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Developmental Trajectories of Respiratory Sinus Arrhythmia and Preejection Period in Middle Childhood

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Abstract

Autonomic nervous system (ANS) activity has been linked repeatedly to children's socioemotional and behavioral adaptive functioning and development, yet the literature on how various indexes of ANS activity develop in childhood is sparse. We utilized latent growth modeling to investigate the development of respiratory sinus arrhythmia (RSA), an established index of parasympathetic nervous system (PNS), and preejection period (PEP), a marker of sympathetic nervous system (SNS) influence on the heart, in children aged 8–10 years. At age 8, 251 children (128 girls, 123 boys; 162 European American, 89 African American) participated. Longitudinal data were collected during two additional waves when children were 9 and 10 years of age, with a 1-year lag between each wave. Children's RSA and PEP exhibited significant stability over time. Marginally significant variability was found among children in how RSA changed over time (slope), but there was no significant interindividual variability in PEP changes over development. A conditional growth curve model (i.e., one with predictor variables) showed that initial levels of RSA and PEP and the slope of RSA over time were predicted by several demographic factors including the child's sex and race; RSA of European American children showed significant increases over time while African American children had higher initial RSA but no significant change over time. Findings extend basic knowledge in developmental biopsychology and have implications for research focusing on ANS measures as important predictors, moderators, and mediators of childhood adaptation.

Keywords

childhood; autonomic nervous system; respiratory sinus arrhythmia; preejection period; longitudinal; developmental trajectories

INTRODUCTION

The use of physiological measures in studies of child adjustment have increased as researchers have begun to focus on how biological functioning or biology by environment interactions may advance understanding of developmental psychopathology processes (Beauchaine, Neuhaus, Brenner, & Gatzke-Kopp, 2008). Two common biological measures of autonomic nervous system (ANS) function, respiratory sinus arrhythmia (RSA), and

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preejection period (PEP), are indicators of parasympathetic nervous system (PNS) and sympathetic nervous system (SNS) influence on the heart, respectively (Berntson et al., 1997; Berntson, Cacioppo, Binkley, et al., 1994; Berntson, Lozano, Chen, & Cacioppo, 2004). Indices of ANS functioning are of interest to researchers focusing on physical health outcomes such as hypertension (Frederickson & Matthews, 1990; Tomaka & Palacios-Esquivel, 1997) as well as mental health outcomes and behavior (Beauchaine, 2001; El-Sheikh et al., 2009). Furthermore, developmental theory emphasizing multiple levels of analysis across biological and environmental domains has implicated ANS activity as an important correlate, pathway of effects, or moderator in the link between various environmental conditions and children's socioemotional, cognitive, and behavioral functioning (e.g., Cummings, El-Sheikh, Kouros, & Buckhalt, 2009; Degnan, Calkins, Keane, & Hill-Soderlund, 2008; Loman & Gunnar, 2010; Steinberg & Avenevoli, 2000).

While there is a growing body of literature on how ANS activity is related to child adaptation and development, very few longitudinal investigations have focused on the development of ANS activity with school-aged children (for exceptions, see El-Sheikh, 2005; Salomon, 2005, for RSA; Alkon et al., 2003; Matthews, Salomon, Kenyon, & Allen, 2002, for PEP). If basal levels of RSA and PEP are to be used as indicators and predictors of child developmental outcomes, it is imperative to have information on their development including their continuity, stability, and variability in childhood. Continuity refers to mean (i.e., group) level change over time. Stability refers to individuals' maintenance of rank in a construct over time. Variability refers to individual differences in levels of a construct within and over time. If, for example, ANS activity is hypothesized to mediate relations between environmental characteristics (e.g., parental socialization) and behavioral outcomes (e.g., externalizing behavior), it would be imperative to know which developmental periods evidence significant continuity, stability, and variability in ANS function (e.g., when it is potentially malleable to environmental influence).

RSA is characterized by heart rate fluctuations in phase with respiration that, when specific conditions are met, serves as an index of parasympathetic influence on the heart (for further details, see Berntson, Cacioppo, & Grossman, 2007; Grossman & Taylor, 2007). Basal RSA is thought to reflect an individual's capacity for emotion regulation (Porges, 1995, 2007) and trait emotionality (Oveis et al., 2009). Further, research comparing typically developing, control children to children and adolescents with conduct problems has found evidence of lower basal RSA in those with conduct problems (Beauchaine, Gatzke-Kopp, & Mead, 2007). Thus, greater understanding of the development of RSA and its predictors and sequelae is essential for a broad array of issues in developmental psychology.

RSA has been shown to exhibit significant mean level increases over time (i.e., discontinuous) and is relatively stable through infancy and early childhood (Alkon et al., 2006; Bar-Haim, Marshall, & Fox, 2000; Bornstein & Suess, 2000; Calkins & Keane, 2004). Continuity in RSA for older children is less evident with some studies indicating mean increases in RSA with children up to 7 years of age (Alkon et al., 2003; Marshall & Stevenson-Hinde, 1998), while others have shown mean decreases or no change in RSA with children and adolescents ages 8 and older (El-Sheikh, 2005; Salomon, 2005). Research with older children and adolescents supports the continued stability of RSA (El-Sheikh,

2005; Salomon, 2005). Thus, developmental change in RSA seems to level off by late childhood or early adolescence and has significant stability during these developmental periods.

PEP is an index of SNS activity and represents the time between the onset of the heart beat (i.e., R-wave in this study as suggested by Berntson et al., 2004) to the ejection of blood into the aorta. Lower PEP indicates increased SNS influence on the heart (Berntson, Cacioppo, Binkley, et al., 1994; Lewis, Leighton, Forester, & Weissler, 1974; Mendes, Reis, Seery, & Blascovich, 2003). Empirical evidence supports PEP as an index of the behavioral activation system (BAS; Brenner, Beauchaine, & Sylvers, 2005; Richter & Gendolla, 2009; Tomaka & Palacios-Esquivel, 1997), which is a hypothetical motivational system governing approach and appetitive behavior to reward and reward sensitivity (Fowles, 1980; Gray, 1987). Like RSA, there is evidence that PEP activity can differentiate on a physiological level typically developing children from those with conduct problems; the latter exhibit higher basal PEP and less PEP shortening (i.e., less SNS reactivity) in response to reward (Beauchaine et al., 2007).

PEP has been established as a good indicator of SNS activity in laboratory settings with adults (Berntson, Cacioppo, & Fieldstone, 1994) and children (Quigley & Stifter, 2006). Few investigations have addressed the development and stability of PEP in children. Mean level age differences have generally indicated that younger children have lower PEPs than older children (Alkon et al., 2003). Similarly, repeated measures of PEP over a 3-year interval indicate developmental increases in PEP in childhood but not in adolescence (Matthews et al., 2002). A study with 8- to 10-year olds and 15- to 17-year olds reported moderate stability of PEP over a 3-year period (Matthews et al., 2002). Notably, a common limitation to all of the studies conducted on RSA or PEP with older children or adolescents is that repeated measures conducted to examine continuity and stability have been limited to two time points.

Associations between either RSA or PEP and demographic variables or child characteristics, such as sex and race, have been less clear. Research conducted with adults indicates that African Americans (AA) and men tend to show different hemodynamic (i.e., circulatory) patterns than European Americans (EA) and women, respectively (Allen, Stoney, Owens, & Matthews, 1993). However, few studies assessing RSA or PEP with children have included ethnically diverse samples and those that have reported few significant race- or ethnic-related effects (for RSA, Salomon, 2005; for PEP, Matthews et al., 2002). Sex-related findings in child samples are inconsistent. Some studies reported no significant relations between sex and RSA or sex and PEP (Alkon et al., 2003). Conversely, other studies have found evidence of sex-related effects indicating that, in comparison to girls, boys have higher levels of RSA (El-Sheikh, 2005; Salomon, 2005) and higher levels of PEP (Matthews et al., 2002). Finally, it is possible that body mass index (BMI) is an important variable in understanding levels and change over time in RSA and PEP; higher BMI has been concurrently related to lower RSA (El-Sheikh, Erath, & Keller, 2007), and adolescent males (the group with the highest BMI) have been found to exhibit higher resting PEP (Matthews et al., 2002). Thus, BMI was considered as a covariate in our analyses. Because

socioeconomic status (SES) and race are often correlated (LaVeist, 2005), SES was also considered as a covariate.

While there are some studies on the development of RSA (and relatively fewer on the development of PEP) in childhood, the literature would be augmented by basic developmental research on changes in RSA and PEP over time. We employed latent growth modeling to examine both the within- and between-individual change that occurs in the activity of these systems with development over the course of 3 years in a large community sample of children in middle childhood (aged 8, 9, and 10). For an elucidation of characteristics relevant to the developmental trajectories of RSA and PEP, we assessed the role of demographic characteristics including children's initial age, BMI, SES, sex, and race in predicting growth in RSA and PEP over development. Given the inconsistent findings between race, sex, and RSA or PEP (e.g., Allen et al., 1993), we also explored whether child race and sex interacted to predict initial levels and growth of RSA and PEP.

METHOD

Families were recruited from three local school systems to participate in a longitudinal study examining the effects of familial violence on children's adjustment and cognitive functioning. All three school systems allowed recruitment letters to be sent home with the children in the 2nd and 3rd grade, and one school system provided researchers with the names and phone numbers of potential participants so that researchers could recruit families over the phone. Only information pertinent to this paper will be discussed. Families participated in the three study waves. At T1, participants were 128 girls and 123 boys from the Southeastern United States (*M* age = 8.23, *SD* = .73) and their parents. Children came from two parent families; 74% lived with both biological parents and 26% lived in reconstituted families. Parents were either married or had been cohabiting for an extended amount of time (*M* = 10 years, *SD* = 5.67). Due to scope of the larger project (e.g., sleep, cognitive functioning), exclusion criteria were a diagnosis of a learning disability, ADHD, mental retardation, or a chronic illness. Out of the families contacted that qualified to participate in the study, 37% participated, 18% declined participation, and 45% were interested but were not included because subsample cells had been filled (either in relation to sex, SES, or race). To reduce confounds between race and SES, we initially oversampled to include EA and AA children across all SES levels.

Based on Hollingshead's (1975) criteria, the sample was composed of families from a wide range of SES backgrounds. Specifically, 25% of families were classified into level 1 or 2 (e.g., unskilled or semi-skilled labor), 34% were in level 3 (e.g., skilled labor), and 41% were in level 4 or 5 (e.g., professional). The median family household income was in the $35,000–$50,000 range. The racial composition of the sample closely resembled the community from which it was drawn: 66% of families were EA and 34% were AA.

One year following their T1 participation, 106 boys and 111 girls and their parents returned for a second wave of data collection [T2; *M* age = 9.31 years (*SD* = .79 months)]. One year after T2, 88 boys and 95 girls and their parents participated in a third study wave [*M* = 10.28 years (*SD* = .99)]. Attrition rates were 14% and 16%, respectively, which are acceptable

given the diversity of the sample in relation to race and SES (Farrington, Gallagher, Morley, St Ledger, & West, 1990). Reasons for attrition included geographic relocation, inability to be located, hectic schedules, and lack of interest. Efforts were made to increase retention rates by sending birthday cards to the children, calling participants every 3 months to obtain updated contact information, obtaining contact information for another person who would be able to locate the family in case of relocation or disconnected phones, and allowing for flexibility in time and day of laboratory sessions. These retention techniques have proven successful with samples that are ethnically and socioeconomically diverse (Janson, Alioto, & Boushey, 2001; Senturia et al., 1998).

Procedures

During each wave of data collection, mothers, fathers, and children visited our on-campus research laboratory. Informed consent and assent were obtained at the beginning of each visit. During the visit, children participated in a physiological assessment (only relevant procedures are described here; for full details, see El-Sheikh et al., 2009, Study 2). Prior to assessment, the researcher explained the purpose of the equipment to reduce potential anxiety among children, and parents were encouraged to be present while the RSA and PEP sensors were affixed to the child. Children were seated, electrodes were attached, and then the researcher and the parent left the room. The child was then given a 6-min resting adaptation period to acclimate to the surroundings before a 3-min baseline was collected; this baseline was used in analyses. During the adaptation period, children were asked to sit still and were told that a researcher would be back shortly. Procedures were identical across all three waves of data collection.

Measures

RSA data acquisition and reduction—The rhythmic fluctuations in heart period that are accompanied by phases of the respiratory cycle are used to determine RSA (Grossman, Karemaker, & Wieling, 1991; Grossman & Wientjes, 1986). Children's RSAwas computed using the peak-to-valley method, and all units are in seconds. This method is one of several acceptable techniques for quantifying RSA, is highly correlated with spectrally computed RSA (Galles, Miller, Cohn, & Fox, 2002), and has the ability to assess RSA during brief time periods similar to the ones used in the present study (see Berntson et al., 1997). Children's RSA was measured following standard guidelines (see Bar-Haim et al., 2000; Berntson et al., 1997). We refer the reader to El-Sheikh et al. (2009) for details on the RSA data acquisition and reduction.

PEP data acquisition and reduction—Four Ag/AgCl spot electrodes were used instead of band electrodes because they provide reliable measures of impedance cardiography (McGrath, O'Brien, Hassinger, & Shah, 2005), are less invasive, and thus may be more appropriate for use with children. Two electrodes were placed on the neck about 3 cm apart and two electrodes were placed vertically along the spine on the mid-lower back, also about 3 cm apart. A portion of the child's chair seat-backing was removed to decrease potential pressure interference that might occur on the impedance cardiography electrodes. Each electrode was connected to the impedance cardiograph (Model HIC 2003 purchased from the James Long Company, Caroga Lake, NY) via a lead. The impedance cardiograph

measures obtained were (1) the basal transthoracic impedance (Z_0), (2) the first derivative of pulsatile changes in transthoracic impedance ($d_z d_t$), and (3) delta *Z* (Berntson et al., 2004; Kubicek, Patterson, & Witsoe, 1970).

The analysis program created by the James Long Company required a scoring technique to be conducted prior to the calculation of PEP. Marks were placed at the onset of the R-wave and at the spot of injection. This scoring technique was performed on the average of the readings for each event (e.g., the average R-wave during the 3 min baseline was used to calculate the PEP for baseline). The manual approach allowed for the detection of outliers and validity checks; an experienced researcher performed the PEP calculations. Once manual scoring had been completed, the time between the onset of the R-wave and spot of ejection was calculated.

Demographic data—Children's demographic data including sex, SES, and race were obtained via parental report. Prior to inclusion in the study, potential participants were asked several questions over the phone: whether they had a boy or girl in the specified age range; the ethnic background of the family; and parents' current employment and education attainment. Parental employment and education were used to compute SES via the Hollingshead (1975) criteria.

Data Analysis

We used latent growth modeling to examine intra- and interindividual change in RSA and PEP across three assessments at ages 8, 9, and 10. Analyses were conducted using SPSS 17 and AMOS 17. Our primary research questions involved defining the initial status (intercepts) of RSA and PEP, their change over time (slopes), and their associated variances. Thus, the initial unconditional growth model included latent intercepts and slopes simultaneously estimated for RSA and PEP (see Curran & Willoughby, 2003; Keiley, Martin, Liu, & Dolbin-MacNab, 2005). Because data were collected at only three time points, we estimated only linear growth for the two domains of development (Burchinal, Nelson, & Poe, 2006). Unconditional and conditional model fit was assessed with the root mean square error of approximation (RMSEA), a common measure of fit (Hu & Bentler, 1995). RMSEAvalues of .08 or less indicate adequate model fit with lower values indicating progressively better fit (Browne & Cudek, 1993).

In addition to defining the average initial levels and change over time in RSA and PEP, we were also interested in predicting variability in these latent constructs. A conditional growth model was used to answer our secondary research questions of whether demographic characteristics and the interaction between race and sex are predictors of initial levels and change in RSA and PEP. This conditional model included demographics and child characteristics (sex, race, SES, age, and BMI) and the race by sex interaction. Simple slopes were plotted at ±1 *SD* for continuous variables or at the appropriate value for categorical variables (e.g., 0 for EA children and 1 for AA children; Aiken & West, 1991). In addition to using traditional *p*-values of .10, .05, and .01 to indicate marginally significant and significant values, R^2 and change in R^2 (ΔR^2) were used as measures of effect size. These measures can be compared to Cohen's (1988) criteria for comparing effect sizes. Accounting

for 10% of variance (i.e., $R^2 = .10$) may be considered a small effect, $R^2 = .30$ may be considered a medium effect, and $R^2 = .50$ may be considered a large effect. Missing data were handled with the default option in AMOS, full information maximum likelihood (FIML) estimation. In FIML, missing data are not imputed; all available data are simply used to estimate model parameters. FIML estimation assumes that data are missing completely at random (MCAR) or missing at random (MAR; Acock, 2005).

RESULTS

Missing Data

Proportions of missing data in the current study ranged from as low as 3.5% to as high as 31.5% (age 10 RSA and PEP). Little's MCAR chi-square test indicated that the missing data were not MCAR, $\chi^2(162) = 229.14$, $p < .01$. Analyses of study attrition (using the Missing Value Analysis in SPSS and independent samples *t*-tests of variables based on study attrition between ages 8 and 10, coded 0 for no and 1 for yes) indicated that children missing physiological data at age 9 had higher BMI. No other study variables were related to study attrition over time. Including variables related to missing data (i.e., BMI) in the substantive analyses corrects for biases in model parameter estimates due to the nonrandom nature of the missing data (Widaman, 2006); thus, BMI was controlled in all models.

Preliminary Analyses

Means, standard deviations, and correlations among all study variables are presented in Table 1. As shown in the table, within domain measures (i.e., repeated measures) for RSA and PEP were highly correlated at all three time points. This indicated that there was considerable stability in these respective repeated measures. Boys had higher PEP during all three time points, as did children who were older at the initial age 8 assessment. Higher initial BMI was related to higher age 10 PEP. AA children had higher RSA at ages 8 and 9 than EA children. Lower SES was related to lower RSA at age 10. Finally, although we oversampled to include AA and EA children across a wide range of SES, AA children still had lower SES.

Unconditional Growth

Our unconditional growth model included the repeated measures of RSA and PEP. Specific factor loadings on the latent intercepts and slopes were used to establish the time metric (Biesanz, Deeb-Sossa, Papadakis, Bollen, & Curran, 2004). The intercept was set to represent initial status at age 8 and the slope was set to represent change over time from that point in 1 year increments (intercept factor loadings of 1, 1, 1, and slope factor loadings of 0, 1, 2).

A model uniquely estimating all error variances and covariances among latent variables was tested first. In order to arrive at the most parsimonious unconditional model, we considered whether freely estimating the error variances of the repeated measures was necessary (Duncan & Duncan, 2004). Constraining these error variances to be equivalent within (not across) repeated measures did not significantly alter model fit as assessed by change in χ^2 and degrees of freedom, so this more parsimonious model with equivalent error variances

was retained. Latent intercepts and slopes were allowed to covary, with the exception of the slope of PEP (discussed below). This unconditional model fit the data well [$\chi^2(14) = 19.07$, RMSEA = .037, $p = .16$] and indicated that the intercept of RSA was positively related to the intercept of PEP ($r = .21$, $p = .03$); children with higher initial (age 8) RSA were found to have higher PEP.

Table 2 presents the unconditional growth for RSA and PEP. RSA exhibited significant variability (i.e., children had a wide range of initial RSA values). The slope of RSA was not significant. Thus, the average change over time was positive but not different from zero, indicating continuous development (i.e., no significant group level change over time). Additionally, there was marginally significant variability in the slope of RSA ($p = .09$), indicating that children may be changing at significantly different rates.

PEP exhibited significant variability in the intercept (i.e., a wide range of initial PEP values). The slope for PEP was positive and significant, indicating discontinuity (significant group level change through time; Bornstein & Suess, 2000). There was not, however, significant variability in the slope of PEP ($p = .84$). This finding indicated that although children had many different starting values, they were all changing at essentially the same rate. Variability is necessary for prediction; because there was no significant variability in how children's PEP changed over time, it was not possible to predict the slope in the conditional analyses (i.e., the latent slope was included in the conditional analyses but it was not the subject of prediction).

Conditional Growth

The conditional model used the latent intercept and slope of RSA and latent intercept of PEP from the repeated measures of RSA and PEP as outcome variables. Because the slope of PEP did not show significant variability, it was not used as a dependent variable in the model. All covariates were used to simultaneously predict the intercept and slope of RSA and the intercept of PEP. Notably, when predicting the slope over time for a variable, we implicitly ask whether the predictor interacts with time (Curran, Bauer, & Willoughby, 2004), so that, for example, we test whether boys and girls have different rates of change in RSA or PEP. With time as a main effect, it is possible to plot and test simple slopes over time for boys, girls, or any other variable of interest at specific levels (in the case of continuous predictors).

Parameter estimates and ΔR^2 for the conditional model are presented in Table 3. In comparison to EA children, AA children had significantly higher initial levels of RSA. This group difference accounted for 12% of the variance in initial RSA. No other variable significantly predicted initial RSA levels. Race also predicted the slope of RSA over time ($\Delta R^2 = .13$). This indicated that while AA children had initially higher RSA, the slopes over time for RSA of EA and AA children were significantly different from one another. Thus, overall EA children had lower initial RSA but exhibited a significant increase over time while AA children had higher initial RSA but did not show significant change in their RSA over time (Fig. 1). Additionally, SES was marginally related to the slope of RSA, indicating that children from higher SES backgrounds showed less positive increases in RSA over time (not figured). Child age was marginally related to the slope of RSA, indicating that children

who were older at Time 1 showed less positive growth in RSA over time. The full model accounted for 31% of the variance in the slope of RSA with the largest amount of variance being accounted for by race-related effects.

Boys exhibited significantly higher initial levels of PEP, as did AA children. The interaction between race and sex, however, was not significant. Children who were older at Time 1 also exhibited higher initial PEP. The total model accounted for 17% of the variance in PEP at age 8.

DISCUSSION

Despite the interest in ANS measures as predictors of children's adjustment (e.g., Beauchaine et al., 2007; El-Sheikh et al., 2009), there has been comparatively little developmental research on ANS measures in childhood. Study of these indexes is important because each has been linked to child adaptation, and each is thought to offer insight into the substrates of central nervous system function. Furthermore, because RSA and PEP measures are examined as correlates and intervening variables linking environmental processes and child adaptation (e.g., Calkins, Graziano, Berdan, Keane, & Degnan, 2008; Cummings et al., 2009), it is imperative to understand their developmental course in childhood and individual differences associated with their development. The purpose of the current study was to fill important gaps in knowledge by investigating continuity, stability, and variability in children's RSA and PEP over 3 years in a community sample at ages 8, 9, and 10 through latent growth modeling. Additionally, we investigated whether demographic characteristics predicted individual differences in initial levels and change over time in children's RSA and PEP.

First, our results indicated that children's RSA over time was continuous (i.e., no significant group level change), and PEP over time was discontinuous (i.e., increased significantly over time). Other studies indicate that both RSA and PEP seem to increase early in children's lives (e.g., Alkon et al., 2003; Marshall & Stevenson-Hinde, 1998) and may level off by late childhood or adolescence (Salomon, 2005), a supposition that was only partially supported by our findings (i.e., RSA did not increase but PEP did). Consistent with other studies sampling children or adolescents (e.g., El-Sheikh, 2005; Matthews et al., 2002; Salomon, 2005), we found that both RSA and PEP showed significant stability over time. We also found marginally significant variability in how children's RSA changed over time (i.e., some children increased while others decreased), but no evidence of significant variability in how children's PEP changed over time (i.e., all children changed in essentially the same way). Compared to other studies, differences in our findings may be attributed to the developmental time frame being assessed; this is one of a very few studies that links the gap between research conducted with younger (e.g., Bornstein & Suess, 2000) and older children or adolescents (Matthews et al., 2002; Salomon, 2005). Biological-developmental processes occurring at the transition to adolescence may help to explain these findings. It is known, for example, that hypothalamic–pituitary–adrenal (HPA) axis activity is negatively related to RSA (e.g., Blair, Peters, & Granger, 2004) and increases in HPA axis activity are positively related to pubertal status (Gunnar, Wewerka, Frenn, Long, & Griggs, 2009). Clearly, a more

complete understanding of developmental biopsychology processes will require future research to consider multiple biological systems and their reciprocal influences.

The secondary study aim was the prediction of individual differences in RSA and PEP trajectories over development. Race-related effects accounted for a moderate amount of variance in initial levels of RSA and PEP and in the growth of RSA. Specifically, EA children had lower initial RSA and PEP than AA children. However, over development, RSA increased for EA but not AA children. These findings expand upon prior studies' investigations of race effects in RSA and PEP activity, which have tended to find no differences between groups (Matthews et al., 2002; Salomon, 2005). It is possible that our findings were due to having a larger sample than other studies, and thus greater power to detect effects. Very few studies have explicitly tested race differences in the development of resting RSA or PEP, and such differences should be viewed as tentative pending replication and expansion across a wider context of biological and environmental contributors to the development of multiple physiological systems. Children who were older at the initial assessment had higher initial PEP. Sex-related effects were also observed; boys had higher initial PEP than did girls. These age and sex effects are consistent with other literature (e.g., Allen & Matthews, 1997; Matthews et al., 2002).

Results of the current study should be interpreted in the context of its sample, methodology, and limitations. The sample was community-based, thus findings may not generalize to other populations. Specifically, children diagnosed with a chronic physical illness, ADHD, learning disability, or mental retardation were excluded from the study. Additionally, the current sample, while socioeconomically diverse, was composed entirely of EA and AA children. Thus, results may not generalize to children of other races or ethnicities. Consistent with the community-based nature of the sample, relatively few children exhibited clinical or clinical risk levels of internalizing or externalizing symptoms at each time point (usually <15%). Nevertheless, it is possible that symptoms of psychopathology (e.g., depression, aggression) or environmental stressors not included in our model predict some of the unexplained variance in children's initial levels and change over time in RSA and PEP. For example, a rapidly developing area of study, allostatic load, focuses on describing how environmental stress in combination with physiological reactivity in dealing with stressors can influence basal levels of function over an extended period of time (McEwen & Stellar, 1993). A second limitation is the narrow age range investigated. We examined developmental trajectories of RSA and PEP in children in middle childhood ranging in age between 8 and 10 years, which is a relatively small window of time into children's development. Important changes in these indexes of autonomic function are occurring at both earlier (e.g., Bar-Haim et al., 2000) and later time periods (e.g., Salomon, 2005), warranting investigations of ANS activity over larger time frames. Finally, although a number of measures were taken to reduce attrition rates, more than 10% of the participants dropped out of the study at each wave. While attrition was not strongly related to any variables normally associated with selective dropout (e.g., SES), attrition does reduce power to detect significant effects, regardless of its source.

Despite study limitations, findings represent an extension of the knowledge based on the development of RSA and PEP in childhood. Perhaps just as important, however, are the

implications of these findings for research focused on child adjustment and development. While there was marginally significant variability in how RSA changed over time, this was not true of PEP. This suggests that, for at least some individuals, during middle childhood PEP may constitute a stable, biological individual difference characteristic, be relatively invariant over time, and be substantially less likely to be influenced by environmental characteristics in comparison to RSA. In other words, by middle or late childhood, PEP may be more likely to serve as a moderator than a mediator of effects in developmental models concerned with child adjustment in the context of various familial and environmental contexts.

The limitations of the study also point to important future directions for investigation. One obvious and potentially significant area of inquiry is the study of RSA and PEP parameters in children across a wider age range and a more diverse demographic. For example, developmental changes during adolescence may spur growth of RSA and PEP trajectories differentially, resulting in greater variability in patterns of change later in life. Clearly, studies focusing on the development of biological characteristics are important; such investigations may reveal that specific periods of development mark biological sensitivity to environmental influences (Belsky, 2005; Boyce & Ellis, 2005) and help to identify developmental periods in which intervention or prevention efforts may be especially fruitful for children at risk for adjustment problems (Beauchaine, Hong, & Marsh, 2008). A second future direction is the study of the development of RSA and PEP in large-scale studies that incorporate *both* normative-community and clinical samples. Even simple comparisons of developmental trajectories of autonomic function in these groups could offer considerable insight into developmental psychopathology processes. Finally, RSA and PEP reactivity to stressors are clearly relevant to changes in resting autonomic activity over time (McEwen & Stellar, 1993), biological self-regulation, and child adjustment (e.g., Beauchaine, 2001) and are important topics for future longitudinal investigations. Understanding trajectories of sympathetic and parasympathetic reactivity to challenges could also contribute substantially to further understanding of the development of ANS parameters in children. Longitudinal studies in these areas will make important contributions to our understanding of how physiological systems develop, their complex interactions with each other, and during what developmental periods they may be modified through the environment.

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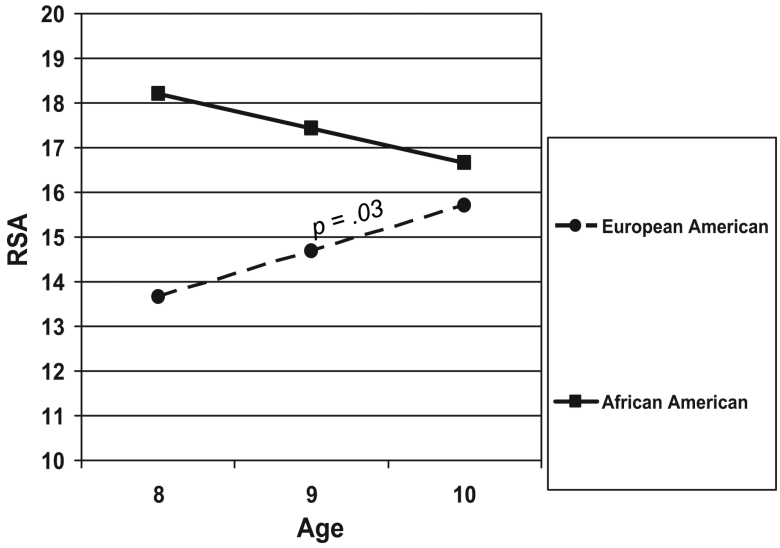

FIGURE 1.

Change in RSA over time for European and African American Children.

Table 1

Descriptive Statistics and Bivariate Correlations among Study Variables

	1	2	3	4	5	6	7	8	9	10	11	*M*	*SD*
1. Sex	—											—	—
2. Race	–.04	—										—	—
3. SES	.04	–.24**	—									.00	.83
4. Age	.20**	–.11	.05	—								98.71	8.64
5. BMI	–.09	.13	–.05	.10	—							19.08	3.88
6. PEP T1	.19**	.07	.01	.22**	.04	—						9.30	1.06
7. PEP T2	.19**	.06	.11	.23**	.12	.40***	—					9.44	1.08
8. PEP T3	.23**	.09	.06	.15*	.17*	.51***	.58***	—				9.91	1.07
9. RSA T1	.02	.28**	–.12	.03	.03	.12	.05	.11	—			15.38	7.91
10. RSA T2	–.04	.16*	–.09	–.04	.05	.10	.06	.14	.63***	—		16.44	8.16
11. RSA T3	.03	.09	–.15*	–.08	.00	.06	.07	.13	.56***	.67***	—	16.17	8.31

SES, socioeconomic status; BMI, body mass index; PEP, preejection period; RSA, respiratory sinus arrhythmia.

Note. Females were coded as 0 and males were coded as 1. European Americans were coded 0 and African Americans were coded as 1. SES is standardized. Age is given in months.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

Table 2

Unconditional Growth of RSA and PEP

Domain	Intercept (*SE*); Variance (*SE*)	Slope (*SE*); Variance (*SE*)
RSA	15.48* (.50); *42.29** (*7.56*)	.41 (.27); *2.67*† (*1.44*)
PEP	9.25* (.07); *.53** (*.08*)	.31* (.04); *.01* (*.03*)

SE, standard error; RSA, respiratory sinus arrhythmia; PEP, preejection period.

Note. Variance estimates and standard errors are in italics.

† $p < .10$.

* $p < .01$.

Table 3

Parameter Estimates, Standard Errors (in Parentheses), and ΔR^2 for Conditional Growth of RSA and PEP

	RSA		ΔR^2 RSA		PEP		ΔR^2 PEP	
	Intercept	**Slope**	**Intercept**	**Slope**	**Intercept**	**Slope**	**Intercept**	**Slope**
Conditional mean	13.51** (.85)	1.04* (.47)	—	—	8.95** (.10)	.29** (.04)	—	—
Predictors								
Sex	.74 (1.20)	.19 (.66)	.00	.00	.42** (.14)	—	.06	
Race	5.12** (1.40)	–1.80* (.78)	.12	.13	.34* (.16)	—	.03	—
SES	–.35 (.59)	–.57† (.33)	.00	.09	.07 (.07)	—	.00	—
Age	.06 (.06)	–.06† (.03)	.01	.08	.02** (.006)	—	.06	—
BMI	–.03 (.13)	.01 (.07)	.00	.00	.02 (.01)	—	.00	—
Race × sex	–1.09 (1.99)	.03 (1.10)	.00	.00	–.21 (.22)	—	.01	—
Total R^2			.13	.31		—	.17	—

SES, socioeconomic status; BMI, body mass index; PEP, preejection period; RSA, respiratory sinus arrhythmia.

Note. Values are unstandardized (*B*) with standard errors (in parentheses). Females were coded as 0 and males were coded as 1. European Americans were coded as 0 and African Americans were coded as 1.

† $p < .10$.

* $p < .05$.

** $p < .01$.