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Early Adversity, RSA, and Inhibitory Control: Evidence of Children's Neurobiological Sensitivity to Social Context

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Abstract

This study examined parasympathetic physiology as a moderator of the effects of early adversity (i.e., child abuse and neglect) on children's inhibitory control. Children's respiratory sinus arrhythmia (RSA) was assessed during a resting baseline, two joint challenge tasks with mother, and an individual frustration task. RSA assessed during each of the joint parent–child challenge tasks moderated the effects of child maltreatment (CM) status on children's independently-assessed inhibitory control. No moderation effect was found for RSA assessed at baseline or in the child-alone challenge task. Among CM-exposed children, lower RSA levels during the joint task predicted the lowest inhibitory control, whereas higher joint task RSA was linked to higher inhibitory control scores that were indistinguishable from those of non-CM children. Results are discussed with regard to the importance of considering context specificity (i.e., individual and caregiver contexts) in how biomarkers inform our understanding of individual differences in vulnerability among at-risk children.

Keywords

attention; early experience; electrophysiology; parental care; stress

INTRODUCTION

A critical component of development in the pre-school years is the emergence and maturation of effective self-regulation of attention, affect, and behavior (e.g., Grolnick & Farkas, 2002; Grolnick & Ryan, 1989; McCabe, Cunningham, & Brooks-Gunn, 2004). Inhibitory control, an important component of self-regulation, involves the capacity to voluntarily inhibit automatic or dominant attentional and behavior responses, and is a

component of the executive attentional system, which emerges during the toddler years and shows rapid development through the end of early childhood (e.g., Rueda, Posner, & Rothbart, 2005). The executive attentional system supports development of internal regulation of emotion and thinking via inhibitory and effortful control of attention and behavior, planning, and problem-solving (Bell & Deater-Deckard, 2007; Kopp, 1982, 1989; Rothbart, 2007). Selective control of attention and behavior enables children to act in accordance with social standards and facilitates development of conscience, empathy, and prosocial behavior (e.g., Eisenberg, Smith, Sadovsky, & Spinrad, 2004; Kochanska, Murray, Jacques, & Coy, 1997). Taken together, these attentional/inhibitory control skills form core components of children's developing self-regulation.

Although the development of self-regulation is considered a universal process of early childhood, pathways to adaptive regulatory development in high risk populations are not well understood. Developmental scientists are increasingly incorporating biomarkers of neural processes to examine these pathways, typically by considering individual differences in biomarkers between groups characterized with good self-regulation or poor self-regulation. This approach inherently assumes uniformity in risk, and does not accommodate models of adaptation whereby children may arrive at adaptive developmental outcomes through multiple routes. This is especially critical in understanding how children in high risk developmental contexts demonstrate resiliency.

Developmental psychopathology provides a framework for understanding both typical and atypical regulatory development in children as a function of multiply-determined transactions between biological, psychological, and social-contextual processes across the lifespan (Cicchetti & Lynch, 1993; Cicchetti & Toth, 2005; Shonkoff, Garner, & The Committee on Psychosocial Aspects of Child and Family Health, Committee on Early Childhood, Adoption, and Dependent Care, and Section on Developmental and Behavioral Pediatrics, 2012). Because the capacity to regulate attention and arousal represents a foundation from which such transactional exchanges occur over development, it is important to examine factors that relate to variation in regulatory capacity during early childhood when regulatory ability is emerging. Early exposure to high levels of chronic stress confers risk for a constellation of impairments across a range of regulatory dimensions in attentional, affective, and behavioral domains (e.g., Shonkoff et al., 2012), yet broad within-group differences in children's reactions to adverse childhood experiences have been routinely documented (Cicchetti & Toth, 2005; Trickett & McBride-Chang, 1995).

Child maltreatment provides one important context in which to examine the effects of early adversity on developmental trajectories. Maltreatment (CM), most commonly in the form of harsh physical punishment, or neglect of a child's basic physical needs, constitutes a violation of the sense of safety and stability typically provided by caregivers in early childhood, and as such represents a broad indicator of a contextual stressor within the primary environment of a developing child. Exposure to CM is known to contribute to impairments across many domains of children's functioning including deficits in executive attention regulation, inhibitory control, and problem solving skills (e.g., DePrince, Weinzierl, & Combs, 2009; Pears, Fisher, Bruce, Kim, & Yoerger, 2010; Pollak, Vardi, Putzer Bechner, & Curtin, 2005; Schatz, Smith, Borkowski, Whitman, & Keough, 2008).

Poor functioning in these domains further establishes risk for problems with subsequent school adjustment and achievement (e.g., Bell & Deater-Deckard, 2007; Blair, 2002; Eckenrode, Laird, & Doris, 1993; Pears et al., 2010; Valiente, Lemery-Chalfant, Swanson, & Reiser, 2008). One critical aspect of self-regulation is inhibitory control, involving the ability to inhibit a dominant response and engage instead in a non-dominant behavior (Kochanska, Murray, & Harlan, 2000; Kochanska et al., 1997). Deficits in inhibitory control are associated with linked to psychopathology and problems with school readiness (Blair, 2002; Denham, Blair, DeMulder, & Levitas, 2003; Eckenrode, Laird, & Doris, 1993), highlighting the importance of inhibitory control in children's developing self-regulation skills.

Despite the risks associated with CM exposure, not all maltreated children display deficits in self-regulation. The reasons for these individual differences are not well understood (Cicchetti & Valentino, 2006). Evidence is increasingly pointing to the importance of considering biology $\times$ environment interactions in understanding individual differences in children's developmental outcomes, as these factors together often explain far more variance than either family context or biological systems are capable of explaining independently (Crowell et al., 2008). Several studies have documented that children's vulnerabilities to early adversity are shaped by individual differences at both the genetic (e.g., Caspi et al., 2002), and the biological level, including hypothalamic–pituitary–adrenocortical (HPA) axis (e.g., Gunnar, Frenn, Wewerka, & Van Ryzin, 2009; Pollak, 2008) and autonomic responding (e.g., Quas, Bauer, & Boyce, 2004), that moderate the effects of environmental stress. Recent evolutionary theories of neurobiological variation in sensitivity to context (Boyce & Ellis, 2005; Ellis & Boyce, 2008; Ellis, Boyce, Belsky, Bakermans-Kranenburg, & van IJzendoorn, 2011) also suggest that neurobiological systems may reflect sensitivity to the effects of environmental influences. Initially examined through cortisol as an indicator of stress reactivity, researchers have reported that individuals with heightened cortisol reactivity evidenced both the best and worst health outcomes compared with individuals with moderate reactivity (Boyce & Ellis, 2005). These variations in susceptibility to the effects of early adversity may be critical for understanding within-group variation in regulatory outcomes. The present study sought to test whether individual differences in children's parasympathetic physiology are a function of CM-exposure, or whether physiology moderates vulnerability to the effects of CM exposure on inhibitory control. We chose to focus on the preschool period because it is a time when inhibitory control is undergoing rapid development and thus may be maximally sensitive to the effects of environmental context (e.g., Best & Miller, 2010; Eisenberg et al., 2004; Kochanska, Coy, & Murray, 2001).

Understanding Parasympathetic Physiology in Context

One physiological marker that has received considerable attention in children's regulatory development is respiratory sinus arrhythmia (RSA). RSA is a measure of the change in oscillatory dynamics of the heart across the respiration cycle and is considered to be a measure of the parasympathetic nervous system's influence on cardiac function (Berntson et al., 1997; Porges, 1995). Parasympathetic control has been identified as a likely mediator of neural regulatory control of arousal, and as such is credited with facilitating positive

prosocial development by allowing an individual to rapidly modulate arousal as needed to engage with environmental demands (Porges, 2003). Parasympathetic control represents a higher order of arousal regulation compared with sympathetic control, which results in a more robust and prolonged state of arousal that is difficult to modulate and can contribute to challenges in controlling temper, focusing and sustaining attention, and participating in cooperative social affiliation (Beauchaine, 2001; Mezzacappa, Kindlon, Saul, & Earls, 1998; Porges, 1995, 2001). Because of the association of RSA to general regulatory ability, this system is particularly relevant for understanding relations between CM-exposure and the ability to regulate attention and arousal.

Under baseline conditions, parasympathetic influence is high, exerting a slowing on cardiac activity that is reflected in greater RSA values. During engagement with the environment, parasympathetic withdrawal releases this dampening effect on the heart, resulting in an immediate increase in arousal as reflected in lower RSA. Thus decreases in RSA from a resting baseline to challenge task (referred to as “suppression” or RSA “reactivity”) mark an increase in arousal that supports cognitive and behavioral focus. Both baseline and reactivity measures of RSA have been demonstrated to possess moderate stability across the preschool years (Calkins & Keane, 2004).

Consistent with this model, higher baseline RSA reflects the extent of an individual’s regulatory capacity, or the degree to which arousal can be increased through parasympathetic withdrawal before sympathetic activation is needed. Findings of better psychological function in the context of high RSA are generally consistent with the notion that RSA indexes regulatory control over affective arousal. Not surprisingly, low baseline RSA has been reported in association with a wide range of psychopathological conditions, and thought to reflect a general marker of dysregulated emotion (Beauchaine, 2001; El-Sheikh, 2005; Katz & Gottman, 1995; Scarpa, Tanaka, & Haden, 2008). RSA levels assessed during engagement in a variety of challenges have also been frequently studied, and research suggests that both baseline and task RSA levels offer unique information and are best examined concurrently (Hinnant & El-Sheikh, 2009). Results associated with changes in RSA from baseline to challenge have been inconsistent, with some studies reporting benefits of greater RSA suppression (e.g., El-Sheikh et al., 2009; Katz & Gottman, 1995), whereas others identify risks associated with RSA suppression (e.g., Calkins, Graziano, & Keane, 2007; Obradovi , Bush, Stamperdahl, Adler, & Boyce, 2010; Skowron et al., 2011).

Moreover, recent studies suggest that the implications of RSA levels may be highly context specific (e.g., Conradt, Measelle, & Ablow, 2013; Quas et al., 2004). Because RSA is thought to modulate arousal, and arousal is considered to contribute to cognitive engagement in a non-linear fashion, RSA responses during a challenge may be modulated by the type of and context in which a challenge is presented. For example, RSA augmentation (i.e., increased parasympathetic activation) has been observed among infants shifting from Still-Face to Social Interaction conditions (Bazhenova, Plonskaia, & Porges, 2001), and adults in conditions specific to emotion regulation in social exchanges (Butler, Wilhelm, & Gross, 2006) and family interactions (Lorber & O’Leary, 2005). Healy and colleagues found that RSA suppression was associated with better executive control function only in the context of

relatively neutral affect. In conditions of negative affect, less suppression was associated with better executive function (Healy, Treadwell, & Reagan, 2011), and the authors posit that in conditions of heightened affective arousal, RSA may have been employed to remain calm in the service of cognitive function.

The theoretical value of considering psychophysiological markers within ecologically meaningful contexts has been proposed to be of considerable importance. Individual differences in response to challenge may be more proximal indicators of capability than baseline values (Coan, Allen, & McKnight, 2006), and it follows logically that the nature of the challenges examined should be germane to the constructs under study. Thus, in the current study, children were assessed during cognitively challenging tasks that were conducted independently and jointly with their CM or non-CM mother. In conditions where the dyadic nature of the task establishes an affective relational context for engaging in a cognitive challenge, RSA activity in a joint caregiver-child context may be a better moderator of vulnerability to CM than RSA activity in non-relational contexts. As such, we reasoned that individual differences in preschool children's RSA levels recorded during challenge tasks faced together with one's primary caregiver may be most salient in terms of modifying the influence of CM-exposure on children's regulatory outcomes.

The Current Study

This study was designed to clarify the role of individual differences in preschool children's RSA at rest and during challenge, and in moderating the effects of early adversity on the development of inhibitory control skills, across several experimental contexts. We first examined the effects of CM status on inhibitory control, with the prediction that CM exposure would be associated with reduced inhibitory control. Next we examined children's RSA across CM and non-CM groups during a joint resting condition, individual challenge, and caregiver-present joint puzzle tasks. Finally we examined the potential moderation effect of RSA levels at resting baseline, and during the individual child and joint mother-child tasks to determine whether children's RSA moderates the association between CM and inhibitory control, and if this moderation effect was context (i.e., task) specific.

METHODS

Participants

Participants were 161 mothers and their preschool children (78 CM dyads). Children ranged in age from 3 to 5 years ($M = 3.71$, $SD = .72$), 50.3% were female, and a majority were Caucasian (82.4%). Mother's average age was 29.9 years ($SD = 5.69$). The majority of the mothers were Caucasian (92.3%), 42.2% were married, 75.2% had a high school degree or less, and 74.2% reported incomes below \$30,000 per year. All CM mothers in the present study had Child Protective Services (CPS) documentation as a perpetrator of maltreatment. Among the CM-exposed children, 28.2% were physically abused and 71.8% were physically neglected, based on documentation from CPS of mother's perpetration toward the target child, and coded using the Maltreatment Classification System (MCS; Barnett, Manley, & Cicchetti, 1993). Consistent with standards in the CM literature (Pollak et al., 2000), CM subtypes were classified hierarchically, so that neglected children may have experienced

emotional maltreatment but did not have records indicating physical abuse, and physically abused children may have also experienced neglect and/or emotional abuse. Comorbidity of CM subtypes (i.e., physical abuse with neglect and/or emotional abuse; physical neglect with emotional abuse) was observed in 46.2% of the CM group, consistent with other published findings (e.g., Belsky, 1993; Kaufman & Ziegler, 1989). The average CM severity experienced in the sample was 3.44 (range =1–5), with no observed differences in the severity levels associated with abuse or neglect.

Non-CM dyads were drawn from a socio-demographically comparable sample from department of public welfare agencies and a database maintained on birth announcements published in local newspapers, and non-CM mothers consented to verification that their family was free of CPS preventive or protective service records. CM and non-CM children did not differ on dimensions of child age, $t(1, 159) = .71, p = .48$, gender, $\chi^2(1, N = 161) = .56, p = .64$, or ethnicity, $\chi^2(4, N = 159) = 1.26, p = .73$. Likewise, no CM group differences were observed on mother's relationship status, $\chi^2(5, N = 160) = 10.23, p = .07$. CM group differences were revealed on children's IQ (i.e., Stanford-Binet-5) scores, $t(1, 153) = 3.24, p = .001$, and mother's educational attainment, $\chi^2(4, N = 160) = 32.30, p = .001$. CM children had lower scores on the SB-5 ($M = 95.41, SD = 14.94$) compared to non-CM children ($M = 103.29, SD = 15.22$), and 92.3% of CM mothers had a high school degree or less compared to 59.8% of non-CM mothers. Given the sample stratification by CM status, maternal education was included in the regression analyses, along with child age and IQ scores.

Procedures

All procedures employed in this study were approved and monitored by the Office for Research Protections. Mother–child dyads were invited to participate if mothers were 18 years of age or older, fluent in English, and living with her preschool child. Mother-child dyads completed the 3-visit protocol over a 2- to 3-week period. Visits were conducted by a team of two trained experimenters and comprised of two home visits for psychosocial and cognitive assessments and one laboratory visit to assess physiological function and parent–child interaction, including assessment of children's general cognitive ability using the abbreviated-Stanford Binet-5 (SB-5; Roid, 2003). Families were paid \$150 to complete the three interviews, provided transportation, snacks, and children's small toys/gifts.

Laboratory Assessment Protocol—Laboratory visits lasted approximately 2½ hr, during which time children and mothers completed a series of tasks. Only procedures related to the current report are summarized. Dyads participated in a 5-min resting baseline period seated together on a comfortable couch with lights dimmed, while viewing a relaxing video segment. Following baseline, mothers and children completed two joint tasks. For the first joint challenge task (i.e., Duplo_{joint}; Hoffman, Crnic, & Baker, 2006), mother and child were seated together at a small table and the child was provided a model figurine and 12 disassembled blocks to construct a replica in 3–5 min. Mothers were asked to assist their children to build a model using the blocks provided, and instructed to help as they might normally, but not to handle any of the blocks. Next, the mother and child participated together in an 8-min competing demands task (i.e., Wait_{joint} Task; Carmichael-Olsen, Greenberg, & Slough, 1985; Cole, Zahn-Waxler, Fox, Usher, & Welsh, 1996). Mothers

were instructed to fill out a questionnaire, after placing a wrapped prize on a table in the view and instructed her child that s/he could open the present after she completed her work. The child was given a zebra with a broken leg with which to play, and mother interacted with her child as needed while she completed her questionnaire. Following, the child was given a snack break while the mother completed a stroop-like task. Children then participated in the 4-min Transparent Box_{solo} task (Goldsmith, Reilly, Lemery, Longley, & Prescott, 1999), an individual Lab-Tab challenge task designed to elicit frustration. The experimenter placed two toys that the child indicated as his/her favorites into a clear box, locked it, and demonstrated to the child how to open the box with a key. The experimenter then gave the child a set of keys that did not work and left the room. After 4 min, the experimenter reentered the room, told the child she gave him/her the wrong key, and opened the box.

Measures

Child Intelligence—Children's IQ was obtained during the first visit using the Stanford Binet-Fifth Edition (SB-5; Roid, 2003). The 2-subtest Abbreviated Battery IQ (ABIQ) was administered to children by a trained experimenter and included assessments of Verbal Knowledge and Nonverbal Fluid Reasoning. Scaled scores were obtained and summed to obtain a total, age-standardized ABIQ scaled score and scores were included as a covariate in the analyses.

Inhibitory Control—Children's *Inhibitory Control* was assessed via the Shapes Stroop (Kochanska et al., 1997) and Day/Night Stroop task (Gerstadt, Hong, & Diamond, 1994); each measure the ability to inhibit pre-potent responding and execute an alternative, non-dominant response. The inhibitory control tasks were presented successively from the easier Shapes to more challenging Day/Night task, and used to create a single composite score to capture the full range of performance, given the limited abilities of children younger than age 4 on Day/Night (Gerstadt et al., 1994), and the sample's continuum of risk. The Shapes Stroop task (Kochanska et al., 1997) presented children with three large and small pictures of fruits and then three pictures depicting a small fruit embedded in a different large fruit (e.g., a small orange pasted on a large banana). The child was told to point to each of the little fruits which were embedded within the larger fruits (e.g., "Show me the little banana"). For each trial, scores ranged from 0 (incorrect), to 1 (incorrect, followed by spontaneous self-correction), and 2 (correct on first response), such that final scores ranged from 0 to 6 ($M = 4.80$, $SD = 1.72$). In the more challenging Day/Night Stroop task (Gerstadt et al., 1994), 16 trials were completed during which children were shown a series of cards with pictures of a sun or moon, and instructed to say "day" whenever they saw a card with a moon on it and to say "night" when they saw a card with a sun on it. Scores ranged from 0 (incorrect), 1 (incorrect, followed by spontaneous self-correction), or 2 (correct on first response) for each trial, with total scores ranging from 0 to 32 ($M = 16.20$, $SD = 10.01$). Scores were standardized and summed across the two indices, with higher scores reflecting greater inhibitory control. It should be noted that RSA was measured during these inhibitory control tasks, however because these constituted a much shorter interval than the other tasks, ranging from 1 to 2 min in total length across two discrete tasks, they were considered inappropriate to directly compare with the other RSA scores.

RSA—Children’s cardiac activity recorded throughout the Baseline, Duplo_{joint} and Wait_{joint} tasks, and the Transparent Box_{solo} conditions was included in this study. Disposable pre-gelled Ag/AgCl electrodes were placed on mothers’ and children’s chests in a modified Lead II placement on the distal end of the right clavicle, lower left rib cage chest, and the lower abdomen. Data were acquired via Mindware Technologies© (Gahanna, OH) ambulatory electrocardiograph MW1000A and sampled at 500 HZ. Data were transmitted via wireless signal to a computer and monitored by a research assistant. Approximately, 15% of the sample had missing physiology data. Of those children with missing data, six children refused placement of electrodes, and the remaining RSA data was missing due to excessive movement artifacts or due to technical problems (i.e., equipment failure such as dropped signals, loosening leads, or child pulling on electrode). In all, child RSA data were available for 136 children during Baseline, 127 during Duplo_{joint}, 130 during the Wait_{joint}, and 119 during the Transparent Box_{solo}.

Electrocardiograph data were processed offline using Mindware Technologies HRV 3.0.10 analysis program, and epochs were visually inspected by trained research assistants. Erroneously identified, or missing heart beats were manually deleted or inserted as appropriate. The resulting inter-beat interval time series was subjected to a fast-Fourier transformation, and power in the respiratory frequency band was derived from the spectral density function. Given the age of the sample, the RSA frequency band was set between .24 and 1.04. RSA values were extracted in 30-s epochs, and epochs were averaged across each task to create single scores for the baseline period (RSA_{baseline}), the joint tasks (RSA_{duplo}, RSA_{wait}) and the individual task (RSA_{trans.box}). Descriptive statistics for children’s RSA scores are presented in Table 1.

Analytical Approach

Hierarchical regressions were conducted to examine whether children’s parasympathetic tone moderated relations between CM status and children’s Inhibitory Control scores. Both Baseline RSA and Task levels of RSA (i.e., RSA_{duplo}, RSA_{wait}, and RSA_{trans.box}) were examined as moderators of CM status and children’s inhibitory control associations. Task levels of RSA were examined along with baseline RSA in order to control for trait-like consistency in RSA within person and identify unique variance associated specifically with RSA during each task. This was considered preferable to the calculation of change scores because magnitude of change is difficult to interpret in the absence of baseline levels because of the Law of Initial Values. In other words, because there are physiological boundaries on the range of cardiac function, change is constrained the nearer a person is to their physiological floor or ceiling and this may be theoretically distinct from their psychological reactivity. Maternal education and child age, IQ, and RSA_{baseline} scores were included as centered covariates in the models with Task RSA. For each model, centered covariates were entered first in Step 1 (maternal education) and Step 2 (child age, IQ scores, and RSA_{baseline}), followed by the predictor (CM) and centered moderator (RSA) in Step 3, and the centered interaction term (CM X child RSA) in Step 4. Main effects of CM status and RSA scores on children’s Inhibitory Control were examined but subsumed under significant interactions when these were observed. Interaction effects were probed through tests of simple effects at +1 SD, 0, and –1 SD of the moderator (Aiken & West, 1991;

Keppel, 1982), interaction contrasts, and tests of the regions of significance (Preacher, Curran, & Bauer, 2006).

RESULTS

CM Status and Children's Inhibitory Control

Independent samples *t*-tests were conducted to examine CM group differences on study variables. Descriptives are shown in Table 1. As expected, CM children ($M = -.44$, $SD = 1.53$) displayed lower Inhibitory Control scores than did non-CM children ($M = .42$, $SD = 1.43$), $t(1,143) = 3.55$, $p = .001$. A CM group X Task (i.e., Baseline, Duplo_{joint}, Wait_{joint}, and Transparent Box_{solo}) repeated measures ANOVA was conducted with child RSA scores entered as the dependent variable. Significant Task effects were observed, $F(3, 108) = 24.88$, $p < .001$, confirming that the experimental manipulations were effective (see Tab. 1). However, CM status was not associated with different levels of RSA in any of the four conditions: RSA_{baseline} [$t(1,133) = .85$, $p = .40$], RSA_{duplo} [$t(1,129) = .24$, $p = .81$], RSA_{wait} [$t(1,130) = -.88$, $p = .38$], and RSA_{trans.box} [$t(1,120) = -.65$, $p = .52$].

Bivariate correlations among the study variables for the entire sample and by CM group are shown in Table 2. Children's RSA scores across baseline and task conditions showed high, positive intercorrelations. In the full sample, children's inhibitory control was positively associated with RSA_{baseline} and RSA_{duplo}. However, when examined within risk groups, only the CM-exposed children evidenced associations between RSA level and inhibitory control, such that higher RSA during the joint tasks only (e.g., RSA_{duplo} and RSA_{wait}) was associated with better performance on the Inhibitory Control measures. Children's Inhibitory Control scores also were associated with child age, $r(145) = .33$, $p = .002$, IQ, $r(141) = .24$, $p = .005$, and maternal education, $r(144) = .19$, $p = .02$.

CM Status, RSA, and Context

The first regression conducted examined whether RSA_{baseline} moderated relations between CM status and inhibitory control. As shown in Table 3, Step 1 and 2 covariates significantly predicted inhibitory control: $F(1, 118) = 9.21$, $p = .002$, $R^2 = .07$, and $F(2, 116) = 10.30$, $p = .001$, $R^2 = .14$, respectively. Greater maternal education [$t(1, 118) = 3.03$, $p = .003$], child age [$t(1, 1118) = 4.14$, $p = .001$], and IQ scores [$t(1, 118) = 2.12$, $p = .04$], all predicted higher child inhibitory control scores. Step 3, in which the main effects of CM status and RSA_{baseline} were assessed, was significant, $F(2, 114) = 2.83$, $p = .01$, $R^2 = .06$, although results indicate that only CM status was a significant predictor of Inhibitory Control at this step. Further, the CM $\times$ RSA_{baseline} interaction was not significant, $F(1, 113) = .41$, $p = .52$, $R^2 = .00$.

Next, children's RSA_{duplo} scores were found to moderate relations between CM status and Inhibitory Control (see Fig. 1). Step 1 and 2 covariates significantly predicted Inhibitory Control: $F(1, 109) = 10.35$, $p = .002$, $R^2 = .09$ and $F(3, 106) = 8.36$, $p = .001$, $R^2 = .18$, respectively. Greater maternal education [$t(1, 109) = 3.22$, $p = .01$], child age [$t(1, 106) = 3.75$, $p = .001$], IQ scores [$t(1, 106) = 1.95$, $p = .05$], and RSA_{baseline} [$t(1, 106) = 2.37$, $p = .02$] all predicted higher child Inhibitory Control scores. Step 3 main effects of CM status and

RSA_{duplo} were near significant, $F(2, 104) = 2.83, p = .06, R^2 = .04$, and a significant CM $\times$ RSA_{duplo} interaction was observed in Step 4: $F(1, 103) = 6.12, p = .02, R^2 = .04$ (see Tab. 3).

Interactions were probed and revealed that CM children with lower RSA_{duplo} scores (i.e., lower parasympathetic tone) performed the poorest on Inhibitory Control measures. As shown in Figure 1, simple slopes observed in the CM group were significant at -1 SD and mean RSA_{duplo} levels ($B = -.89, SE = .31, t = -2.91, p = .005$; $B = -.41, SE = .20, t = -2.03, p = .05$, respectively), but not at $+1$ SD RSA_{duplo} ($B = .08, SE = .31, t = .27, p = .79$). Non-CM children showed similarly high Inhibitory Control scores regardless of their RSA_{duplo} levels: $B = .42, t = 1.43, SE = .30, p = .16$ (-1 SD); $B = -.01, SE = .18, t = 1.58, p = .12$ (mean); and $B = .16, SE = .28, t = .56, p = .58$, ($+1$ SD). Interaction contrasts were conducted to test for CM versus non-CM group differences and probed to identify regions of significance. Significant differences were observed across the CM and non-CM groups at -1 SD ($p = .001$) and mean ($p = .02$) RSA_{duplo} levels, but not at $+1$ SD ($p = .85$), with the region of significance at $z < .26$ level of the moderator. After accounting for RSA_{baseline} scores, CM children showed significantly lower Inhibitory Control scores than did non-CM children at -1 SD RSA_{duplo} (i.e., at lower parasympathetic tone) and mean RSA_{duplo} levels. However, at higher RSA_{duplo} levels (i.e., $+1$ SD, higher parasympathetic tone), CM and non-CM children did not significantly differ in their inhibitory control scores.

Children's RSA_{wait} scores also moderated associations between CM status and inhibitory control, $F(1, 105) = 4.44, p = .04, R^2 = .03$. As shown in Figure 2, simple slopes for the CM group were significant at -1 SD and mean levels of RSA_{wait} scores ($B = -.89, SE = .30, t = -2.91, p = .005$; $B = -.41, SE = .20, t = -2.03, p = .05$, respectively), but not at $+1$ SD ($B = .08, SE = .27, t = -.71, p = .79$). For the non-CM group, the simple slopes were significant only at -1 SD RSA_{wait} ($B = .54, SE = .28, t = 1.94, p = .05$), but not significant at mean levels and $+1$ SD RSA_{wait} ($B = .26, SE = .19, t = 1.40, p = .16$; $B = -.02, SE = .31, t = -.07, p = .95$, respectively). Next, interaction contrasts between the CM and non-CM groups were conducted and probed to identify regions of significance. Significant differences emerged across CM and non-CM groups both at -1 SD ($p = .002$) and mean ($p = .02$) RSA_{wait} levels, but not at $+1$ SD ($p = .65$; region of significance $z < .33$). Consistent with the moderating effects observed for RSA_{duplo}, CM children with low RSA_{wait} scores (i.e., lower parasympathetic tone) during the joint wait task performed worse on the Inhibitory Control measures than did non-CM children with low RSA_{wait} scores. At high RSA_{wait} levels (i.e., at higher parasympathetic tone), CM and non-CM children did not differ in their Inhibitory Control scores.

Finally, children's individual task RSA_{trans.box} scores were tested as a moderator between CM status and Inhibitory Control. Neither the main effects of CM status nor the individual task RSA_{trans.box} scores were significant in Step 3, $F(1, 98) = 2.51, p = .09, R^2 = .04$, nor the CM $\times$ RSA_{trans.box} interaction (Step 4) were significant, $F(1, 97) = .58, p = .45, R^2 = .00$.

Follow-up tests were conducted to determine whether levels of social engagement differed across CM and non-CM dyads, possibly confounding the joint task RSA moderation effects

observed. However, no significant differences in number of dyadic speaking turns was observed in CM dyads ($M = 74.5$, $SD = 27.8$ turns) versus non-CM dyads ($M = 72.7$, $SD = 30.9$) during the two joint tasks, $t(161) = -.39$, $p = .70$. Likewise, no within-CM-group associations were observed in levels of positive or aversive parenting and children's joint task RSA scores, $r's = .05$ and -0.02 , $p's = NS$, suggesting that the joint task RSA moderation effects were not merely a function of differences in proximal parenting.

DISCUSSION

Consistent with previous literature, we found that CM exposure was associated with lower levels of inhibitory control in preschool children. The experience of having a maltreating parent who is a source of threat and inconsistent caregiving appeared to compromise children's capacities for selective control of attention. However, although CM exposure was directly associated with inhibitory control, no main effect of CM on children's RSA during baseline or in response to challenge was observed, suggesting that CM does not probabilistically influence RSA in this age range.

Perhaps the most significant contribution from this study is the observation of context-specific effects in this high-risk sample of preschool children. The moderating effects of CM-exposed children's RSA response to challenges were unique to those faced in contexts where their maltreating caregiver was present, a finding in keeping with theory and research documenting the role of one's early social/caregiving environment in the dynamics of this regulatory system (e.g., Bazhenova et al., 2001; Cacioppo, Berntson, Sheridan, & McClintock, 2000; Lupien, McEwen, Gunnar, & Helm, 2009; McEwen, 2006; Pollak, 2008; Porges, 2001, 2003, 2011). Analyses revealed that the association between CM status and inhibitory control performance was moderated by children's RSA, indicating that RSA during laboratory tasks completed together with one's mother functioned to predict inhibitory control differently between the two groups. Specifically, among children who displayed lower joint task RSA, those who were not maltreated performed better on the inhibitory control task than did CM-exposed children. In contrast among CM-exposed children, lower RSA during a challenge faced together with one's CM mother was associated with poor inhibitory control scores, indicating that this physiological marker is not inherently adaptive. Indeed in CM children, higher joint task RSA scores appeared to be protective, in that they were associated with inhibitory control scores on par with lower risk non-CM children, and better inhibitory control than CM-exposed children who showed lower joint task RSA. In sum, age-appropriate inhibitory control development appears associated with different physiological profiles among CM-exposed and non-CM children, indicating that the adaptive quality of physiological arousal may be dependent on developmental context.

Contrary to some studies, no interactions between CM exposure and children's RSA were found for RSA assessed during a calm acclimation (i.e., resting) period. Some researchers have suggested that that baseline differences in RSA reflect an emergent developmental property that is not routinely evidenced until later in childhood (Beauchaine, Gatzke-Kopp, & Mead, 2007), and that assessments during laboratory challenge are more informative (Fortunato, Gatzke-Kopp, & Ram, 2013). Given the high correlations among all RSA

variables, it is noteworthy that among the three challenge tasks the children participated in, RSA levels recorded during the tasks in which the mother was present were the only conditions in which RSA levels conveyed a significant association with inhibitory control. Thus, RSA levels assessed when participating in a joint activity with the mother explained unique variance in children's inhibitory control, above and beyond the contribution of resting RSA. The interaction effects observed across both joint task conditions indicate that CM-exposed children with relatively higher vagal tone during caregiver-present challenges (i.e., child cognitive challenge, and maternal split-attention task) evidence greater inhibitory control, whereas higher RSA did not confer this advantage in non-CM children. Instead, CM children who showed low RSA during joint challenge tasks with mother displayed the lowest observed levels of inhibitory control, though this profile was associated with the higher levels of inhibitory control sample-wide. These findings were independent of the effects of socioeconomic status, child age and IQ, maternal education, baseline levels of RSA prior to task engagement, and in light of the fact that level of dyadic interaction (i.e., social engagement) during the joint tasks did not vary across groups. RSA levels during the child-alone challenge task also were not associated with inhibitory control for either group. Taken together, these findings suggest a meaningful role for the context in which children's physiological regulation is employed.

The context-specific findings observed here highlight the need for the field to interpret young children's physiological data within the environmental domains of a study, given that only findings observed during the caregiver interactions supported a role for PNS involvement in sensitivity to CM exposure. Low RSA observed among CM children during interactions with their mothers was associated with poorer performance on independent behavioral measures of inhibitory control. In other studies, RSA suppression (i.e., reductions in RSA levels from resting baseline in response to a challenge) has been shown to facilitate adaptation (e.g., Calkins, Smith, Gill, & Johnson, 1998; El-Sheikh et al., 2009; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). While this study did not examine suppression per se, the findings are consistent in that lower joint task RSA scores were associated here with better performance in the non-CM children relative to the CM-exposed children.

The current findings linking low RSA in CM-exposed children to poor inhibitory control are in line with other studies indicating that suppression is not uniformly adaptive (e.g., Beauchaine, 2001; Calkins et al., 2007; Hastings et al., 2008; Obradović et al., 2010). One speculation is that low child RSA in a CM caregiver-present context reflects hyper vigilance to environmental cues in anticipation of potential threat. Such hyper vigilance is well documented in CM children (e.g., Gunnar, Fisher, & The Early Experience, Stress, and Prevention Network, 2006; Pollak, 2008; Shackman, Shackman, & Pollak, 2007; Shonkoff et al., 2012; Watts-English, Fortson, Gibler, Hooper, & DeBellis, 2006) and while considered to be an adaptation, the consequences of such vigilance can be costly for developing affect regulation systems. Research indicates that early in life children rely on parents and other external sources to help them regulate their emotions and behavior, and as they age into preschool, children gradually begin to internalize those relationally-derived regulatory functions and develop increasing strategies for self-directed, internal control of attention, emotions, and behavior (Kopp, 1982, 1989; Thompson, 1991; Winsler, Diaz,

McCarthy, Atencio, & Chabay, 1999). Attention to threat could result in perpetual activation of the stress response system, which has been shown to compromise the development of higher order regulatory functions (e.g., Beers & DeBellis, 2002; Pollak et al., 2005, 2010; see National Scientific Council on the Developing Child, 2005, for a review).

CM-exposed children who were able to maintain high RSA levels during the joint tasks may have been actively self-regulating by maintaining optimal arousal appropriate for the nature of the laboratory interaction, an affective regulatory strategy that may enable development of broader attentional engagement, flexibility, and delay in responding, even in the context of risk exposure. In other words, this pattern of maintaining higher parasympathetic tone during challenge is likely to have a protective effect on neural development whereby excessive and chronic arousal is avoided. Variation in contextually-specific RSA responding may therefore reflect an important individual difference in CM-exposed children that may foster resiliency in the face of adversity. How this path may lead toward enhanced inhibitory control among children exposed to extreme adversity requires further clarification of other inputs from temperamental factors and the proximal environment, for example.

Future research is also needed to further elucidate how the relative activation across the parasympathetic (RSA) and sympathetic systems contribute to this phenomenon. It is plausible that CM children are more likely to activate sympathetic reactivity which is disruptive to attentional focus. In this scenario, those who display higher RSA may be compensating to maintain balanced arousal in the service of task engagement, but perhaps at a higher long-term physiological cost owing to the increased demands on the physiological systems. Those who suppress RSA in this context would be especially vulnerable to the disruptive effects of heightened arousal and the impact of sympathetic activation on the HPA system. Thus, although there is an apparent advantage for CM-exposed children to maintain high RSA while interacting with their CM caregiver, it is not clear if this is still accompanied by increased risk or protection over the developmental span of childhood. Indeed, recent studies have begun to clarify the importance of the reciprocal or coordinating activation of both the PNS and SNS systems on children's outcomes in the context of adversity (e.g., El-Sheikh et al., 2009).

Further, RSA response to challenge may be less a characteristic of trait differences between children and instead reflect different experiences of these children within the dyadic caregiver context. It is conceivable that CM-exposed children who display lower RSA in response to challenge are experiencing more aversive interchanges, whether actual or perceived, in the proximal context with parent, which then compromise their capacities for independent, regulatory control, while in contrast, those CM children who show higher RSA when challenged might have more positive perceptions of their interactions with their caregiver than other CM children. Although no within-CM-group differences in levels of positive or aversive parenting were observed in this study, we cannot rule out the possibility that these observed individual differences in children's RSA responding are tied to variations in attributions and perceptions, or dyadic interactive processes (i.e., positive interactive synchrony, quality of rupture/repair processes) that serve to influence a child's level of calm or arousal, and promote or inhibit subsequent regulation (e.g., Miller, 2010).

Implications

Knowledge is accumulating about the ways in which children's neurobiology appears to moderate links between risk context and children's propensity for externalizing and internalizing disorders (Gunnar & Quevedo, 2007), though greater insights are needed into how CM children's parasympathetic function relates with early exposure to adversity to influence proximal regulatory processes involved in psychopathology. The current study indicates that the pattern of physiological responding frequently associated with optimal cognitive performance in normative samples appeared to amplify the negative effects of CM exposure on children's regulatory outcomes. Higher RSA in response to challenges experienced in a joint context with one's maltreating mother appeared to maximize CM-exposed children's abilities to perform well on independent laboratory tasks requiring selective control of attention. This finding suggests that resilience in the face of significant stress during development may rely on the ability to marshal cognitive and physiological resources differently than that which is successful for children in lower stress contexts. These results offer some insight into the often observed but poorly understood resiliency phenomenon documented among CM children, and implicate a role for the effects of parasympathetic functioning during caregiver interactions in dampening the negative effects of adversity on children's inhibitory control.

Our findings regarding low task RSA observed in non-CM children vs. CM children aligns with research linking parasympathetic tone with developmental outcomes in early childhood. However, consistent with other studies of high risk children, our findings support the adaptive value of high RSA among CM while they are engaged with their CM caregiver, helping them make the best of a bad situation, namely when facing a challenge while interacting with one's caregiver—not when confronting a challenge alone. These domain- or context-specific effects of children's PNS responding highlight the need to extend beyond identification of consistent patterns of "good" or "bad" physiological profiles, toward interpreting physiological data both within a study's broad social contextual framework (i.e., CM exposure, SES), and in light of the proximal contexts in which children's neurobiological systems are being observed.

Limitations and Future Directions

This study of CM-exposed children reported context-specific moderating effects of PNS functioning on inter-individual variability in preschool children's emerging self-regulation capacities. However, several limitations should be noted. Sample size may have precluded detection of smaller differential effects in RSA responding than were observed here, particularly among the non-CM children sampled. Small CM subgroup sizes limited our ability to explore within-CM group differences in the moderation effects observed. In addition, the periods of observation were relatively brief, and questions remain about whether these findings on children's RSA response to challenge in individual and joint settings during a laboratory visit would generalize to naturalistic, home settings. The cross-sectional design precluded determination of causal associations, leaving important questions about the extent to which exposure to adversity conditions is shaped or moderated by children's RSA response to challenge.

These findings emphasize the importance of broadening the study of PNS functioning in early childhood to include assessment of RSA responding in both individual and caregiver-engaged stress paradigms. Development of PNS functioning in relational, care-giving contexts needs to be better understood (Porges, 2011), particularly in the early years when regulatory systems are shifting from almost exclusively relational in nature, with caregivers serving regulatory functions for children in infancy, to the internalization and consolidation of those regulatory capacities in the preschool years and beyond.

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FIGURE 1.

Children's *standardized* inhibitory control scores as a function CM status and children's joint Duplo Task RSA at -1 SD, Mean, and +1 SD.

FIGURE 2.

Children's *standardized* inhibitory control scores as a function CM status and children's joint Wait Task RSA at -1 SD, mean, and +1 SD.

Table 1

Descriptive Statistics for Preschoolers' RSA and Inhibitory Control Variables

RSA	CM (<i>n</i> = 78)			Non-CM (<i>n</i> = 83)			Total Sample (<i>n</i> = 161)		
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
RSA _{baseline}	6.01	1.33	1.61–9.87	6.20	1.37	2.86–8.53	6.11	1.35	1.61–9.87
Task RSA _{uplo}	5.51	1.25	1.51–9.29	5.57	1.33	1.36–8.60	5.54	1.29	1.36–9.29
Task RSA _{wait}	5.92	1.27	2.03–9.33	5.72	1.20	1.80–8.69	5.81	1.28	1.80–9.33
Task RSA _{trans.box}	5.47	1.25	2.11–8.82	5.32	1.23	2.30–8.43	5.39	1.23	2.11–8.82
Inhibitory control	–.44*	1.53	–4.40–2.24	.42*	1.42	–4.20–2.14	.01	1.53	–4.40–2.24

Note: Inhibitory control reflects the standardized composite score on Shapes and Day/Night tasks.

* *p* < .05.

Table 2
Bivariate Correlations between RSA and Inhibitory Control in the Full Sample and by CM Status

	1	2	3	4	5
Total sample					
1. RSA _{baseline}	—				
2. Task RSA _{duplo}	.76**	—			
3. Task RSA _{wait}	.70**	.85**	—		
4. Task RSA _{trans.box}	.65**	.77**	.79**	—	
5. Inhibitory Control	.22*	.20*	.12	.17	—

	1	2	3	4	5
Non-CM Group					
1. RSA _{baseline}	—				
2. Task RSA _{duplo}	.76**	—			
3. Task RSA _{wait}	.72**	.92**	—		
4. Task RSA _{trans.box}	.60**	.80**	.82**	—	
5. Inhibitory Control	.15	.00	.00	.15	—

	1	2	3	4	5
CM Group					
1. RSA _{baseline}	—				
2. Task RSA _{duplo}	.77**	—			
3. Task RSA _{wait}	.70**	.79**	—		
4. Task RSA _{trans.box}	.71**	.73**	.76**	—	
5. Inhibitory Control	.23	.42**	.28*	.24	—

Note:

* $p < .05$.
** $p < .01$.

Table 3

Standardized Regression Coefficients for Analyses Testing the Moderating Effects of Baseline RSA and Task Level RSA on CM Status and Inhibitory Control

	<i>B</i>	<i>SE (B)</i>	β	<i>R</i> ²
I. RSA _{baseline}				
Step 1				.07**
Maternal education	.43	.14	.27**	
Step 2				.14**
Child age	.71	.17	.34**	
SB-5	.02	.01	.18*	
Step 3				.06**
CM Status	.63	.28	.21*	
RSA _{baseline}	.17	.09	.15 ⁺	
Step 4				.00
CM Status $\times$ RSA _{baseline}	-.12	.18	-.08	
Total <i>R</i> ²				.27
II. RSA _{duplo}				
Step 1				.09**
Maternal education	.47	.15	.29**	
Step 2				.18**
Child age	.67	.18	.32**	
SB-5	.02	.01	.17*	
RSA _{baseline}	.23	.10	.20*	
Step 3				.04 ⁺
CM Status	.66	.30	.21*	
RSA _{duplo}	.12	.15	.10	
Step 4				.04*
CM Status $\times$ RSA _{duplo}	-.49	.20	-.31*	
Total <i>R</i> ²				.35
III. Task RSA _{wait}				
Step 1				.07**
Maternal education	.43	.14	.27**	
Step 2				.17**
Child age	.68	.18	.33*	
SB-5	.02	.01	.18*	
RSA _{baseline}	.20	.10	.18*	
Step 3				.04 ⁺

	<i>B</i>	<i>SE (B)</i>	β	R^2
CM Status	.68	.29	.22*	
RSA _{wait}	.02	.14	.02	
Step 4				.03*
CM Status $\times$ RSA _{wait}	-.42	.20	-.24*	
Total R^2				.31
IV. Task RSA _{trans.box}				
Step 1				.08**
Maternal education	.46	.16	.28**	
Step 2				.18**
Child age	.71	.19	.33**	
SB-5	.02	.01	.19*	
RSA _{baseline}	.20	.10	.17*	
Step 3				.04 ⁺
CM Status	.68	.31	.22*	
RSA _{trans.box}	.06	.14	.05	
Step 4				.00
CM Status $\times$ RSA _{trans.box}	-.17	.22	-.10	
Total R^2				.30

Note:

⁺ $p < .10$.

* $p < .05$.

** $p < .01$.

Steps 1 and 2 are identical for all three models. *B* =unstandardized beta coefficient. *SE (B)* =standard error of unstandardized beta coefficient. β =standardized beta coefficient. R^2 =*R* square change value.