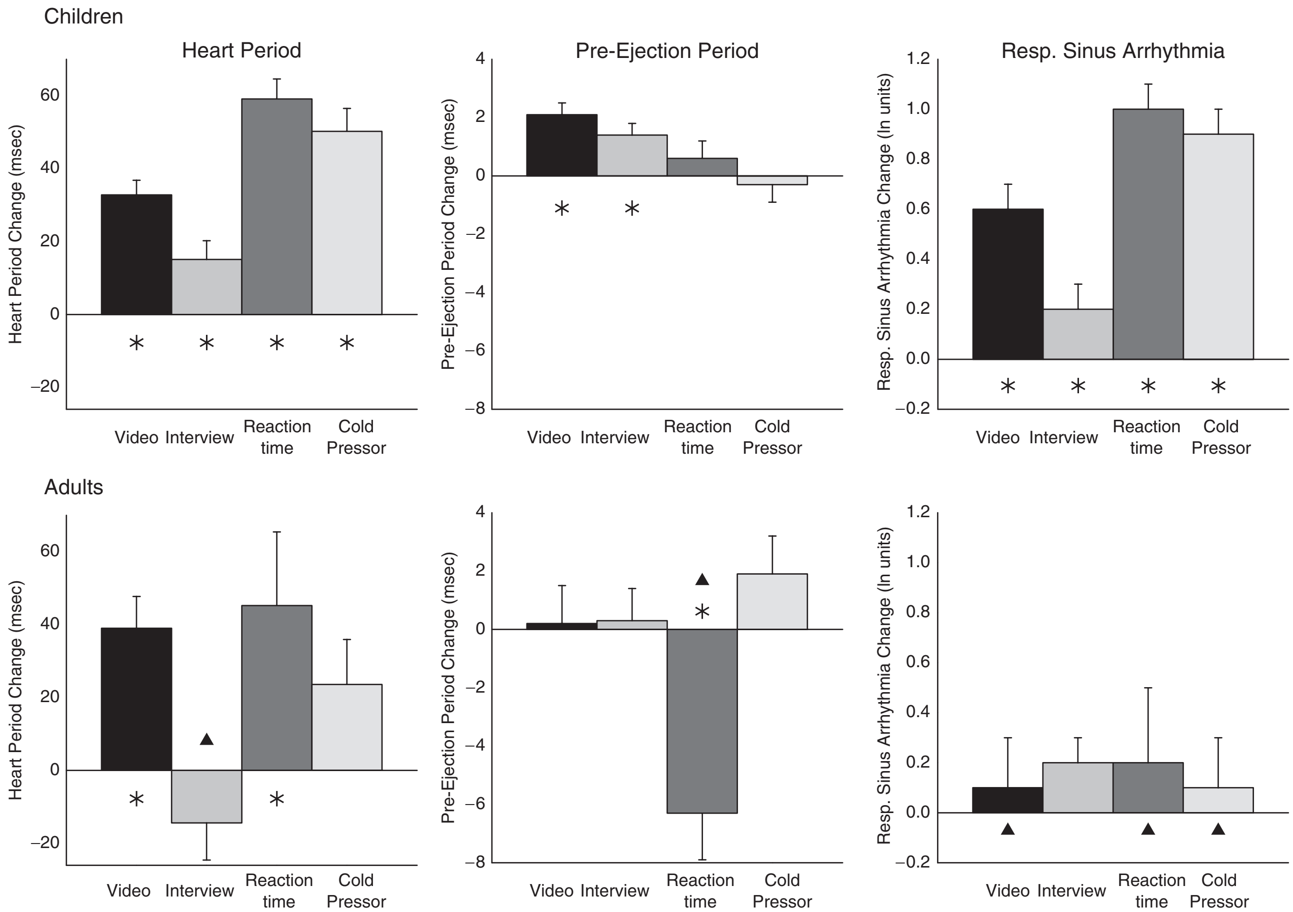

Figure 1. Mean changes (with standard error bars) in heart period, pre-ejection period, and respiratory sinus arrhythmia for children and adults during the video, interview, reaction time, and cold pressor tasks. Asterisks (*) are used to indicate differences from zero for both children and adults. Triangles (▲) are used to indicate that the group level response for adults is different from that of the children.

reaction time tasks, $t(15) = 2.24$, $p < .05$, $d = 0.56$, and significant PEP reactivity to the reaction time task, $t(13) = 4.04$, $p < .002$, $d = 1.08$. All other tests were nonsignificantly different from zero.

Comparison of reactivity in children and adults. When comparing child and adult cardiac reactivity, independent samples *t* tests revealed a significant difference in the RSA response to the video, $t(27.9) = 2.59$, $p < .02$, $d = 0.84$, with children showing a greater increase in RSA than adults (see Figure 1). No other differences were found for the video. In the interview task, children and adults differed only in their heart period response, $t(55) = 2.89$, $p < .01$, $d = 0.81$, with children showing heart period lengthening and adults heart period shortening (Figure 1). In the reaction time task, children had significantly different responses than adults in both PEP and RSA, $t(17.6) = 4.11$, $p < .002$, $d = 1.68$, and $t(19.0) = 2.29$, $p < .05$, $d = 0.96$, respectively. Children showed no change in PEP to this task, whereas adults showed a significant shortening (Figure 1). Conversely, children as a group had a significant increase in RSA to this task, whereas adults as a group showed no RSA change. In response to the cold pressor task, children and adults exhibited differential RSA reactivity, $t(53) = 3.35$, $p < .002$, $d = 0.96$, with children showing a greater increase than adults, who had no change. In sum, at the group level, the response in children and adults did not differ for heart period (except for the interview) or pre-ejection period (except for the reaction time task), but they did differ for RSA (except for the interview; see Figure 1).

Because we used brief (2 min) baselines between tasks for the adults that are shorter than usual and because the adults had significant PEP shortening, we also assessed whether PEP returned to baseline prior to the reaction time and cold pressor tasks (and in the posttask baseline) for the adults. For most individuals, PEP had returned to within 1 ms of the average pretask baseline by the second baseline minute (88% of participants before the reaction time task, 71% before cold pressor, and 76% after cold pressor).

We also examined whether children and adults varied in a more general way in their response to these laboratory tasks as our a priori hypothesis was that they would be directionally similar even though they might vary in response magnitude. To assess this, we characterized the responses on each task and each variable as either increased or decreased from baseline irrespective of the size of the response (using the means shown in Figure 1). Nine of the 12 comparisons showed the same direction of response and 3 showed a different response direction. We calculated a one-tailed binomial test of the alternative hypothesis of a greater than chance likelihood of having the same direction of reactivity in children and adults, and this test was marginally

Table 2. *Intertask Correlations for Change Scores of Children and Adults for Each Pair of Tasks*

	Video–interview	Interview–RT	RT–cold pressor	Cold pressor–video	Video–RT	Cold pressor–interview
Children						
Heart period (ms)	0.47**	0.64***	0.67***	0.34*	0.50**	0.55**
PEP (ms)	0.70***	0.81***	0.61**	0.61***	0.75***	0.66***
RSA (ln ms^2)	0.40*	0.51**	0.60***	0.41*	0.61***	0.48**
Adults						
Heart period	0.10	0.69**	0.44†	0.67**	0.20	0.47*
PEP	0.50*	– 0.12	0.42	0.55*	– 0.14	0.53*
RSA	0.82***	0.60*	0.72**	0.82***	0.67**	0.68**

Note: Coefficients significant at $p<.001$***, $p<.01$**, $p<.05$*, $p<0.10$†

significant, $p = .07$. This result suggests a trend toward the children and adults having directionally similar responses across the four tasks.

Intertask response consistency. Another goal of the present study was to determine whether there was significant intertask consistency in the adult and child samples. These data are shown in Table 2. The data reveal strikingly good intertask consistency for the children, with all correlations significant and all at .34 or above. There was less consistency for the adults than for the children for heart period and PEP, although RSA reactivity was consistent across all task pairs for adults. To examine whether individual differences in autonomic response were greater in adults than children, we made an idiographic assessment of the autonomic modes of control for each task for both children and adults.

Idiographic analyses. To examine individual differences in response patterns, we defined a change in parasympathetic activity as a change greater than 0.1 ln ms^2 in either direction from baseline and a change in sympathetic activity as a change greater than 2 ms in either direction of baseline. These cutoff values for parasympathetic and sympathetic change were chosen to be greater than the measurement error for the variable such that a larger change most likely reflects a true response, rather than just random error. Results for the autonomic patterns across individuals for both children and adults are shown in Figure 2 where the size of each dot represents the proportion of individuals in the sample who showed that mode of control. This figure shows that adults had a greater variety of autonomic patterns of response to the cold pressor and video (as evidenced by a greater number of modes coupled with fewer large dots), and more sympathetic activation in the video and interview tasks than did children. If one considers only parasympathetic activation (regardless of the sympathetic contribution), then more than 50% of children showed parasympathetic activation in each of the four tasks. This strong tendency toward parasympathetic activation in the children with minimal sympathetic involvement appears to drive the smaller individual differences in the children.

Comparability of Tasks

Although the reaction time task was adapted to the age level of the participant, we compared performance on the reaction time task for the children and adults to address the comparability of this task across groups. Children had longer reaction times on the target (bunny) trials (mean $\pm$ *SEM* $= 844 \pm 33$ ms) than adults (475 ± 5 ms; $t(51) = 8.58$, $p<.0001$). Children also had more errors of commission (children: 1.9 ± 0.4; adults: 0.5 ± 0.2, $t(56) = 2.36$, $p<.02$), but a similar number of errors of omission (children: 0.26 ± 0.1; adults: 0.60 ± 0.2; $t(56) = 1.61$, n.s.). The difference in reaction times is consistent with another study finding longer reaction times in 7-year-old children than adults (Fan, McCandliss, Sommer, Raz, & Posner, 2002).

To assess whether adults and children were comparable on their reactions to the video, we compared the intensity ratings they reported for each video segment. These analyses revealed that the children had higher intensity ratings for their feelings about specific segments of the video than did the adults, with three of five segments rated significantly higher, $ts>2.0$, $ps<.05$. This could either be because the children use these types of rating scales differently or that they truly found the scenes to provoke more intense feelings.

Discussion

In keeping with our hypothesis that preschool age children and adults would show similar changes in PEP to evocative laboratory tasks, we found at the group level that children and adults did not differ in their reactivity to a video, a social interview, and a cold pressor task, which all produced modest lengthening of PEP. Moreover, the group level change in PEP for children was small for all tasks and idiographic analyses showed that even at the individual level, the cold pressor task was the only case in which a larger proportion of children than adults exhibited sympathetic activation. In the other three tasks, the proportion of children with sympathetic activation was small relative to the proportion of adults. In the reaction time task where adults had the most potent sympathetic activation, there was little group-level PEP change in the children and a small proportion (fewer than one-third) of children with this response. Children did show significant RSA and heart period responses to the tasks, however, suggesting that the small PEP responses are not because the tasks were not evocative for children. Rather, children of this age may have less capacity or less need for a sympathetically mediated cardiac response to such tasks than adults.

Several explanations could account for the generally more modest PEP responses in children. One possibility is that children younger than 5 years of age cannot mount a phasic sympathetic cardiac response. This suggests that there could be a developmentally based, physiological limitation in phasic sympathetic changes in younger organisms and there is support for this notion in animals. Studies by Campbell and colleagues showed vagally mediated responses to aversive stimuli in postnatal day 16 rats (adolescents), but a substantial sympathetic contribution to the response to these same stimuli at postnatal day 75 (adults; Kurtz & Campbell, 1994; Richardson, Wang, & Campbell, 1996).

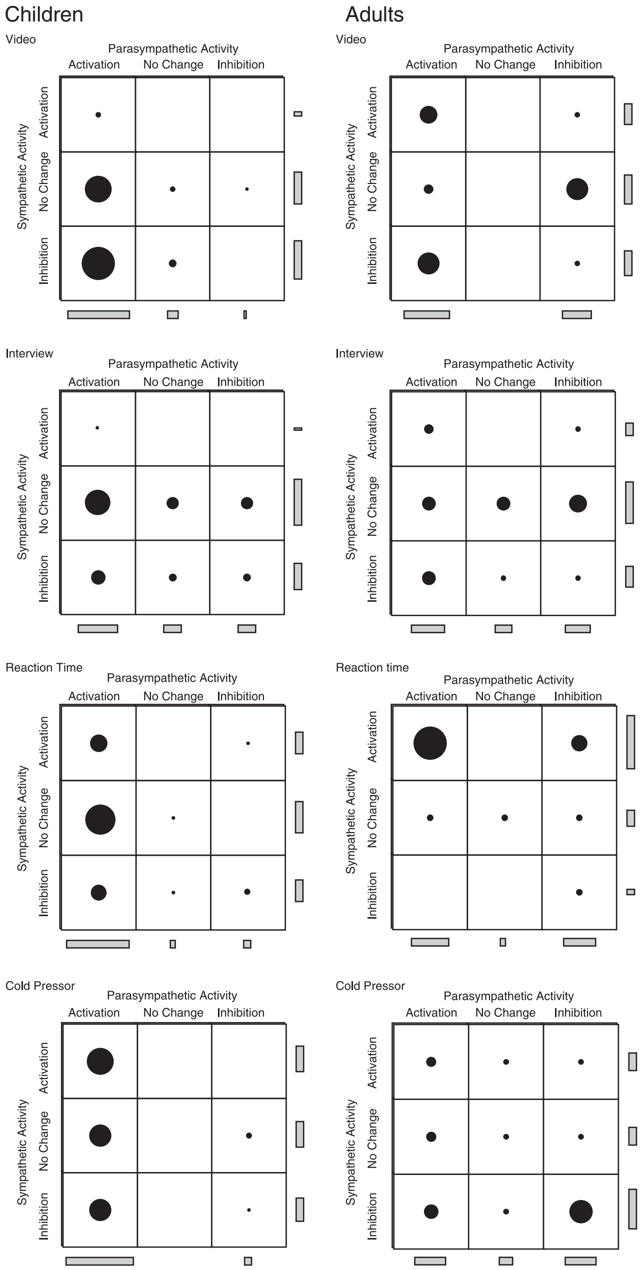

Figure 2. This figure depicts the relative proportions of each mode of autonomic response for the nine possible modes of control for each of the four tasks for both children and adults. The diameter of the dot in each cell reflects the proportion of the sample exhibiting that mode of control. For example, the diameter of a dot representing 100% would fill the center of a cell from edge to edge. The gray bars alongside the cells represent the marginal proportions. For example, a bar representing 100% would be exactly the length of one cell. This depiction provides a visual comparison of the proportion of individuals in the sample who displayed each of the nine modes (dots) and had changes in activity of each of the autonomic branches (bars).

Another possibility is that there is no physiological need to change sympathetic function, either because children have sufficient parasympathetic tone and good capacity for altering parasympathetic function that can drive any changes in heart period required by challenges or because the psychological antecedents and the physiological consequences of the tasks are different for children. Finally, it is also possible that basal PEP is already near the physiological minimum in young children, and, thus, further PEP shortening is constrained (i.e., a Law of Initial Values effect). We have no way to know which of these processes play a role in the current data, but they should be viewed as theoretically distinct.

Our second hypothesis was that children and adults would show similar intertask consistency in PEP reactivity, indicating that individuals with larger sympathetic responses to one task would have a similarly greater response to another task. This hypothesis was supported. Although as a group, children produced small changes in PEP, the changes within individuals were consistent across tasks. Interestingly, adults had less intertask consistency for both PEP and heart period. The less consistent intertask correlations for the adults may derive from the fact that the tasks were designed so that they were evocative and still appropriate for both children and adults (video), and they could be performed by both the children and adults. As a result, the tasks appeared to be less potent for the adults. The less consistent intertask correlations for adults also may result from greater individual differences in autonomic response across tasks. We explored individual differences in response by examining the autonomic modes of control evoked across tasks. Lower intertask consistency in adults was particularly apparent in PEP reactivity to the reaction time task, which differed (at the group level) from all other tasks. Intertask consistency was high for both children and adults for vagal responses, with adults being even more consistent across tasks than children.

Our idiographic analysis suggested there were larger individual differences in the adults than in the children, most likely because of less common sympathetic activational responses in children. Data from Salomon et al. (2000) suggested that the individual differences in autonomic patterns of response that we observed in young adults were beginning to emerge in school-age children. The reaction time task used by those investigators was a go/no-go task similar to that used here, and they also used an interview task (although the social competence interview used by Salomon et al. and designed for use in older children is likely more evocative than the interview used here). In their study, both tasks produced significant interindividual response variation. For example, although the main response pattern was a reciprocal sympathetic activation and vagal withdrawal, at least 25% of subjects did not display this pattern for each of these tasks.

Given our finding that children were less likely than adults to produce shortened PEP responses, we compared the younger and older groups in the Salomon et al. data (K. Salomon, personal communication; the data in the Salomon et al. paper were collapsed across the 8–10- year-olds and the 15–17-year-olds because of cell sizes for some patterns of autonomic activity). There was no difference in the proportion of children with sympathetic activation (both reciprocal sympathetic and coactivation) for the two age groups. However, in their earlier analysis, older children showed greater decreases in PEP for the reaction time task than the younger children, but this effect was not seen for any other task (Allen & Matthews, 1997). Thus, the tendency for younger children in our sample to show little sympathetic activation seems to shift to a more adultlike pattern by 8–10 years of age, although not for all tasks.

Beyond demonstrating that preschool-age children have small but individually reliable changes in PEP to evocative laboratory tasks, we also found response consistency across the groups for both RSA and heart period. For the video, reaction time, and cold pressor tasks, children and adults had similar changes in heart period, and for the video, interview, and cold pressor, they had similar, though small, changes in PEP. For all but the interview and reaction time tasks in the adults, the PEP and RSA results are reasonable with respect to the expected direction of change in heart period. One exception was the interview task, where adults had a group-level response of heart period shortening that is not what would be expected from a minimal change in PEP and small increase in RSA. We also did not expect the group-level response to the reaction time task in adults to be a lengthened heart period in combination with a shortened PEP and little change in RSA. This suggests that there are some individual differences in the responses to the interview and reaction time tasks that are not reflected in the group-level responses.

The possibility of substantial individual differences is bolstered by the idiographic data showing different autonomic modes of control to the interview task for adults and prominent coactivation in the reaction time task by a large proportion (43%) of the adults (see Figure 2). A coactivation response to the reaction time task is consistent with the group-level result of shortened PEP and lengthened heart period as long as the vagal activation is large enough to override the sympathetic activation. Vagal activation was not apparent at the group level, highlighting the importance of examining both group- and individual-level results. Similarly, although for the adults in the interview and cold pressor tasks there was no significant reactivity for any cardiac variable at the group level, there were meaningful responses in some individuals, as evidenced by intertask consistency (Table 2) and by changes larger than the level of error (i.e., activation or inhibition in Figure 2).

There are inevitable limitations to a comparative analysis across such a wide age range. It is likely that there are differences in the motivational, affective, social, and cognitive demands across the two age groups for different tasks. In fact, the similarity of the change scores across tasks for heart period and PEP (for all but one task in each case) is rather surprising. Further, although RSA responses were larger for the children than the adults for three of four tasks, these were differences in magnitude, not response direction, and idiographic analyses also suggested a significant and similar proportion of each group with vagal activation across all tasks. Despite these differences, the data taken together show considerable similarities across the adults and children and are more similar than one might expect, given likely differences in the tasks for these two groups. Short baselines between tasks for both adults and children (about 2 min between tasks) are another limitation. Carryover effects are possible, particularly when responses were large or systematically diminished across tasks. For example, in children the PEP response was smaller with each successive task. Although carryover is possible, the small size of the PEP response across tasks in the children makes this relatively unlikely. Another concern is whether the large response to the reaction time task for adults carried over to the response to the cold pressor task. Again, this would appear to be minimal because the group-level response to the cold pressor was in the opposite direction. We cannot exclude the possibility, however, that some of the responses were affected by residual changes from a previous task.

Together these data indicate that PEP reactivity in preschool-age children, although modest, is reliable across individuals using these laboratory tasks. In addition, the data suggest that in young adults, some of these tasks evoke greater individual differences in the patterns of autonomic cardiac activity than is true in preschool children, most likely because sympathetic activation, in particular, was less common in children. Despite the small mean group PEP responses, good intertask consistency was observed. These data document that PEP can be measured reliably in preschool-age children, a group that has received less attention in the developmental literature both in terms of autonomic cardiac function and behavior than the more accessible infant and school-age populations.

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