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The Interaction Between Child Respiratory Sinus Arrhythmia and Early Sensitive Parenting in the Prediction of Children's Executive Functions

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This study investigated the interaction between children's parasympathetic functioning and maternal sensitive parenting behaviors during infancy and toddlerhood in the prediction of children's executive functions (EF) at the age of 5 years. Participants included 137 children and their mothers who were followed from the age of 3 months to 5 years.

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Children's cardiac activity was recorded at rest at multiple times from ages 3 to 36 months, and estimates of respiratory sinus arrhythmia (RSA; a measure of parasympathetic functioning) were calculated. Sensitive parenting was assessed during a mother–child play task at ages 6, 12, 24, and 36 months, and 5 years. Children completed age appropriate EF tasks at the age of 5 years. The link between sensitive parenting during toddlerhood (ages 24 and 36 months) and children's later EF was moderated by children's RSA such that this positive link was evident only among children who had low levels of baseline RSA, and not among those who had high levels of baseline RSA. These findings were obtained while controlling for concurrent sensitive parenting and maternal and child verbal abilities. Results from this study provide evidence for the significant role of biopsychosocial processes in early childhood in the development of EF.

Executive functions (EF) refer to higher order cognitive regulatory processes (i.e., inhibitory control, working memory, and set shifting) that underlie goal-directed behaviors (Friedman et al., 2008). EF are critical to various aspects of children's functioning, including early school achievement, emotion regulation, and social competence (Blair & Razza, 2007; Raver et al., 2011). Although most children exhibit improvements in EF between infancy and early childhood, the etiology of individual differences in these competencies is still not well understood (Bernier, Carlson, & Whipple, 2010; Cuevas et al., 2014). There is evidence that environmental factors, such as early caregiving behaviors, contribute to the consolidation and development of executive functions (Bernier et al., 2010; Blair et al., 2011; Cuevas et al., 2014; Deater-Deckard, 2014). However, little is known about early child vulnerability or protective factors that may modulate these links. According to the biological sensitivity to context (BSTC; Boyce & Ellis, 2005) and differential susceptibility (DS; Belsky, 2005) hypotheses, children with certain physiological profiles may be more vulnerable to negative contextual factors, but may also have greater capacity to benefit from positive environments. Informed by a biopsychosocial perspective, which underscores how early biological underpinnings interact with the child's environment to produce patterns of growth and change of critical skills (Calkins, 2015), this study examines the interplay between children's physiological functioning and mothers' caregiving behaviors in the later development of children's EF. We specifically focus on examining these dynamic processes during infancy and toddlerhood acknowledging that caregiving behaviors in this period play a key role in supporting the emergence of the executive attention network (Swingler, Perry, & Calkins, 2015), laying the foundation for the development of higher order attention abilities (Garon, Bryson, & Smith, 2008).

PARENTING BEHAVIORS AND CHILDREN'S EF

An emerging body of evidence identifies the early caregiving environment as a foundational context for the development of children's EF (Bernier et al., 2010; Blair et al., 2011; Cuevas et al., 2014; Deater-Deckard, 2014). This process is theorized to begin during infancy, when caregivers act as external regulators of infants' physiological rhythms, affect, and attention (Calkins, 2008). The caregiver's ability to appropriately interpret and respond to the infant's signals and redirect his or her attention in ways that maintain optimal levels of arousal contributes to the infant's ability to integrate these experiences into an emerging set of self-regulatory skills (Calkins, Graziano, Berdan, Keane, & Degnan, 2008; Swingler et al., 2015), which lay the foundation for higher order cognitive control in early childhood (Posner & Rothbart, 1998; Swingler et al., 2015). Between the ages 3 and 5 years, the emergence of the executive attention network enables children to resolve increasing levels of conflict, for example, holding a rule in mind, detecting mismatch between dominant and subdominant responses, and responding according to this rule (Posner, Rothbart, Sheese, & Voelker, 2014). Thus, the toddlerhood period which precedes the emergence of the executive attention network may be a period in which parental behaviors that support children's attempts to practice their emerging cognitive control skills are particularly important (Camerota, Willoughby, Cox, & Greenberg, 2015). Indeed, there is empirical evidence that parenting behaviors during infancy and toddlerhood are related to children's EF (Blair et al., 2011; Cuevas et al., 2014; Deater-Deckard, 2014; Kraybill & Bell, 2013; Rhoades, Greenberg, Lanza, & Blair, 2011). For example, maternal positive affect during an interaction with the infant at the age of 10 months predicted both preschool and postkindergarten EF skills (Kraybill & Bell, 2013). Furthermore, a composite of positive parenting behaviors (i.e., sensitivity, positive regard, and appropriate stimulation for development) across 7–24 months of age positively predicted children's EF performance at 3 years of age (Blair et al., 2011; Rhoades et al., 2011).

Interestingly, findings suggest that the effects of parenting on children's EF may differ as a function of developmental period (Camerota et al., 2015; Holochwost et al., 2016; Landry, Miller-Loncar, Smith, & Swank, 2002). A recent study with the current sample found that for European American families, sensitive parenting during toddlerhood was positively related to EF at the age of 5 years, while parenting during infancy was not (Holochwost et al., 2016). Furthermore, Landry et al. (2002) found that mothers' verbal scaffolding at the age of 3 years influenced children's executive processing abilities at the age of 6 years, while four-year maternal scaffolding behaviors did not (Landry et al., 2002). In addition, the consideration of developmental timing may be particularly important for children at risk. For example, findings from a recent study revealed that sensitive parenting behaviors in infancy (6 and 15 months) and toddlerhood (24 and 36 months) were similarly associated with higher levels of children's EF at the age of 48 months (Camerota et al., 2015). However, children born at low birthweight (i.e., high-risk group for EF deficits) were particularly affected by parenting during toddlerhood (and not infancy) such that children born at low birthweight performed at similar levels to normal birthweight infants if exposed to highly sensitive parenting during toddlerhood only (Camerota et al., 2015). Taken together, these findings imply that children may be particularly susceptible to environmental support at a time period in which a specific skill is rapidly emerging and further highlights the need to consider differential timing effects when examining the link between parenting behaviors and children's EF.

INFANT PHYSIOLOGICAL FUNCTIONING, PARENTING, AND THE DEVELOPMENT OF EF

Accumulating evidence suggests that children's early behavioral and physiological functioning interacts with environmental experiences to shape children's emerging cognitive abilities (Blair, 2002; Obradović, Bush, Stamperdahl, Adler, & Boyce, 2010). The BSTC (Boyce & Ellis, 2005) and DS (Belsky, 2005) hypotheses both suggest that individuals with heightened behavioral or physiological reactivity are likely to be more susceptible to adversity but also more sensitive to enriching environmental experiences. Recent literature has examined this notion in the prediction of children's EF using measures of children's temperamental qualities as markers of sensitivity or susceptibility. For example, maternal attention-maintaining behaviors predicted higher levels of conflict inhibition (an element of EF) but only for children who had inhibited or exuberant temperaments at the age of 24 months (Conway & Stifter, 2012). Similarly, children with more difficult temperament, who were exposed to low maternal positivity at 12 months, had the lowest inhibitory control scores, but these children actually performed the best when experiencing positive maternal behaviors (Rochette & Bernier, 2016). Together, these findings suggest that children with highly reactive temperamental profiles may particularly benefit from maternal behaviors that allow them to organize and control their attentional focus, supporting the development of adaptive EF (Conway & Stifter, 2012). However, these findings are limited to behavioral measures of reactivity. This study aimed to test this notion using a BSTC perspective (Boyce & Ellis, 2005) by examining a physiological measure of susceptibility to environmental experiences (i.e., baseline RSA) in the development of EF.

Child RSA

One physiological measure that has received much attention in this literature because of its association with attentional and emotional processes is respiratory sinus arrhythmia (RSA), the variability in heart rate that occurs at the frequency of breathing, which indexes parasympathetic control of the heart via the vagus nerve (Porges, 2007). It is theorized that high baseline RSA represents greater myelinated vagal control of the heart, which enables the individual to maintain homeostasis in the face of situational change by allowing attention to shift from internal processes to external demands (Calkins, Propper, & Mills-Koonce, 2013; Porges, 2007). Overall, research supports the notion that higher levels of baseline RSA reflect more effective regulation of attention and emotion during early childhood, including higher soothability and attentional control, higher positive emotional reactivity during play and lower negative reactivity, and better EF (Calkins, 1997; Feldman, 2009; Huffman et al., 1998; Marcovitch et al., 2010; Richards, 1987).

In addition, it is theorized that during challenge RSA tends to decrease (i.e., RSA withdrawal) to support active coping, and increased heart rate, during environmental challenge (Calkins & Keane, 2004). RSA withdrawal has been linked to various social–emotional outcomes (e.g., Calkins & Keane, 2004; Graziano & Derefinko, 2013; Vasilev, Crowell, Beauchaine, Mead, & Gatzke-Kopp, 2009); however, findings on the relations between RSA withdrawal and children's cognitive functioning and control are mixed (Graziano & Derefinko, 2013), possibly nonlinear (Marcovitch et al., 2010) and may depend on task context or task-specific demands (Sulik, Eisenberg, Spinrad, & Silva, 2015). Although it is important to clarify the relationship between RSA withdrawal and EF, the current investigation will focus on baseline RSA as a first step in understanding this complex relationship. We view baseline RSA as an index of individuals' attentional abilities and awareness of their environment (Marcovitch et al., 2010) and thus a potential susceptibility marker to parenting in prediction of developing child EF.

Although individual differences in children's baseline RSA have been shown to moderate the effects of the caregiving environment on children's adaptation (Bagner et al., 2012; Conradt, Measelle, & Ablow, 2013; Eisenberg et al., 2012; Hastings & De, 2008), the direction of this moderating effect has not been consistent across studies. For example, two studies have found that infants with high baseline RSA were more strongly affected by the quality of their caregiving environments in the development of early aggression and behavior problems compared to infants with low baseline RSA (Conradt et al., 2013; Eisenberg et al., 2012). These findings support the view that infants with high baseline RSA may have an early propensity for heightened behavioral reactivity, which under supportive environments may be canalized toward positive behavioral adaptation, but under negative environments may lead to the consolidation of maladaptive coping strategies that portend behavior problems later in development (Conradt et al., 2013).

In contrast, there is some empirical support that low baseline RSA reflects greater susceptibility to environmental influence. For example, parents' emotion socialization strategies were more strongly associated with children's social competence, internalizing, and externalizing problems for children with low baseline RSA than for children with high RSA (Hastings & De, 2008). Furthermore, children with low baseline RSA showed greater improvements in disruptive behavior following a parent–child interaction therapy program than children with high baseline RSA (Bagner et al., 2012). These findings are consistent with the idea that infants with low baseline RSA are characterized by low attentional and emotional regulatory skills, making them more strongly dependent on and affected by external regulation provided by their caregivers (Hastings & De, 2008).

CURRENT STUDY

To the best of our knowledge, this study is the first to consider the interactive effects of baseline RSA and parenting behaviors on the development of later EF. We specifically focus on children's baseline RSA and parenting throughout the first 3 years of life, a time period in which the rapid maturation of the prefrontal cortex lays the foundation for the emergence of higher order cognitive processes later on in the preschool years (Garon et al., 2008). Assessing parenting behaviors in both infancy and toddlerhood also enables us to examine whether parenting is differentially related to EF between these two developmental periods, a question that has important implications for designing and implementing intervention programs to support the development of EF. We hypothesized that the link between maternal sensitivity and children's EF would be moderated by child baseline RSA. Given inconsistent previous findings regarding the nature of children's physiological susceptibility to their care-giving environments (Bagner et al., 2012; Conradt et al., 2013; Eisenberg et al., 2012; Hastings & De, 2008), we suggested two competing hypotheses for the direction of the moderation. Consistent with the BSTC hypothesis (Boyce & Ellis, 2005; Conradt et al., 2013), children with high baseline RSA may be more susceptible to parenting influences: they may exhibit the lowest EF when exposed to low levels of sensitive parenting, but the highest EF when exposed to high levels of sensitive parenting compared to children with low RSA. On the other hand, consistent with the notion that children with low RSA are in greater need of parental support to regulate attentional and emotional processes (Bagner et al., 2012; Hastings & De, 2008), children with low baseline RSA may be more strongly affected by sensitive parenting compared to children with high RSA in the development of EF. We also proposed a developmental timing hypothesis for the interaction between RSA and parenting. Based on previous research (e.g., Camerota et al., 2015), we hypothesized that baseline RSA would interact with sensitive parenting specifically during the toddlerhood period, a time in which EF begin to emerge, and not during infancy. Because our goal was to better understand the direct and interactive influences of sensitive parenting and parasympathetic functioning in *early* childhood on children's EF, later measures (age 60 months) of mothers' verbal ability, children's verbal ability, and sensitive parenting were included as covariates in all analyses.

METHODS

Participants

Participants in this study were a subsample of The Durham Child Health and Development Study (DCHDS), a longitudinal study of 206 socioeconomically and racially diverse families living in and around a midsized southeastern city. Families were recruited at 3 months of infants' age from a largely urban community via fliers and postings at birth and parenting classes, as well as through phone contact via birth records. The study included only infants who were healthy, full-term, and born without significant complications. Infant race was determined by the mother or primary caregiver; income status was assessed based on size of the family in relation to their household income in accordance with the 2002 federal poverty guidelines. Demographic information was collected during the first visit at 3 months of age and updated at each subsequent visit. Observational and self-report data were collected during home and laboratory visits that occurred when infants were 3, 6, 12, 18, 24, 30, 36, and 60 months old. The subsample used in the current study included families in which the participating child was administered an EF battery at the age of 60 months (n = 137). In this subsample, 48% of the children were female, 58% were African American (41.6% were European American), and approximately 42% of the sample was low income (below 200% of the poverty level). This subsample did not differ significantly from the complete sample on any of these variables.

Measures

Sensitive parenting

Mothers and their infants were observed during a play task when the infants were 6, 12, 24, and 36 months of age. When children were 6 and 12 months old, a set of standard toys was arranged on a blanket and the mothers were asked to play with their infants as they normally would on a typical day. At 24 and 36 months, mothers and their children were asked to complete a puzzle task during which they were presented with three puzzles of increasing difficulty. The mother–child play task at each time point was structured to last 10 min, and all interactions were video-taped and later viewed by trained and reliable coders who rated the interactions using 5-point subscales to measure parental sensitivity, detachment, stimulation of development, positive regard, and animation (measures adapted from the NICHD Early Child Care

Research Network, 1997). Intraclass correlations (ICC) were calculated as estimates of interrater reliability and coders demonstrated high reliability at 6 (ICC = .87), 12 (ICC = .88), 24 (ICC = .92), and 36 (ICC = .92) months.

Similar measures have been used by the NICHD Study of Early Child Care (1997), the Family Life Project (Blair et al., 2011), and other reports based on the current DCHDS study sample. Previous factor analysis supported the creation of a composite measure of maternal sensitivity that included measures of sensitivity, detachment (reverse scored), stimulation of development, positive regard, and animation. An infancy sensitive parenting measure was created by computing an unweighted average of parenting at 6 (M = 3.32, SD = .82; range: 1–5) and 12 (M = 3.14, SD = .77; range: 1–5) months (r = .64, p < .001). Similarly, a toddlerhood sensitive parenting measure was created by computing an unweighted average of parenting at 24 (M = 4.57, SD = 1.21; range: 1–7) and 36 (M = 4.50, SD = 1.13; range: 1–7) months (r = .49, p < .001).

Respiratory Sinus Arrhythmia

Respiratory sinus Arrhythmia (RSA) was measured as the variation in interbeat intervals (IBI; the length of time between heart beats) linked to respiration and was used as a specific index of parasympathetic functioning of the ANS. RSA was measured at multiple time points, including ages 3, 6, 12, 18, 24, 30, and 36 months. The Mini Logger 2000 was used to collect IBIs (Mini Logger 2000; Mini-Mitter Corp., Bend, OR, USA). Researchers placed two electrodes on the child's chest at the beginning of the assessment for a 2–4 min measure of baseline cardiac function while at rest. Electrodes were connected to a preamplifier which transmitted IBIs to a monitor. Data files were then transferred to a computer for artifact editing and analysis. The files were edited by two reliable researchers using MXEdit software (Delta Biometrics, Bethesda, MD, USA). Porges' (U.S. Patent No. 4,510,944, 1985) method of calculating RSA was used, in which a moving polynomial filter is used to remove frequencies lying outside a normal physiological range, and the estimate of RSA is reported in units of $\ln(\text{ms})^2$. RSA was calculated every 15 sec for the baseline period and the mean of epochs was used to represent early parasympathetic functioning.

At each time point, between 22% (n = 31) to 56% (n = 73) of the children had missing RSA data. Reasons for missing data included heart rate monitor problems or failure, collected heart rate data contained too many artifacts to use due to movement or removal of equipment by infant, or children's adverse reaction to electrode placement. RSA estimates were positively related between time points (r ranged between .16 and .53), with the exception of RSA from 12 and 24 months (r = –00) and the 12 months estimate was therefore removed from the analysis in the current study. Additionally, RSA measures at the ages of 3, 6, 18 and 24 months were significantly lower than RSA at the age of 36 months, $F(5, 20) = 5.42$, p = .003. We utilized RSA data from all time points (except the 12 months measure that was excluded) to create a child baseline RSA measure by creating an unweighted average of all available time points for each child. Because RSA at 36 months was significantly higher than RSA at 24 months and below, we only included children who had at least one RSA measurement from the ages 3–24 months, and at least one RSA measurement from the ages 30 and 36 months, n = 104. Means, standard deviations of the RSA measures by age and the child RSA composite score are presented in Table 1. Children with missing RSA data (n = 33) did not differ from children without missing data in terms of child sex,

TABLE 1
Mean and Standard Deviations for Child RSA Measures by Age

	M	*SD*	*Range*
RSA 3 m	3.41	.96	1.13–6.28
RSA 6 m	3.65	.88	1.63–5.77
RSA 12 m	3.67	.93	1.75–6.28
RSA 18 m	4.50	1.57	2.37–9.41
RSA 24 m	4.92	1.49	2.46–9.61
RSA 30 m	4.86	1.40	1.92–8.36
RSA 36 m	5.34	1.25	2.72–8.41
Child RSA composite	4.46	.94	2.44–6.95

Note. The child RSA composite included an unweighted mean average of RSA values from ages 3, 6, 18, 24, 30, and 36 months.

race and family income group. Children were divided into high- and low-RSA groups based on the median split (*Med* = 4.45), consistent with previous research on RSA in early childhood (Feldman & Eidelman, 2009).

Child EF

Children's executive functioning was measured using three widely used tasks that were administered to the child when he or she was 60 months old. Children completed the day/night task (DNT; Gerstadt, Hong, & Diamond, 1994), the backward digit span task (BS; McCarthy, 1972), and the Flexible Item Selection Task (FIST; Jacques & Zelazo, 2001). The DNT requires children to respond counter to the prepotent tendency of saying "day" when a card depicting a sun is presented and saying "night" when a card with a moon is presented. A correct response is marked when the child says the opposite of what the card depicts. Practice trials were administered until the child successfully labeled each card once. Upon completion of the practice trials, children were shown 10 "night" and 10 "day" cards. The proportion of correct trials (of a maximum possible of 20 trials) was used as the analysis variable for the DNT (M = .78, SD = .25; range: 0–1). While the scoring of the DNT task is straight forward (did the child say "day" or "night), because children responded at a rapid speed and often mumbled or answered quietly, there was a chance for error in live scoring of children's responses. Thus, the task was video-taped and subsequently scored. Two coders independently scored 30% of the participants and intercoder agreement was 98%. The internal consistency of the DNT was α = .92.

The BS is a measure of working memory span and requires children to manipulate information stored in memory. The task is comprised of two forward series of numbers and two backward series of numbers and the children are asked to repeat the numbers depending on the directions for that series. Children's responses were live scored, and the analysis variable was the number of digits successfully reported during the backward digit span (M = 2.15, SD = 1.25; range: 0–4). The internal consistency of the DS was α = .84.

The FIST is an assessment of cognitive flexibility and is assessed by asking children to identify two of the three objects that are similar along one dimension (i.e., color) but then to shift to identify two of three objects that are similar along as second dimension (i.e., size). Upon completion of practice trials, children were presented with 12 trials in which they were given three items that varied by size, shape, number, or color. Children's responses were live scored, and the analysis variable was the number of correct responses divided by the total number of trials (M = .40, SD = .32; range: 0–1). The internal consistency of the FIST was α = .86.

Previous factor analytic work with this sample suggests that the 3 EF tasks load on one latent EF factor in a structural equation framework (Nesbitt, Baker-Ward, & Willoughby, 2013). Thus, an unweighted mean of the z-standardized scores on the three measures was used in the current application.

Covariates

Child's race and *sex* were reported by the child's primary caregiver at the time of recruitment. *Family income-to-needs ratio* was determined using the mother's or primary caregiver's report of the total family yearly income at the first grade visit, the size of the family, and the 2003 federal poverty guidelines. *Maternal verbal ability* was measured from the verbal scale from the Wechsler Adult Intelligence Scale–Third Edition (WAIS–III; Wechsler, 1997). *Children's verbal ability* was measured using the receptive language scale from the Wechsler Preschool and Primary Scale of Intelligence—Third Edition (WPPSI-III; Wechsler, 2002) which was administered during the 60-month laboratory visit. *Concurrent sensitive parenting* was assessed during a mother–child structured play task completed at the 60-month laboratory visit. During the 60-month laboratory visit mothers and their children completed two interactive tasks which lasted a total of 15 min. The first task involved building towers with wooden blocks and the second was a card game called "Slap Jack" in which mothers and their child competed to win cards. Interactions were video-taped and coded by a team of reliable coders. Interrater reliability for sensitive parenting at 60 months was high (ICC = .94).

Among the 137 children who completed the EF battery, the percent of missing values was 9.5% (n = 13) for the concurrent sensitive parenting measure, 2% (n = 3) for the infancy sensitive parenting measure, 2.9% (n = 4) for the toddlerhood sensitive parenting measure, and 2.9% (n = 4) for mothers' WAIS scores. Children with missing data did not differ from children without missing data in terms of child sex, child race, or family income group.

Analytic Strategy

To account for missing data, we utilized a full maximum likelihood (FIML) estimator for all analyses. This technique is considered appropriate when data is missing at random and is preferable to the more typical ordinary least squares regression because estimates are produced using all information that is available for each participant (Bollen & Curran, 2006). Analyses were conducted using AMOS 23 software. The primary analytic strategy involved estimating a series of regression models. Continuous predicators were standardized prior to the creation of the interaction terms to aid interpretation (Schielzeth, 2010). In the first step, covariates (i.e., child race, child sex, family income-to-needs ratio, maternal and child verbal ability, and concurrent 60-month sensitive parenting) were entered into the model. Next, the main effect associations between model predictors (i.e., child RSA, infancy and toddlerhood sensitive parenting) and children's EF at the age of 5 years were tested. Third, the two-way interactions between child RSA and sensitive parenting in infancy and toddlerhood were entered into the model. Significant interactions were probed using the online utility and computational tools for probing interactions in differential susceptibility research (Roisman et al., 2012).

To ascertain whether the interactions involving infant RSA and early sensitive parenting are consistent with the BSTC/DS hypotheses we followed analytic recommendations suggested by Roisman et al. (2012). Specifically, significant interactions involving child RSA were probed by estimating simple slopes at ±2 *SD* of sensitive parenting, followed by regions of significance (RoS) analysis. A BSTC/DS was inferred when the association between the moderator and the outcome was significant at both the low and high ends of the distribution of the maternal variable. We also used the *Proportion of the Interaction* (PoI) index for identifying differential susceptibility effects. The PoI expresses the proportion of the total interaction that is represented on the right side of the crossover point for the interaction (i.e., the area for which the effect of the independent variable on the dependent variable is "for better"). PoI values close to 0.50 suggest evidence for differential susceptibility.

RESULTS

Preliminary Analyses

Table 2 presents the bivariate correlations, means, and standard deviations for the model covariates and variables of interest. Given our moderation hypotheses, we also examined the correlations between the predicting sensitive parenting variables and children's EF separately for children with high and low RSA. The correlations between infancy sensitive parenting and children's EF were overall similar between children with low and high RSA ($r = .27$, $p = .05$; $r = .23$, $p = .10$, respectively). On the other hand, the correlations between toddlerhood sensitive parenting and children's EF were stronger for children with low RSA ($r = .55$, $p < .001$) than for children with high RSA ($r = .24$, $p = .08$). The differences between the correlation coefficients approached significance ($z = 1.85$, $p = .06$).

Regression Models

We estimated a series of regression models to test the direct and interactive associations between child RSA and sensitive parenting in the prediction of children's EF at the age of 5 years (Table 3). First, child EF was regressed on model covariates ($R^2 = .19$). Only child verbal abilities was a significant predictor of child EF ($\beta = .23$, $p = .01$). Next, in model 2 child RSA and the predicting sensitive parenting variables were added. In this model, child verbal abilities ($\beta = .23$, $p = .01$) continued to be the only significant predictor of child EF ($R^2 = .24$). Finally, in model 3 interaction terms were entered, and a significant interaction was observed between child RSA and toddlerhood sensitive parenting ($\beta = -.38$, $p = .03$) in the prediction of children's EF. Additionally, there was a significant direct effect of toddlerhood sensitive parenting ($\beta = .50$, $p = .008$) and child verbal abilities ($\beta = .21$, $p = .03$) on child EF. The final model accounted for 27% of the variance in children's EF (see Table 3).

Because of the significant correlations found between race, sensitive parenting, and EF, we also examined whether the interaction between child RSA and toddlerhood

TABLE 2
Zero-Order Bivariate Correlations Between Study Variables and Covariates

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1. Child Race (0 = European-American)	–									
2. Child Sex (0 = male)	.08	–								
3. Household Income-to-needs Ratio	–.36***	–.05	–							
4. Mother Verbal Abilities	–.53***	–.06	.51***	–						
5. Child Verbal Abilities (60 m)	–.50***	.00	.41***	.41***	–					
6. Concurrent Sensitive Parenting (60 m)	–.46***	–.06	.25**	.42***	.29***	–				
7. Child RSA (3, 6, 18, 24, 30, and 36 m)	.17′	.00	–.23*	–.23*	–.28**	–.19*	–			
8. Infancy Sensitive Parenting (6 and 12 m)	–.46***	.03	.40***	.53***	.33***	.35***	–.23*	–		
9. Toddlerhood Sensitive Parenting (24 and 36 m)	–.46***	.07	.40***	.57***	.50***	.47***	–.11	.72***	–	
10. Child EF (60 m)	–.30***	–.00	.30***	.30***	.37***	.25***	.00	.26**	.40***	–
Mean	–	–	3.84	11.13	11.18	3.57	–	3.24	4.54	.00
Standard deviation	–	–	2.67	3.50	2.80	1.70	–	.74	1.02	.69

Note. ′$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$; m = child age in months.

TABLE 3
Regression Analysis in the Prediction of Children's EF at the Age of 60 months

	Model 1 *β (SE)*	*Model 2* *β (SE)*	*Model 3* *β (SE)*
Child Race	−.04	−.02	−.06
Child Sex	.02	−.00	−.00
Household Income-to-needs Ratio	.12	.13	.10
Maternal Verbal Abilities	.09	.05	.08
Child Verbal Abilities (60 m)	.23*	.23*	.21*
Concurrent Sensitive Parenting (60 m)	.08	.06	.02
Child RSA (3, 6, 18, 24, 30, and 36 m)		.14	.13
Infancy Sensitive Parenting (6 and 12 m)		−.04	−.21
Toddlerhood Sensitive Parenting (24 and 36 m)		.20	.50**
Child RSA × Infancy Sensitive Parenting			.21
Child RSA × Toddlerhood Sensitive Parenting			−.37*
R^2	.19	.24	.27

Note. *$p \leq .05$; **$p \leq .01$.

sensitive parenting differed between African American and European American participants. To that aim, we estimated a model in which child EF was regressed on a three-way interaction between race, toddlerhood parenting, and child RSA. The three-way interaction was nonsignificant ($\beta = -.11$, $p = .66$) indicating that the interaction between child RSA and toddlerhood sensitive parenting did not vary by race.

The significant interaction between child RSA and toddlerhood sensitive parenting was probed at high and low levels of child RSA (Figure 1). The positive association between toddlerhood sensitive parenting and children's EF was significant only for children who had low levels of baseline RSA (simple slope = 0.35, $t = 2.68$, $p = .008$), and not for children who had high levels of baseline RSA (simple slope = −.01, $t = .09$, *ns*). Then, to examine whether this interaction was consistent with the BSTC/DS hypotheses, simple slopes for high (+2*SD*) and low (−2*SD*) levels of early sensitive parenting were estimated revealing that the association between infant RSA and child EF was significant under low [simple slope = .91, $t = 6.97$, $p \leq .001$] but not under high [simple slope = −.53, $t = 1.06$, *ns*] levels of toddlerhood sensitive parenting. RoS indicated that when sensitive parenting scores were below −.08 (slightly below the mean) children with low RSA had significantly lower EF scores at the age of 5 years than children with high RSA. PoI was .25 indicating that the interaction between infant RSA and early sensitive parenting is mostly represented on the left side (low levels) of toddlerhood sensitive parenting.

DISCUSSION

This study investigated the interaction between children's capacity for physiological regulation, indexed by children's baseline RSA, and sensitive parenting behaviors during infancy and toddlerhood in the prediction of EF at the age of 5 years. Because EF are critical for children's school readiness, emotion regulation, and social competence (Blair & Razza, 2007; Raver et al., 2011), it is important to understand how parental behaviors and child psychophysiology interact early in life to support the development of EF.

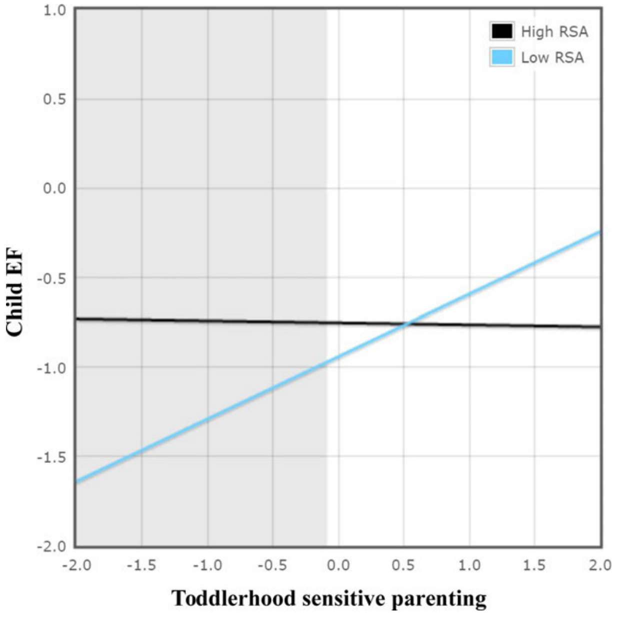

Figure 1 Regions of significance analysis for the interaction between child RSA and toddlerhood sensitive parenting on EF at the age of 5 years. Values of sensitive parenting and child EF scores are standardized values. The shaded area represents the RoS: the values of sensitive parenting for which RSA and EF at the age of 5 years are significantly related.

We found that child RSA moderated the link between maternal sensitive parenting during toddlerhood and later EF. Toddlerhood sensitive parenting was positively related to EF at the age of 5 years only for children who had low levels of baseline RSA in early childhood, and not for children with high levels of baseline RSA. Post hoc RoS analysis indicated that children with low RSA had significantly lower EF when exposed to low levels of maternal sensitive parenting compared to children with high RSA. However, when exposed to higher levels of sensitive parenting children with high and low RSA did not differ in their EF at the age of 5 years. These findings are consistent with previous studies that conceptualized high RSA as a protective factor that buffers children against the effects of environmental adversity (e.g., El-Sheikh, Harger, & Whitson, 2001; El-Sheikh & Whitson, 2006). These studies have shown that children with high baseline RSA were less negativity affected by marital conflict, whereas children with low RSA were found to be more vulnerable, exhibiting more behavioral problems and poorer health in the context of high marital conflict (El-Sheikh & Whitson, 2006; El-Sheikh et al., 2001). Our findings expand this idea beyond socio-emotional development to include a cognitive aspect of development, namely EF. Children with low baseline RSA, which has been associated with lower attentional regulatory capacity (Feldman, 2009; Linnemeyer & Porges, 1986; Marcovitch et al., 2010; Richards, 1987), may be more negatively affected by interactions with caregivers who display low responsiveness to the child's emotional and attentional cues. Low sensitive parenting could include behaviors such as detachment and disengagement with the child, accompanied by lack of developmentally appropriate stimulation, which may be particularly harmful for children who have difficulties focusing their attention. However, in the presence of sensitive parenting that includes behaviors such as appropriate attention focusing and level of stimulation, children with low RSA do not differ from children high RSA in their later EF. This implies that sensitive parenting can be a protective factor for children with inefficient physiological regulation capacities.

The interaction between baseline RSA and parenting in the prediction of children's EF did not fully support the DS hypothesis, because children with low RSA did not outperform children with high RSA when exposed to enriching caregiving environments (i.e., high levels of sensitive parenting). Rather, the interaction was consistent with the diathesis-stress hypothesis (Monroe & Simons, 1991) suggesting that biologically reactive children are particularly vulnerable to stressful experiences (i.e., low levels of sensitive parenting), showing high levels of maladjustment in the context of environmental risk. In corroboration with our findings, previous research examining diathesis–stress versus DS patterns of interactions generally supports diathesis–stress effects of parenting on infants' cognitive functioning (Gueron-Sela, Atzaba-Poria, Meiri, & Marks, 2015; Kochanska, Kim, Barry, & Philibert, 2011; Roisman et al., 2012). Because intellectual abilities (and EF in particular) are strongly genetically determined (Friedman et al., 2008) there may be an upper threshold for cognitive functioning that is predetermined (Gueron-Sela et al., 2015). However, this explanation is currently hypothetical and needs to be tested empirically in future research.

Our findings suggest that sensitive parenting during toddlerhood was the strongest predictor of children's EF at the age of 5, whereas parenting during infancy and concurrent parenting were not significantly related to children's EF, after accounting for demographic covariates. Furthermore, children with low RSA were particularly affected by sensitive parenting behaviors during this developmental period. Consistent with previous studies (Camerota et al., 2015; Landry et al., 2002), these findings suggest that children may be particularly susceptible to environmental support at a time period in which EF is emerging and that children at risk for regulatory difficulties particularly benefit from parental support at this time period. The transition from infancy to toddlerhood is marked by a number of rapid advances in children's mobility, verbal ability, attention skills, and bids for autonomy (NICHD Early Child Care Research Network, 1999). Furthermore, the toddlerhood period is also often characterized by an increase in negativity and oppositional behavior (Keenan & Wakschlag, 2000), making parent–child interactions more challenging during this time period. Because of the relevance of parenting for EF during this time, it is important to support parents' ability to assist toddlers in the process of acquiring emotional and attentional regulatory skills.

The interaction between child baseline RSA and sensitive parenting in the prediction of EF did not differ between European American and African American participants. Although African American families exhibited lower levels of sensitive parenting and lower child EF scores, it seems that children's psychophysiological susceptibility to the caregiving environment operates similarly across racial groups. Nevertheless, the significant correlations that were found between demographic factors (such as race and socioeconomic status), sensitive parenting, and EF highlight the potential that early intervention efforts may have in supporting the development of children's EF in low income minority families.

LIMITATIONS AND CONCLUSIONS

Findings from the current study should be considered in light of the following limitations. First, this study included only baseline measures of RSA, and not measures of RSA withdrawal. Previous research suggests that the relations between RSA withdrawal and EF are complex (Marcovitch et al., 2010; Sulik et al., 2015), and that RSA withdrawal to cognitive versus interpersonal challenges may represent different markers of biological sensitivity to contextual influences that may have different implications for children's functioning (Obradović, Bush, & Boyce, 2011). It is thus essential to further examine the interactive links between RSA withdrawal and parenting in the development of EF while considering withdrawal during different tasks that vary on aspects such as context (e.g., cognitive versus interpersonal), motivation (e.g., cool versus hot EF tasks), and task demands (e.g., inhibitory control versus set shifting). Second, although there is robust evidence for the contribution of sensitive parenting to children's EF (Blair et al., 2011; Rhoades et al., 2011), it is necessary to focus on specific parental practices that promote EF, such as attention-directing behaviors (Conway & Stifter, 2012). Uncovering the specific parental behaviors that foster EF has important implications for tailoring intervention programs. Finally, the inclusion of child EF measures from additional time points would enable the examination of bidirectional effects between RSA, caregiving, and EF across time. We believe that the current study provides ample justification for such future endeavors.

Despite these limitations, the current study has a number of strengths including the use of a longitudinal design, observational measurement of parenting behaviors and EF, and the inclusion of behavioral and physiological levels of analysis. Our findings indicate that the emergence of children's EF is optimally supported when experiencing interactions with sensitive caregivers. Furthermore, the stronger link between sensitive parenting during toddlerhood and EF that was observed for children with low baseline RSA suggests that a supportive caregiving environment is particularly important when internal regulatory resources are lacking.

Findings from this study also have important clinical implications, particularly for working with high-risk families. It seems that low income minority children may be at high risk for EF deficits and that they are also exposed to low levels of maternal sensitive behaviors. Efforts should be made to target low income minority families in the implementation of intervention programs, which focus more on enhancing the positive aspects of parenting such as sensitive responsiveness, positive affect, and stimulation for development rather than solely reducing negative aspects such as harsh and intrusive parenting. For example, the "Attachment and Biobehavioral Catch-up intervention" (ABC; Dozier et al., 2006) is an evidence-based program designed for infants and toddlers, in which parent coachers provide training in the home that focuses on supporting caregivers' ability to reinterpret children's behavioral signals through live and video feedback, in the goal of creating a responsive, predictable environment. The ABC could be particularly beneficial for low income families that lack the resources to actively seek parenting guidance and support.

To sum, this study represents an important step in testing the time-varying environmental and biological pathways that support the development of EF. It is essential to further investigate possible mechanisms by which physiological reactivity, parenting behaviors, and environmental risk may work together in multiple processes that shape children's emerging EF skills.

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