Received: 3 September 2018 | Revised: 4 November 2018 | Accepted: 5 November 2018
DOI: 10.1002/dev.21812

RESEARCH ARTICLE

WILEY Developmental Psychobiology

Parasympathetic regulation in cognitive and emotional challenge contexts differentially predicts specific aspects of children's emotional functioning

Laura E. Quiñones-Camacho | **Elizabeth L. Davis**

Department of Psychology, University of California, Riverside, California

Correspondence
Elizabeth L. Davis, Department of Psychology, University of California, Riverside, CA.
Email: elizabeth.davis@ucr.edu

Funding information
The first author was supported by a National Science Foundation Graduate Research Fellowship (NSF DGE-1326120).

Abstract

Parasympathetic regulation has been consistently linked with better emotional functioning in childhood, but it is still not clear if parasympathetic regulation serves as a transcontextual marker of adaptive emotional functioning or if this link is context-specific. This study tested this by examining the specificity of the relation between parasympathetic regulation in distinct types of challenge tasks and different aspects of children's emotional functioning. Emotional functioning included parent-reported emotional reactivity, parent-reported general emotion regulation ability, and child-reported emotion regulation strategy knowledge. One hundred and forty-four 4- to 9-year-olds (*M* = 6.88 years; *SD* = 1.80; 52% girls) participated in a cognitive (inhibitory control) and two discrete emotional (disappointing, fear-eliciting) challenges. Resting and reactive indices of respiratory sinus arrhythmia quantified parasympathetic regulation. Emotional reactivity was predicted by parasympathetic regulation during the cognitive challenge, general emotion regulation was predicted by regulation during the fear-eliciting task, and emotion regulation strategy knowledge was predicted by regulation during the disappointment task. Results highlight the importance of considering task context in investigations of how parasympathetic regulation relates to children's functioning.

KEYWORDS
context, emotion regulation, emotional reactivity, parasympathetic regulation, resting RSA, RSA reactivity

1 | INTRODUCTION

Theories on the function of the parasympathetic nervous system (PNS) have long argued that the PNS evolved to support the neurophysiological foundations of affective processing and is thus implicated in adaptive emotional functioning and self-regulation (Porges, 1995, 2011; Thayer & Brosschot, 2005; Thayer & Lane, 2009). In fact, better parasympathetic regulation (in the form of higher resting parasympathetic function and moderate changes in parasympathetic activity in response to a challenge) consistently correlates with and predicts better emotional functioning (Calkins, 1997; Calkins & Keane, 2004). Although the importance of PNS functioning for emotional development has been established, it is unclear whether PNS regulation is a transcontextual marker of adaptive functioning, as would be suggested by measures of PNS functioning that predict adaptive responding independent of the specific outcome, or if the link to adaptive responding is specific to certain task contexts and emotional functioning outcomes. This study addresses recent calls to characterize children's emotional functioning by clarifying our understanding of the role of context (e.g., Hastings, Klimes-Dougan, Kendziora, Brand, & Zahn-Waxler, 2014) by examining PNS regulation and its links to emotional functioning across multiple tasks.

1.1 | Is parasympathetic regulation a transcontextual or context-dependent marker of adaptive emotional functioning?

Respiratory sinus arrhythmia (RSA) refers to high-frequency heart rate variation in the range of normal respiration that is controlled by efferent fibers of the vagus nerve and has often been used to study the relation between the PNS and affective functioning (Calkins & Keane, 2004; Obradović, Stamperdahl, Bush, Adler, & Boyce, 2010). Changes in the magnitude of RSA from rest to a task indicate active PNS functioning (Porges, 2007). Decreases in RSA, or RSA suppression, are thought to be elicited by threatening or challenging stimulus that require the mobilization of resources for active coping (Hastings & Miller, 2014). In contrast, increases in RSA, or RSA augmentation, are usually observed when the task/stimulus is not particularly threatening or challenging, supporting calm engagement with the task. By measuring RSA across tasks, it is possible to assess PNS functioning in a more dynamic way, as the demands of each task will result in different patterns of decreases or increases in RSA (Porges, 2007). Thus, in the current study, we aimed to explore multiple contexts that would be likely to elicit different patterns of RSA. By exploring disparate contexts including a cognitive (neutral task), a fear-inducing (or threatening) task, and a disappointing (but not threatening) task, we are able to offer an empirical test of these theorized links.

Because the PNS is essential for the body's calming response, theoretical accounts of PNS function have highlighted its role in self-regulation processes (Porges, 1995; Thayer & Brosschot, 2005; Thayer & Lane, 2009). By enabling control over one's behavioral and physiological responses, the PNS supports the ability to actively regulate arousal (Porges, Doussard-Roosevelt, & Maiti, 1994). Because of this, Porges has argued that the PNS has evolved to support the neurophysiological foundations of emotional functioning (Porges, 1995, 2011; Porges et al., 1994). Supporting this theorized link, research examining the relation between emotional functioning and RSA has found that higher resting levels of RSA are associated with better functioning across a wide range of domains, including social competence and emotion regulation (Calkins, 1997; Calkins & Keane, 2004; Obradović et al., 2010). Moreover, some studies have also shown links between PNS functioning, both resting and reactivity measures, and maladaptive outcomes such as internalizing and externalizing symptoms, highlighting the importance of PNS functioning for emotional functioning more broadly (e.g., Hinnant & El-Sheikh, 2009).

Although RSA has been theorized to be a transcontextual marker of adaptive functioning, findings from recent studies suggest that the link between PNS regulation and socio-emotional outcomes is more complex than previously hypothesized (Buss, Davis, Ram, & Coccia, 2018; Calkins, Graziano, & Keane, 2007; Hastings et al., 2014; Hinnant & El-Sheikh, 2009). For example, meta-analytic associations suggest that the link between PNS regulation during cognitive challenges and adaptive functioning is slightly smaller than for PNS regulation in emotional challenges (Graziano & Derefinko, 2013), suggesting that different reactivity contexts may tap into distinct (albeit related) elements of parasympathetic regulation. Moreover, although RSA suppression may be the most adaptive physiological response in some contexts (e.g., a cognitively demanding engaging task; Quas, Bauer, & Boyce, 2004), this is not necessarily true for contexts in which someone is attempting to enact or maintain a calming response (e.g., when faced with a sad film; Davis, Quiñones-Camacho, & Buss, 2016). What constitutes the "most adaptive" pattern of RSA reactivity will thus be constrained by the specific task context. Recently, there has been an acknowledgment that the choice of tasks in which RSA is measured should influence how measures of RSA relate to adaptive functioning (Graziano & Derefinko, 2013; Hastings et al., 2014), but more research is needed to fully delineate the important differences among distinct contexts and the role of resting RSA in constraining these patterns.

A recent meta-analysis found that children with higher resting RSA showed more RSA suppression during tasks (Graziano & Derefinko, 2013), suggesting that resting levels of RSA constrain children's reactivity. This is important, as not all studies consider both resting and reactivity measures within the same model. Although both resting and reactive measures of PNS regulation predict socio-emotional outcomes, examination of both at the same time seems to give unique insight. For example, Hinnant and El-Sheikh (2009) found that although children's RSA reactivity while overhearing an argument did not directly predict internalizing symptoms, it interacted with resting RSA to predict it. Resting RSA was positively associated with internalizing symptoms only for children who showed an increase in RSA during the argument. The authors also assessed RSA reactivity to a star-tracing task (a cognitive stressor). They found that children who showed an increase in RSA to the cognitive stressor at age eight showed higher levels of externalizing symptoms at age ten. Resting RSA was positively associated with symptoms only for children who showed a decrease from baseline during the challenge.

Although we know that PNS regulation differentially predicts adaptive outcomes depending on the kind of context that elicited the parasympathetic regulation (Calkins et al., 2007; Hastings et al., 2014; Hinnant & El-Sheik, 2009), greater insight is needed to fully understand the role of task contexts in these associations. The few studies that have explored multiple contexts point to the importance of considering different task contexts when interpreting the link between PNS function and emotional functioning. Hastings and colleagues (2014) explored the role of RSA reactivity to scary and sad films on adolescents' internalizing symptoms. They found that more RSA suppression to a sad film predicted more internalizing symptoms only for girls, whereas more RSA suppression to fear-eliciting films interacted with parenting to predict internalizing symptoms. Calkins and colleagues (2007) explored differences in patterns of RSA reactivity across cognitive (effortful control task) and emotional (frustration task) contexts for 5-year-old children with and without behavioral problems. They found that children with mixed behavioral problems (children with more internalizing *and* externalizing symptoms) showed a different pattern of RSA responding than did children with greater externalizing symptoms only. But this study evaluated only one negative context, limiting what can be said about patterns across negative emotions. The study by Hastings and colleagues (2014) suggests that tasks that elicit different negative emotions should give rise to different patterns of RSA reactivity and that these should differentially relate to adaptive functioning. This is important, as the dysregulation of specific emotions (e.g., sadness) is often more strongly related to some behavioral problems than others (e.g., depression but not conduct problems). It is still not entirely clear, however, if these different patterns of physiological responding would be relevant for emotional processes that precede the emergence of disorders (e.g., poor emotion regulation). Thus, in the current study, we extend this work by focusing on precursors of psychopathology (i.e., poor emotional functioning) in childhood using a thorough investigation of different emotional contexts to elucidate the role of PNS functioning in the processing of emotions, and in turn, its implications for adaptive functioning.

1.2 | Emotional functioning in childhood

Emotional functioning encompasses children's reactivity to emotional situations and regulation of emotions and has been linked to better problem solving, academic achievement, and peer acceptance, as well as a reduced risk of psychopathology (Carthy, Horesh, Apter, Edge, & Gross, 2010; Cisler, Olatunji, Feldner, & Forsyth, 2010; Denham et al., 2003; Kim & Deater-Deckard, 2011; Raver et al., 2011; Suveg & Zeman, 2004). Emotional reactivity refers to characteristics of emotional responding, such as the intensity with which an emotion is experienced, the sensitivity to stimuli that could generate emotional responses, the expression of an emotion, as well as difficulties recovering from negative reactions (Carthy et al., 2010; Kim-Spoon, Cicchetti, & Rogosh, 2013). Emotion regulation refers to the ways in which we change our emotional experiences in the service of our goals and motivations (Campos, Mumme, Kermoian, & Campos, 1994; Campos, Frankel, & Camras, 2004). Difficulties with appropriate reactivity to and regulation of negative emotions have been linked to many negative outcomes such as more anxiety and depression symptoms (Carthy et al., 2010; Suveg & Zeman, 2004); thus, a greater understanding of the contexts under which a link between PNS regulation and emotional functioning is present or attenuated would help us understand how patterns of PNS functioning relate to maladaptive developmental trajectories in childhood.

1.2.1 | Emotional reactivity

Although interpersonal variability in emotional reactivity is normative, some children show intense and frequent negative emotional responses that comprise hyper-reactivity to emotional information from the environment (Carthy et al., 2010). This hyper-reactivity has been linked with dysregulated physiology in the form of amygdala hyper-activation and increased heart rate (Goldin, Manber, Hakimi, Canli, & Gross, 2009; Killgore & Yurgelun-Todd, 2005; Weems, Zakem, Costa, Cannon, & Watts, 2005). Thus, physiological measures can offer important information about emotional reactivity and changes in emotional reactivity throughout childhood, but more work is needed to delineate the role physiological regulation under various contexts plays in this.

1.2.2 | Emotion regulation

Because problems with emotion regulation (broadly defined) have been linked with negative developmental outcomes (Cisler et al., 2010), many studies focused on emotion regulation have used broad measures of children's general ability to calm themselves. But, measures of more specific emotion regulation processes, such as measures of children's emotion regulation strategy knowledge, are necessary to further our understanding of children's PNS functioning and emotion regulation. As children develop, emotion regulation strategy use shifts from relying on external and behavioral sources of regulation to more sophisticated, self-generated cognitive ways of dealing with emotions (Braungart & Stifter, 1991; Davis et al., 2010). Rather than replacing simpler behavioral strategies, these cognitive strategies are added to children's repertoires, providing more options for managing emotional experiences. Children's strategy knowledge represents a novel aspect of emotional functioning that is often obscured in studies that examine only parents' perceptions of a child's regulatory ability.

1.3 | Current study

The goal of this study was to test whether PNS regulation is better viewed as a transcontextual marker or as a context-specific marker of emotional functioning. To clarify the findings from past studies that have explored links between some aspects of emotional functioning and RSA reactivity in the childhood years, we chose to study these relations in a sample of 4- to 9-year-old children. We measured PNS functioning during a resting baseline and throughout three challenge contexts (a cognitive task, a fear-eliciting task, and a disappointment task). We explored how these PNS assessments related to three aspects of children's emotional functioning: parent-reported emotional reactivity, parent-reported general emotion regulation, and child-described emotion regulation strategy knowledge. Although we expected greater RSA reactivity during the challenge tasks would be positively associated with emotional functioning, we had no a priori hypotheses about the most adaptive patterns for each outcome. But, based on previous studies showing that different tasks elicit different types of RSA reactivity (i.e., suppression vs. augmentation; e.g., Hastings et al., 2014), we expected the direction of reactivity that would be most adaptive for each outcome to vary based on the nature of the challenge and the emotional functioning outcome being considered.

2 | METHOD

2.1 | Participants

One hundred and forty-four 4- to 9-year-old children (*M* = 6.88; *SD* = 1.80; 52% girls) and their caregivers participated in a biobehavioral study of socio-emotional development. Participants were recruited from inland southern California at public events, child development centers, and by posting fliers in public places. The sample was ethnically diverse and representative of the area; Hispanic (29%), Caucasian (18%), African-American (10%), Asian (2%), other (2%), or belonging to more than one racial/ethnic group (36%). Parents did not report this information for 3% of children. One caregiver accompanied the child to the laboratory, resulting in 24 fathers and 114 mothers taking part in this study (6 parents did not report gender). Families received an honorarium for their participation, and children took home a small toy. Study procedures were approved by the institutional review board. Written consent was obtained from parents, and assent (verbal only, or verbal and written for children seven years and older) was obtained from children.

2.2 | Procedure

Families came to the laboratory for a 3.5-hr visit. Parents provided information about themselves, their family, and their children via surveys. While the parents completed the questionnaires, the children were brought to another room where they took part in a series of brief tasks. Cardiovascular electrocardiogram (ECG) data were collected continuously during the laboratory visit. Seven self-adhesive electrodes were placed on the child's torso by a trained experimenter, and ambulatory devices wirelessly transmitted the acquired data to a computer in the laboratory control room. The child was asked to sit quietly for a few minutes after acclimating to wearing the sensors, to enable the first baseline of cardiac physiology to be obtained. After this, children completed several tasks, including the inhibitory control task (go/no-go), and the two emotion-eliciting tasks, all of which were used to derive RSA reactivity. Because behavioral measures during these tasks are also meaningful for our understanding of emotional responding in childhood (e.g., expressed distress during the disappointment task), we included behavioral measures from each task as covariates in analyses.

2.2.1 | Cognitive task

To assess inhibitory control, children completed a go/no-go task that was done before any emotion elicitation. Children played a short game on a computer, presented in E-Prime, in which they saw cartoon images of Pokémon and pressed the space bar as fast as they could whenever a Pokémon character appeared (the "go" stimuli). They were told to refrain from pressing the spacebar when a specific Pokémon (Meowth) appeared (the "no-go" stimulus). Children were given five practice trials, including go and no-go trials, to ensure comprehension. The task consisted of 75 trials (63 "Go" trials and 12 "No-Go" trials). For each trial, children saw a Pokéball for 5 s and were then presented with the target for a total of 3 s. Given how high accuracy was for this task (*M* = 92% *SD* = 12%), we used response times to correct "go" trials in analyses as a covariate. The task took about 10 min to complete.

2.2.2 | Emotion regulation interview

Next, children were interviewed about recent events that had made them feel anger, fear, and sadness. The order of the emotions was constant across participants (sad, fear, anger). The experimenter said, "*I'd like to know about a time recently that you felt VERY [ANGRY/SCARED/SAD]. Please take a few moments to think about and remember a time recently when you felt VERY [ANGRY/SCARED/SAD]. Think about what happened and about all of the little details you can remember about it.*" After this, the experimenter gave the child a minute to think about a *recent* event they had experienced that made them feel the target emotion and were given a piece of paper and writing/drawing implements to use if they liked. Children were asked the same question for each emotion separately. After the minute had passed, the experimenter asked the child to say as many details as possible about the events. After three prompts, the experimenter asked the child to report what they had done to make themselves feel better after they had experienced that by saying, "*When you felt that way, what did you try to do or think about to make yourself feel LESS [ANGRY/SCARED/SAD]?*" followed by two additional prompts (e.g., "*What else did you do?*," "*What other things did you do or think about?*"). Children were asked to provide information about their strategy use three times in each discrete emotion phase of the interview, but they could say as many things as they wanted for each of the prompts. Our strategy repertoire measure was derived from the set of open-ended questions and prompts about emotion regulation (described below).

2.2.3 | Fear-eliciting episode

The fear-eliciting episode took place immediately after children were given a snack break designed to facilitate their return to a neutral emotional state. The fear-eliciting task was adapted from the *Playing with Masks* LabTAB temperament assessment task that has been widely used with toddlers and young children (Buss & Goldsmith, 2000). The episode involves an unusual social interaction with an unfamiliar adult and is designed to provoke mild wariness. In this adaptation of the task, an unfamiliar female experimenter wearing a mask and a hooded sweatshirt waited in an observation room for the participant to enter. After the snack break, the experimenter guided the child into this room, asked the child to sit on the couch, then left the room and closed the door. Once the door closed, the unfamiliar experimenter turned to face the child and stood (without speaking) for 15 s. Then, she took one step toward the child, continued to make eye contact, and remained silent for another 15 s. Then, while still wearing the mask, she said, "*Hi, my name is Jamie*," in a neutral tone of voice. After an additional 15 s, the experimenter removed the mask and said, "*Hi! I was just playing with some Halloween costumes. Would you like to touch the mask? Go ahead and touch the eyes. Now let's touch the nose together.*" She then offered the mask to the child to touch, play with, or try on and left the room. The entire task took about two minutes. The behavioral distress children exhibited during this episode was globally coded by trained research assistants based on the intensity and the duration of children's observed distress behavior. Levels of distress were differentiated based on the duration and frequency of distress behaviors throughout the task (5 = *high distress;* 1 = *low distress*). For example, a child who was smiling, comfortably talking, and showing no outward signs of distress was coded as a 1. In contrast, a child who screamed when they saw the mask, ran to the opposite side of the room, and/or started crying was coded as a 5. Inter-rater reliability was calculated for 80% of the files and was good (k = 0.86). This distress code was included in analyses as a covariate.

2.2.4 | Disappointment episode

Soon after arriving at the laboratory, children were asked to rank six toys from most to least preferred and were told they would receive their preferred toy at the end of the visit. After doing all the other activities, the experimenter told the child that he will receive a prize for the great job he had done. The experimenter proceeded to give the child a gift box and told him to open it. The box contains the toy that was ranked as the least desirable by the child, which was also broken. After one minute with the experimenter, the child was left alone for another minute; then, the parent was asked to enter the room to interact with the child however they normally would. This task took about three minutes; we focused on the first minute (when children initially experienced the disappointment). The other two minutes were considered to be recovery periods. Videos for this task were also globally coded for level of distress using the same scale as above (5 = *high distress;* 1 = *low distress*) based on the intensity and the duration of distress/negative behaviors shown during the task. Similar to the fear task, a score of 1 of distress was given to children who showed no distress during the task, and a score of 5 was given to children who showed high signs of distress, such as crying, throwing the box, or screaming to the experimenter. Inter-rater reliability was again calculated for 80% of the files and was excellent (k = 0.83). This code was included in analyses as a covariate.

2.3 | Stimuli and measures

2.3.1 | Emotional reactivity and general emotion regulation

Children's emotional reactivity and general emotion regulation ability were measured using the parent-report *Emotion Regulation Checklist* (ERC; Shields & Cicchetti, 1997). The ERC consists of 24 items that form an emotion regulation and an emotional reactivity subscale. The emotional reactivity subscale consists of 16 items (e.g., "exhibits wide mood swings"). The emotional regulation subscale consists of 8 items (e.g., "Can modulate excitement in emotional arousing situations"). Parents responded on a 4-point scale how much their child was like the child described in each statement (4 = *always*; 1 = *never*), and responses were averaged to create the subscale score. Higher scores indicate more emotional reactivity and better emotion regulation. The internal consistency in our sample was good for the emotional reactivity subscale (α = 0.78), but poor for the emotion regulation subscale (α = 0.51). Exclusion of the item, "Displays appropriate negative emotions in response to hostile, aggressive, or intrusive acts by others" improved internal consistency for this scale, so we dropped this item and used the mean of the other seven items to create the measure of emotion regulation ability used in analyses (α = 0.66).

2.3.2 | Emotion regulation strategy repertoire

Responses to the emotion regulation interview were transcribed, and strategies were coded using a coding scheme used in previous work (e.g., Quiñones-Camacho & Davis, 2018). The coding scheme included multiple strategies used to create our repertoire measure to better capture children's knowledge of strategies (Table 1). The inter-rater reliability for this coding was calculated on 30% of responses and was very good (k = 0.87). We operationalized strategy repertoire as the total number of unique strategies (e.g., cognitive reframing, cognitive distraction) reported across all emotions. If a child endorsed the same strategy more than once during the interview (e.g., described distraction to manage the sad and the scary event), this counted only once in the repertoire measure.

2.4 | RSA

Electrocardiograph (ECG) data collected during (1) a resting baseline (after consent, but before any task), (2) an inhibitory task, (3) a fear-eliciting task, and (4) a disappointment task were used. For the baseline, children were asked to sit quietly and look at a book, complete a simple puzzle, or do some coloring for five minutes. These instructions were meant to calm children and minimized gross motor movements. After the baseline, children completed the go/no-go computer tasks. The emotion-eliciting tasks took place later in the visit. RSA was calculated offline using the Mindware Heart Rate Variability (HRV 3.0.2) software program. The high-frequency bandpass range for children in this sample (middle childhood) was derived from estimates of the average respiration rates of children in this age range (i.e., typically between 16 and 25 breaths per minutes) and set at 0.15–0.80 Hz (e.g., Johnson et al., 2017; Quiñones-Camacho & Davis, 2018). This somewhat conservative range was chosen to fall between the recommended range used for early childhood (0.24–1.04 Hz; Bar-Haim, Marshall, & Fox, 2000) and adults (0.12–0.40 Hz; Porges, 1986). Adjusting these parameters to fall between the early childhood and adult ranges has been used in previous studies with wide age ranges like this one (Porges et al., 2013; Quiñones-Camacho & Davis, 2018). RSA was reliably scored in 30-s epochs, and RSA for baseline and tasks was calculated by averaging all epochs available for that task. Coders' scored RSA values for each 30 s epoch had to fall within 0.1 of each other to be considered reliable; 25% of the epochs were double scored

TABLE 1 Emotion regulation strategy coding

Emotion regulation strategy	Example
Problem-focused/ Problem-solving	
Goal reinstatement	"I turned on the light"
Agent focused	"I kicked him back"
Change thoughts	
Cognitive reframing	"I was thinking about how it wasn't real"
Cognitive distraction	"I thought about ice cream"
Thought suppression	"I forgot about it"
Sleep/Change mental state	"I took a nap"
Imagined social support	"I thought someone was sleeping right next to me"
Other	
Change Goals	
Goal substitution	"Went around Sea World with family to see everything instead of going on the ride"
Goal forfeit	"I decided not to play anymore"
Expressive suppression	"I tried not to cry"
Avoidance/Withdrawal	"I tried to leave the funeral"
Behavioral distraction	"Just sat there and watched tv"
Social support	
Sought	"Talked to my mom"
Received	"Mom came inside to watch me play"
Other	
Did nothing	
Acceptance of emotion	"I just cried"
Did nothing	"I didn't do anything"
Religious Activity	
Prayed	"I prayed"
Religious ritual	"Went to church"
Change physiological experience	
Breathing	"Took a breath"
Calm Down	"Try to calm down"
Other	

(percent agreement for RSA values within 0.1 = 97%; e.g., Davis et al., 2016).

RSA reactivity was calculated as the difference from initial resting baseline to the given task (task – baseline). Negative RSA reactivity scores represent suppression (decreased RSA in response to a task), and positive scores represent augmentation (increased RSA in response to a task). There was some variability in the patterns for the children in the study, but most participants showed augmentation to each task. A total of 9 (7%) children showed suppression during the inhibitory control task, 44 (35%) children showed suppression during the fear-eliciting task, and 33 (26%) showed suppression during the disappointment task.

TABLE 2 Means and standard deviations of key study variables

	Mean	SD	Range
Cognitive task RT	1,092.07	288.31	582.25–1881.54
Distress to disappointment task	1.88	0.68	1.00–3.00
Distress to fear-eliciting task	1.99	1.20	1.00–5.00
Resting RSA	6.44	1.09	3.52–9.50
RSA reactivity to cognitive task	0.75	0.56	−1.17–2.39
RSA reactivity to disappointment task	0.52	0.82	−1.44–3.42
RSA reactivity to fear-eliciting task	0.46	1.16	−1.64–6.36
Emotional reactivity	1.79	0.48	1.00–3.67
General emotion regulation	3.39	0.43	2.14–4.00
Strategy knowledge repertoire	3.23	1.48	0.00–8.00

Note. Values for the original data before the multiple imputation; RT = Reaction Time.

3 | RESULTS

3.1 | Preliminary analyses

We first examined whether any of our variables of interest differed by gender. There were no differences between boys ($n = 69$) and girls ($n = 75$) for most variables, all $ts < 1.502$, $ps > 0.135$. The only gender difference was in emotional reactivity ($t_{110.903} = 3.306$, $p = 0.001$, $d = 0.628$), such that boys ($M = 1.931$, $SD = 0.552$) were rated as more reactive than girls ($M = 1.666$, $SD = 0.368$). Because of this, gender was covaried in analyses.

3.2 | Missing data analyses

Eighteen participants were missing some or all data. RSA variables had the most missingness, due to movement artifacts, electrodes falling off, or children touching the electrodes. Ten children were missing resting RSA data, 12 were missing RSA from the Go/No-Go task, 16 were missing RSA from the fear episode, and 18 were missing RSA for the disappointment task. Because resting RSA was part of the reactivity calculations, the 10 children who did not have resting RSA data also did not have RSA reactivity data. To retain all of our participants, we multiply imputed missing data, an approach that is recommended over listwise deletion (Royston, 2004). Ten imputed datasets were computed using SPSS 24.0 and pooled estimates are reported in all subsequent analyses.

TABLE 3 Bivariate correlations among key study variables

	1	2	3	4	5	6	7	8	9	10	11
1. Cognitive task RT	–										
2. Distress to disappointment task	0.087	–									
3. Distress to fear task	0.217*	−0.113	–								
4. Resting RSA	−0.038	−0.213*	0.029	–							
5. RSA reactivity to cognitive task	−0.035	−0.024	−0.051	−0.295**	–						
6. RSA reactivity to disappointment task	0.036	−0.030	−0.032	−0.184*	0.366**	–					
7. RSA reactivity to fear task	−0.093	0.026	−0.245**	−0.410**	0.363**	0.381**	–				
8. Emotional reactivity	−0.151	−0.018	−0.120	−0.106	0.028	−0.012	0.079	–			
9. General emotion regulation	0.199*	−0.025	0.144	0.110	−0.148	0.030	−0.272**	−0.503**	–		
10. Strategy knowledge repertoire	−0.069	−0.042	−0.302**	0.196*	−0.052	0.007	0.008	0.025	0.006	–	
11. Age	−0.505**	−0.078	−0.334**	0.160	−0.061	−0.121	0.083	0.187*	−0.203*	0.334**	–

Note. Correlations represent the pooled results with the 10 imputed data sets; *$p < 0.05$; **$p < 0.01$

3.3 | Descriptive statistics

Descriptive statistics are given in Table 2, and bivariate correlations are presented in Table 3. Resting RSA was negatively correlated with RSA reactivity to the cognitive task ($r = -0.295$, $p = 0.001$), RSA reactivity to the disappointment task ($r = -0.184$, $p = 0.048$), and RSA reactivity to the fear-eliciting task ($r = -0.410$, $p < 0.001$), such that higher resting RSA was associated with less augmentation/greater RSA suppression in all contexts. All three reactivity variables were positively correlated, such that greater augmentation in one task was associated with greater augmentation in the other tasks. RSA reactivity to the fear-eliciting task was negatively correlated with distress during the fear task ($r = -0.245$, $p = 0.008$), such that greater RSA suppression to the fear task was associated with greater behavioral distress during the task. RSA reactivity to the fear task was also negatively correlated with parent-reported emotion regulation ability ($r = -0.272$, $p = 0.002$), such that greater RSA suppression in the fear-eliciting task was associated with better emotion regulation. Distress during the disappointment task was associated with resting RSA ($r = -0.213$, $p = 0.018$), such that children with higher resting RSA showed less distress. Resting RSA was also associated with child-reported emotion regulation strategy knowledge ($r = 0.196$, $p = 0.022$), such that higher resting RSA was associated with larger strategy repertoires. Distress during the fear-eliciting task was associated with strategy repertoire ($r = -0.302$, $p < 0.001$), such that having a larger repertoire was associated with showing less distress during the task. Lastly, reaction times on the cognitive task were positively associated with parent-reported emotion regulation ability ($r = 0.199$, $p = 0.047$), such that slower reaction times were associated with better emotion regulation.

Children's age was associated with reaction times to the cognitive task ($r = -0.505$, $p < 0.001$), emotional reactivity ($r = 0.187$, $p = 0.032$), and general emotion regulation ($r = -0.203$, $p = 0.019$). Age was also correlated with strategy repertoire ($r = 0.334$, $p < 0.001$), such that being older was associated with a larger repertoire. Lastly, age was correlated with distress during the fear-eliciting task ($r = -0.344$, $p < 0.001$). Younger children showed greater distress during the task. Given these patterns, age was covaried in the regression models.

3.4 | RSA reactivity comparisons across tasks

First, we conducted paired-sample *t*-tests between resting RSA and RSA during each of the tasks; all comparisons were significant. Children's RSA during the inhibitory control task ($M = 7.19$, $SE = 0.095$) was higher than RSA during the baseline ($M = 6.44$, $SD = 0.097$), $t_{(143)} = 13.724$, $p < 0.001$. The same was true for the fear-eliciting task ($M = 6.90$, $SD = 0.111$) $t_{(143)} = 4.415$, $p < 0.001$, and for the disappointment task ($M = 6.93$, $SD = 0.111$) $t_{(143)} = 7.147$, $p < 0.001$. Then we conducted paired-sample *t*-tests to compare RSA reactivity measures. RSA reactivity (the change from baseline to task) was significantly different for the inhibitory control task ($M = 0.75$, $SE = 0.055$) versus the fear-eliciting task ($M = 0.46$, $SD = 0.103$), with children showing more augmentation to the inhibitory control task, $t_{(143)} = 3.105$, $p = 0.002$. A similar pattern emerged for the difference between the inhibitory control task ($M = 0.75$, $SE = 0.055$) and the disappointment task ($M = 0.52$, $SE = 0.073$). Children showed more augmentation to the inhibitory control task, $t_{(143)} = 3.036$, $p = 0.003$. But, children did not differ significantly in their level of augmentation to the disappointment task ($M = 0.52$, $SE = 0.073$) compared to the fear-eliciting task ($M = 0.46$, $SD = 0.103$), $t_{(143)} = 0.567$, $p = 0.571$.

3.5 | Is RSA reactivity a transcontextual or context-specific marker of emotional functioning?

Variables were mean-centered before the creation of the interactions and inclusion in the models. When relevant, interactions were plotted at points ±1SD (corresponding to low and high levels) from the mean (Aiken, West, & Reno, 1991). A total of 9 hierarchical linear regressions were conducted to test our expectation that the three components of emotional responding (emotional reactivity, general emotion regulation, and strategy repertoires) would be predicted by each of the three types of RSA reactivity (to the disappointing, fear-eliciting, and cognitive tasks). In the first step of each model, we entered age, gender, resting RSA, and the relevant behavioral measure for the task (e.g., behavioral distress during the fear task was included in models examining RSA reactivity to the fear-eliciting episode). In the second step, we entered RSA reactivity to the task (e.g., RSA reactivity to the fear task). At step 3, we entered the interaction between RSA reactivity for the specific task and resting RSA.

3.5.1 | Emotional reactivity

RSA reactivity during the cognitive task

The first step of the model resulted in a significant model, $F(4, 139) = 4.687$, $p = 0.002$ (Table 4a). Gender was a significant covariate ($b = -0.232$, $t = -2.979$, 95% CI [−0.386, −0.080]), such that girls were rated as being less reactive than boys. The second step resulted in a nonsignificant change to the model, $F\Delta(1, 138) = 0.265$, $p = 0.658$. At step 3, the addition of the two-way interaction between RSA reactivity during the cognitive task and RSA baseline improved the model, $F\Delta\ (1, 137) = 6.100$, $p = 0.016$. The interaction was significant ($b = 0.142$, $t = 2.418$, 95% CI [.027, 0.258]). Follow-up of the interaction of RSA reactivity to the cognitive task and resting RSA (Figure 1) suggests that for children with higher resting RSA, showing less augmentation during the cognitive task was associated with less emotional reactivity ($b = 0.172$, $p = 0.033$). In contrast, for children with lower resting RSA, RSA reactivity to the task was not associated with emotional reactivity ($b = -0.138$, $p = 0.185$).

RSA reactivity during the disappointment task

The first step of the model resulted in a significant model, $F(4, 139) = 4.546$, $p = 0.002$ (Table 4b). The addition of other terms in subsequent steps did not improve the model.

RSA reactivity during the fear task

The first step of the model resulted in a significant model, $F(4, 139) = 4.557$, $p = 0.001$ (Table 4c). The addition of other terms in subsequent steps did not improve the model.

Thus, RSA reactivity during an inhibitory control cognitive challenge emerged as a uniquely important psychophysiological factor in predicting children's emotional reactivity, and this effect was qualified by resting RSA. The typical pattern of higher RSA predicting better functioning, as evidenced by less emotional reactivity, was detected only for children who showed less RSA augmentation (greater RSA suppression) during the cognitive challenge.

3.5.2 | General emotion regulation

RSA reactivity during the cognitive task

The first step of the model resulted in a significant model, $F(4, 139) = 3.089$, $p = 0.023$ (Table 5a). The addition of RSA reactivity to the cognitive task and the two-way interaction did not improve the model.

RSA reactivity during the disappointment task

The first step of the model resulted in a significant model, $F(4, 139) = 2.566$, $p = 0.047$ (Table 5b). Neither the addition of RSA reactivity nor the two-way interaction improved the model.

RSA reactivity during the fear task

The first step resulted in a significant model, $F(4, 139) = 2.717$, $p = 0.040$ (Table 5c). The addition of RSA reactivity to the fear task resulted in a significant change to the model, $F\Delta(1, 138) = 6.440$, $p = 0.018$, such that more RSA suppression during the fear task was associated with better general emotion regulation ability ($b = -0.087$, $t = -2.426$, 95% CI [−0.157, −0.017]). The addition of the two-way interaction did not improve the model, $F\Delta\ (1, 137) = 0.244$, $p = 0.687$.

In summary, only RSA reactivity to the fear-eliciting task predicted children's general emotion regulation, such that children were reported as being more well-regulated as they showed greater RSA suppression (less RSA augmentation) during the fear-eliciting task.

3.5.3 | Emotion regulation strategy knowledge

RSA reactivity during the cognitive task

The first step of the model resulted in a significant model, $F(4, 139) = 6.707$, $p < 0.001$ (Table 6a). The addition of RSA reactivity to the cognitive task and the interaction did not improve the model.

RSA reactivity during the disappointment task

The first step resulted in a significant model, $F(4, 139) = 6.149$, $p < 0.001$ (Table 6b). The addition of RSA reactivity to the disappointment task did not improve the model, $F\Delta(1, 138) = 1.016$, $p = 0.343$. The addition of the two-way interaction between RSA reactivity to the disappointment task and resting RSA improved the model, $F\Delta\ (1, 137) = 6.687$, $p = 0.016$; the interaction was significant

TABLE 4 Regression model predicting emotional reactivity

	R^2	ΔR^2	ΔF	p	b	SEb	T	p
a. RSA cognitive task								
Step 1	**0.119**	**0.119**	**4.687**	**0.002**				
Sex					**−0.232**	**0.078**	**−2.979**	**0.003**
Age					0.041	0.027	1.507	0.132
Resting RSA					−0.059	0.036	−1.640	0.101
RT cognitive task					−0.000	0.000	−0.472	0.638
Step 2	0.120	0.001	0.265	0.658				
RSA reactivity to cognitive task					−0.026	0.077	−0.334	0.738
Step 3	**0.158**	**0.038**	**6.100**	**0.016**				
RSA reactivity to cognitive task × Resting RSA					**0.142**	**0.059**	**2.418**	**0.016**
b. RSA disappointment task								
Step 1	**0.116**	**0.116**	**4.546**	**0.002**				
Sex					**−0.236**	**0.078**	**−3.019**	**0.003**
Age					**0.047**	**0.023**	**2.084**	**0.037**
Resting RSA					−0.063	0.037	−1.716	0.086
Distress disappointment task					−0.028	0.060	−0.468	0.640
Step 2	0.116	0.000	0.150	0.763				
RSA reactivity to disappointment task					−0.011	0.051	−0.222	0.824
Step 3	0.124	0.008	1.179	0.529				
RSA reactivity to disappointment task × Resting RSA					0.048	0.069	0.698	0.487
c. RSA fear task								
Step 1	**0.115**	**0.115**	**4.557**	**0.001**				
Sex					**−0.234**	**0.078**	**−2.985**	**0.003**
Age					0.044	0.024	1.861	0.063
Resting RSA					−0.058	0.036	−1.610	0.107
Distress fear task					−0.015	0.035	−0.422	0.673
Step 2	0.116	0.001	0.189	0.718				
RSA reactivity to fear task					−0.009	0.041	−0.225	0.822
Step 3	0.117	0.001	0.067	0.816				
RSA reactivity to fear task × Resting RSA					−0.005	0.032	−0.144	0.885

Note. Steps include variables in previous steps of the model; Results with imputed datasets; RSA = Respiratory Sinus Arrythmia; RT = Response Time; $+p < 0.10$; $^*p < 0.05$; $^{**}p < 0.01$
Bold indicates significant effect of $p < 0.05$

($b = 0.421$, $t = 2.423$, 95% CI [0.080, 0.762]). Follow-up of the interaction (Figure 2) suggests that for children with higher resting RSA, showing more RSA augmentation to the disappointment task was associated with having a larger repertoire ($b = 0.656$, $p = 0.019$). On the other hand, for children with lower resting RSA, RSA reactivity to the disappointment task was not associated with their repertoire ($b = -0.268$, $p = 0.253$).

RSA reactivity during the fear task

The first step was significant, $F(4, 139) = 8.587$, $p < 0.001$, $R^2 = 0.198$ (Table 6c). The addition of RSA reactivity to the fear task and the interaction did not improve the model.

In summary, only RSA reactivity during the disappointment task predicted children's self-described emotion regulation strategy knowledge, and this effect was again moderated by resting RSA.

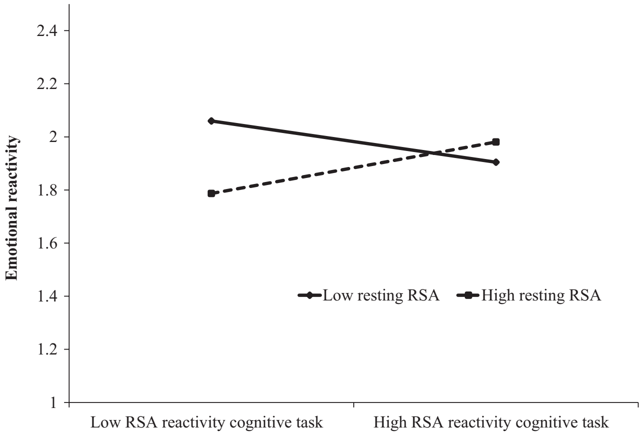

FIGURE 1 Two-way interaction of RSA reactivity to the cognitive task and resting RSA predicting emotional reactivity. Low resting RSA (solid line): $b = -0.138$, $t = -1.332$, $p = 0.185$; High resting RSA (dashed line): $b = 0.172$, $t = 2.153$, $p = 0.033$

Contrary to our findings for emotional reactivity and general emotion regulation, for child strategy knowledge it was RSA augmentation to the disappointment task coupled with higher resting RSA that was associated with larger repertoires.

4 | DISCUSSION

The goal of this study was to explore whether RSA reactivity is best thought of as a transcontextual or context-specific marker of emotional functioning in childhood. We explored how resting RSA and RSA reactivity during multiple task types (i.e., cognitive, fear-eliciting, and disappointing tasks) predicted three aspects of children's emotional functioning: emotional reactivity, general emotion regulation, and emotion regulation strategy knowledge. We found that RSA reactivity during the cognitive task interacted with resting RSA to predict parent-reported emotional reactivity, that RSA reactivity to the fear-eliciting task directly predicted better parent-reported general emotion regulation, and that RSA reactivity to the disappointment challenge interacted with resting RSA to predict children's self-described emotion regulation strategy repertoires. Thus, each RSA reactivity context we examined was linked with a specific aspect of emotional functioning, supporting the view of PNS regulation as a marker of adaptive emotional functioning that is context dependent rather than transcontextual. These findings certainly highlight the importance of considering contextual aspects of laboratory challenges when clarifying the role of physiology on healthy functioning (e.g., Hastings et al., 2014) and suggest the importance of thinking more deeply about the fit between the outcome being assessed and the task context used to elicit reactivity. As for the direction of RSA reactivity that was associated with better emotional functioning, as expected, we found that greater RSA suppression during the cognitive task and the fear-eliciting task, and greater RSA augmentation during the disappointment task predicted better emotional functioning. Thus, our findings add to a growing body of knowledge suggesting that the directionality (i.e., suppression vs. augmentation) of physiological reactivity that is most beneficial is dependent on the task demands (e.g., Calkins & Keane, 2004; Davis et al., 2016).

4.1 | Resting RSA and emotional functioning

Contrasting with the vast literature on this topic, we found that higher resting RSA was associated with emotion regulation strategy knowledge, but not other aspects of emotional functioning (Calkins, 1997; Calkins & Keane, 2004). A larger strategy repertoire in childhood reflects children's growing capacity to regulate their emotions (by suggesting a more extensive knowledge of strategies), and our finding that a larger repertoire was associated with higher resting RSA supports this idea. Our results that higher resting RSA was associated with a larger repertoire offer support for measures of strategy knowledge as a useful index of individual differences in children's growing regulatory abilities. Moreover, the fact that resting RSA contextualized the effects of RSA reactivity for two of our three outcomes aligns with recent calls to consider resting RSA in conjunction with reactivity to fully understand the role of reactivity in adaptive functioning (Graziano & Derefinko, 2013).

4.2 | RSA reactivity and emotional functioning

The most noteworthy pattern of findings from our study was that each outcome was predicted by a different RSA reactivity measure. Supporting previous research showing that greater suppression seems to be the most adaptive pattern of RSA reactivity to cognitive tasks (i.e., Quas et al., 2004), we found that for children with higher resting RSA, showing less augmentation (or suppression) to the cognitive task was associated with less emotional reactivity. However, it is important to highlight that on average, children showed augmentation to this task. It is possible that most children showed augmentation to this task because they did not find it particularly demanding, which allowed them to elicit a calming response while still engaging with the task. The high accuracy rate for this task >90% further suggests that this task might not have been perceived by the children in the study as particularly demanding, reducing the amount of resources that had to be deployed to perform well in the task. It makes sense that RSA reactivity to a cognitive task predicted emotional reactivity, as inhibitory control (the measure used for this task) might be particularly relevant for aspects of emotional functioning that are encompassed by emotional reactivity, such as the intensity with which one experiences an emotion and how sensitive one is to external input that might generate an emotional response. PNS regulation during a cognitive task might reflect a general ability to adaptively engage with the environment, and this might be more closely related to children's general tendencies for emotional reactions than it is to children's active regulation of negative emotions. This is important as difficulties with emotional reactivity might indicate an inability to adaptively engage with the environment and might serve as a precursor for later psychopathology.

TABLE 5 Regression model predicting parent-reported emotion regulation

	R^2	ΔR^2	ΔF	*p*	*b*	SE*b*	*T*	*p*
a. RSA cognitive task								
Step 1	**0.081**	**0.081**	**3.089**	**0.023**				
Sex					0.054	0.074	0.736	0.462
Age					−0.039	0.025	−1.538	0.125
Resting RSA					0.056	0.037	1.496	0.136
RT cognitive task					0.000	0.000	1.048	0.297
Step 2	0.095	0.014	2.005	0.179				
RSA reactivity to cognitive task					−0.093	0.069	−1.348	0.178
Step 3	0.095	0.000	0.143	0.753				
RSA reactivity to cognitive task × Resting RSA					−0.016	0.057	−0.282	0.778
b. RSA disappointment task								
Step 1	**0.069**	**0.069**	**2.566**	**0.047**				
Sex					0.058	0.074	0.783	0.434
Age					**−0.054**	**0.021**	**−2.515**	**0.012**
Resting RSA					0.057	0.037	1.547	0.123
Distress disappointment task					−0.007	0.057	−0.116	0.907
Step 2	0.070	0.001	0.256	0.718				
RSA reactivity to disappointment task					0.017	0.048	0.343	0.732
Step 3	0.082	0.012	1.750	0.332				
RSA reactivity to disappointment task × Resting RSA					0.059	0.068	0.860	0.394
c. RSA fear task								
Step 1	**0.073**	**0.073**	**2.717**	**0.040**				
Sex					0.056	0.074	0.753	0.451
Age					**−0.048**	**0.022**	**−2.132**	**0.033**
Resting RSA					0.055	0.036	1.531	0.127
Distress fear task					0.024	0.033	0.735	0.462
Step 2	**0.114**	**0.041**	**6.440**	**0.018**				
RSA reactivity to fear task					**−0.087**	**0.036**	**−2.426**	**0.015**
Step 3	0.118	0.004	0.244	0.687				
RSA reactivity to fear task × Resting RSA					−0.010	0.031	−0.308	0.758

Note. Steps include variables in previous steps of the model; Results with imputed datasets; RSA = Respiratory Sinus Arrythmia; RT = Response Time; $+p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$

Bold indicates significant effect of $p < 0.05$

When looking at children's emotion regulation, the fact that better emotion regulation was predicted by greater physiological suppression during an emotional task is not new, but the fact that this was dependent on the discrete emotional context (fear but not disappointment) is highly novel. It is possible that these different patterns emerged because of the nature of our laboratory tasks. Our fear-eliciting task was a quick and unexpected negative event where the child had no control over the situation. Because of the uncontrollable nature of the emotion-inducing task, it is likely that children would have attempted to regulate their emotions in ways that are natural for them and require less effortful regulation. Given this, the implicit forms of regulation that would arguably be captured by general measures of children's regulatory ability, such as children's attention shifting, would have been most directly relevant during this task, potentially explaining why we saw the association for our general measure but not our strategy measure.

TABLE 6 Regression model predicting child-reported emotion regulation strategy knowledge

	R^2	ΔR^2	ΔF	*p*	*b*	SE*b*	*T*	*p*
a. RSA cognitive task								
Step 1	**0.161**	**0.161**	**6.707**	**<0.001**				
Sex					0.370	0.237	1.566	0.117
Age					**0.321**	**0.079**	**4.083**	**<0.001**
Resting RSA					0.186	0.110	1.695	0.090
RT cognitive task					0.001	0.000	1.203	0.230
Step 2	0.163	0.002	0.186	0.691				
RSA reactivity to cognitive task					0.087	0.219	0.399	0.690
Step 3	0.165	0.002	0.317	0.625				
RSA reactivity to cognitive task × Resting RSA					0.089	0.183	0.487	0.627
b. RSA disappointment task								
Step 1	**0.150**	**0.150**	**6.149**	**<0.001**				
Sex					0.384	0.227	1.617	0.106
Age					**0.271**	**0.0267**	**4.056**	**<0.001**
Resting RSA					0.199	0.114	1.747	0.081
Distress disappointment task					0.038	0.180	0.209	0.834
Step 2	0.156	0.006	1.016	0.343				
RSA reactivity to disappointment task					0.141	0.149	0.946	0.344
Step 3	**0.196**	**0.040**	**6.687**	**0.016**				
RSA reactivity to disappointment task × Resting RSA					**0.421**	**0.174**	**2.423**	**0.016**
c. RSA Fear Task								
Step 1	**0.198**	**0.198**	**8.587**	**<0.001**				
Sex					0.416	0.230	1.810	0.070
Age					**0.202**	**0.069**	**2.938**	**0.003**
Resting RSA					−0.059	0.037	−1.593	0.111
Distress fear task					0.027	0.068	0.403	0.687
Step 2	0.198	0.000	0.033	0.878				
RSA reactivity to fear task					0.013	0.112	0.116	0.907
Step 3	0.207	0.009	1.582	0.269				
RSA reactivity to fear task × Resting RSA					−0.110	0.100	−1.096	0.274

Note. Steps include variables in previous steps of the model; Results with imputed datasets; RSA = Respiratory Sinus Arrythmia; RT = Response Time; $+p < 0.10$; $*p < 0.05$; $**p < 0.01$
Bold indicates significant effect of $p < 0.05$

The nature of our disappointing task offers a clue as to why this task context was a meaningful predictor of children's emotion regulation strategy knowledge. The experience of disappointment (or sadness) often requires finding different ways of thinking about the disappointing experience and engaging in other forms of cognitive regulation, especially in social contexts like this laboratory task. This process of internally regulating the experience of disappointment arguably reflects more flexible forms of regulation that are difficult to capture with general measures of emotion regulation but emerge more clearly in measures of children's self-described knowledge of emotion regulation strategies.

Additional to the discrete emotion differences in these patterns, it is also important to highlight that the directionality of RSA

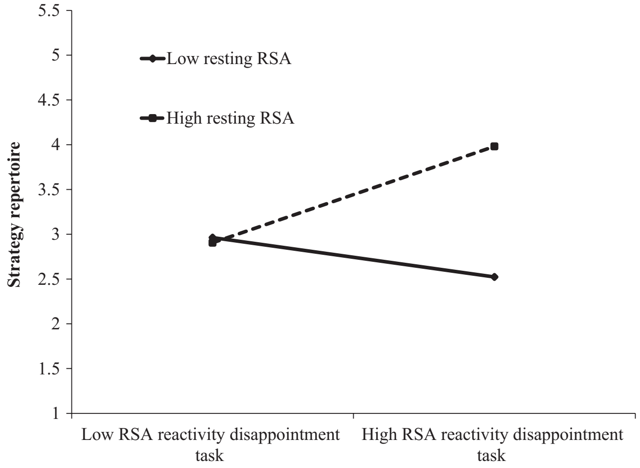

FIGURE 2 Two-way interaction of RSA reactivity to the disappointment task and resting RSA predicting emotion regulation strategy repertoire. Low resting RSA (solid line): *b* = −0.268, *t* = −1.147, *p* = 0.253; High resting RSA (dashed line): *b* = 0.656, *t* = 2.372, *p* = 0.019

reactivity that seemed to be linked to the most adaptive pattern of emotional functioning also varied across tasks. The differences across emotional contexts are consistent with a functionalist view of emotions and the kind of goals and motivations that are associated with each of the emotional contexts (Campos et al., 2004; Campos, Mumme, Kermoian, & Campos, 1994). Disappointment (or sadness) is often associated with the loss of a goal and the understanding that the lost goal must be relinquished. In this case, preparing the body for goal-related action might not be very adaptive as the goal has already been lost. Focusing on maintaining a calm response, especially due to the social nature of the task, is probably a sign of healthy regulation in the context of this disappointment task as it signals a child's attempt to adaptively engage with the environment by stopping responses that will not aid in recovering the lost goal. Our findings suggest that children's engagement in this adaptive pattern of parasympathetic regulation is in fact associated with behavioral measures of adaptive emotional functioning.

4.3 | Comparisons with previous studies on the link between RSA and emotional functioning

Although some studies have explored the links between some aspects of emotional functioning and RSA, few have used multiple measures of RSA and multiple emotional outcomes within the same study; thus, we synthesize here how our findings compare to previous studies on these associations to showcase this strength of the study. First, our finding that less augmentation (or suppression) for a cognitive challenge was associated with emotional reactivity is consistent with Calkins and Keane (2004) findings with younger children. In that study, they used an attention task while in this study we used an inhibition task; nonetheless, the similarity of our results further supports our argument that RSA during a cognitive task might better reflect a general ability to adaptively engage with the environment that is particularly relevant for emotional reactivity. Additionally, our inclusion of a strategy repertoire measure helps to clarify some of the nonfindings from previous studies. For example, as was the case in our study, Calkins and Keane (2004) also failed to find associations between a general measure of emotion regulation (i.e., ER subscale of ERC) and resting RSA. The fact that we also did not find this association but found a link with emotion regulation strategy repertoires suggests that this lack of findings might be due to a mismatch between RSA measure and emotional outcome of interest. Rather than interpreting resting RSA as uninformative for emotion regulation measures in general, our findings suggest that resting RSA is better suited for studies using strategy measures. Research on emotion regulation strategy repertoires in childhood is nascent; thus, our findings suggest novel and exciting directions for future research aiming to further explore the role of RSA on children's growing regulatory repertoires. More broadly, our finding that the level of reactivity differed across tasks fits well with the Calkins and Keane (2004) study, which documented a similar pattern. Our study extends this with older children and across disappointment and fear contexts. Thus, findings contribute to the growing body of knowledge about emotional functioning and RSA and suggest novel ways that physiological measures can inform this understanding.

4.4 | The importance of considering context to clarify the link between emotional functioning and parasympathetic regulation

As highlighted in the introduction, RSA reactivity has often been thought of as a domain-general marker of adaptive functioning. Although some research supports this (Calkins, 1997; Calkins & Keane, 2004; Obradović et al., 2010), recent research suggests that task context matters (Calkins et al., 2007; Hastings et al., 2014; Hinnant & El-Sheik, 2009) and that RSA reactivity may not be as domain-general as previously thought. Although this insight is not new, as other researchers have mentioned similar ideas in the past (e.g., Calkins & Keane, 2004), our study offers strong support for exploring RSA as a context-specific mechanism. In the current study, we sought to examine this and found strong evidence that the link between emotional functioning and RSA reactivity is most usefully interpreted within the context under which reactivity is measured. Prior studies have been limited in the information they provide about how reactivity across *several* contexts relates to emotional functioning more broadly. The differences we found across emotional and nonemotional contexts in the current study serve to highlight the complexity of these associations and the need to consider discrete contexts when examining PNS functioning as it relates to other regulatory processes. Moreover, the specificity of our findings across areas of emotional functioning strongly suggests the importance of considering not only the context under which reactivity is measured but also the construct of interest as part of a larger consideration of fit between task contexts and outcomes.

4.5 | Limitations and future directions

Some limitations of the current study should be noted. It is necessary to acknowledge the modest reliability of the parent-reported emotion regulation subscale, and future studies should aim to replicate these findings in a sample with more reliable scores of parent-reported emotion regulation. Additionally, we acknowledge that there are many contexts that would potentially influence adaptive emotional functioning beyond the three considered here. For example, children are often in social situations, and reactivity to these social situations is potentially meaningful for children's understanding of how someone else feels, an essential emotional functioning skill children acquire in childhood. Additionally, in terms of RSA acquisition, we note that different task contexts had different postural demands (standing, sitting) that could potentially have contributed to differences in the reactivity measures between tasks. However, ECG is robust and our data were not unduly affected by movement or postural artifacts. Additionally, children experience other types of discrete emotions not considered in this study, such as anger and happiness, and reactivity to these types of emotions should also relate to emotional functioning in specific ways. But, no study can explore all possible contexts and our study indicates that looking at several contexts within a single study is a necessary step toward a full understanding of emotional development. Lastly, given our modest sample size, we were unable to thoroughly explore age differences in the pattern of results. Of course, childhood is a developmental phase in which substantial improvements in emotional functioning occur, and thus, our findings should be viewed as a promising but initial step toward a more complete understanding of the relations between age, physiology, and emotional functioning in childhood.

5 | CONCLUSION

Our findings highlight the importance of considering discrete task contexts when trying to understand relations between physiological and emotional responding in childhood. This study offers some of the first empirical evidence that RSA reactivity is not a domain-general measure of emotional functioning but is best understood and conceptualized as a context-dependent marker. This insight represents an important contribution to our understanding of emotional functioning and PNS regulation in childhood.

ACKNOWLEDGMENT

We thank the families who participated in the study, and the research assistants who helped collect and code these data.

ORCID

Elizabeth L. Davis https://orcid.org/0000-0003-2599-4390

REFERENCES

Aiken, L. S., West, S. G., & Reno, R. R. (1991). *Multiple regression: Testing and interpreting interactions*. Thousand Oaks, CA: SAGE Publications Inc.

Bar-Haim, Y., Marshall, P. J., & Fox, N. A. (2000). Developmental changes in heart period and high-frequency heart period variability from 4 months to 4 years of age. *Developmental Psychobiology*, *37*, 44–56. https://doi.org/10.1002/1098-2302(200007)37:1%3C44:AID-DEV6%3E3.0.CO;2-7.

Braungart, J. M., & Stifter, C. A. (1991). Regulation of negative reactivity during the strange situation: Temperament and attachment in 12-month-old infants. *Infant Behavior and Development*, *14*(3), 349–364. https://doi.org/10.1016/0163-6383(91)90027-P.

Buss, K. A., Davis, E. L., Ram, N., & Coccia, M. (2018). Dysregulated fear, social inhibition, and respiratory sinus arrhythmia: A replication and extension. *Child Development*, *89*(3). https://doi.org/10.1111/cdev.12774.

Buss, K. A., & Goldsmith, H. H. (2000). *Manual and normative data for the Laboratory Temperament Assessment Battery: Toddler version*. Madison, WI: Psychology Department Technical Report, University of Wisconsin.

Calkins, S. D. (1997). Cardiac vagal tone indices of temperamental reactivity and behavioral regulation in young children. *Developmental Psychobiology*, *31*, 125–135. https://doi.org/10.1002/(SICI)1098-2302(199709)31:2<125:AID-DEV5>3.0.CO;2-M

Calkins, S. D., Graziano, P. A., & Keane, S. P. (2007). Cardiac vagal regulation differentiates among children at risk for behavior problems. *Biological Psychology*, *74*(2), 144–153. https://doi.org/10.1016/j.biopsycho.2006.09.005.

Calkins, S. D., & Keane, S. P. (2004). Cardiac vagal regulation across the preschool period: Stability, continuity, and implications for childhood adjustment. *Developmental Psychobiology*, *45*(3), 101–112. https://doi.org/10.1002/dev.20020.

Campos, J. J., Frankel, C. B., & Camras, L. (2004). On the nature of emotion regulation. *Child Development*, *75*(2), 377–394. https://doi.org/10.1111/j.1467-8624.2004.00681.x.

Campos, J., Mumme, D., Kermoian, R., & Campos, R. (1994). A functionalist perspective on the nature of emotion. *Monographs of the Society for Research in Child Development*, *59*(2/3), 284–303. https://doi.org/10.2307/1166150

Carthy, T., Horesh, N., Apter, A., Edge, M. D., & Gross, J. J. (2010). Emotional reactivity and cognitive regulation in anxious children. *Behaviour Research and Therapy*, *48*, 384–393. https://doi.org/10.1016/j.brat.2009.12.013.

Cisler, J. M., Olatunji, B. O., Feldner, M. T., & Forsyth, J. P. (2010). Emotion regulation and anxiety disorders: An integrative review. *Journal of Psychopathology and Behavioral Assessment*, *32*(1), 68–82. https://doi.org/10.1007/s10862-009-9161-1.

Davis, E. L., Levine, L. J., Lench, H. C., & Quas, J. A.. (2010). Metacognitive emotion regulation: Children's awareness that changing thoughts and goals can alleviate negative emotions. *Emotion*, *10*(4), 498-510. https://doi.org/10.1037/a0018428.

Davis, E. L., Quiñones-Camacho, L. E., & Buss, K. A. (2016). The effects of distraction and reappraisal on children's parasympathetic regulation of sadness and fear. *Journal of Experimental Child Psychology*, *142*, 344–358. https://doi.org/10.1016/j.jecp.2015.09.020.

Denham, S. A., Blair, K. A., DeMulder, E., Levitas, J., Sawyer, K., Auerbach-Major, S., & Queenan, P. (2003). Preschool emotional competence: Pathway to social competence? *Child Development*, *74*(1), 238–256. https://doi.org/10.1111/1467-8624.00533.

Goldin, P. R., Manber, T., Hakimi, S., Canli, T., & Gross, J. J. (2009). Neural bases of social anxiety disorder: Emotional reactivity and cognitive regulation during social and physical threat. *Archives of General Psychiatry*, *66*, 170–180. https://doi.org/10.1001/archgenpsychiatry.2008.525.

Graziano, P., & Derefinko, K. (2013). Cardiac vagal control and children's adaptive functioning: A meta-analysis. *Biological Psychology*, *94*(1), 22–37. https://doi.org/10.1016/j.biopsycho.2013.04.011.

Hastings, P. D., Klimes-Dougan, B., Kendziora, K. T., Brand, A., & Zahn-Waxler, C. (2014). Regulating sadness and fear from outside and within: Mothers' emotion socialization and adolescents' parasympathetic regulation predict the development of internalizing difficulties. *Development and Psychopathology*, *26*(4pt2), 1369–1384. https://doi.org/10.1017/S0954579414001084.

Hastings, P. D., & Miller, J. G. (2014). Autonomic regulation, polyvagal theory, and children's prosocial development. In L. M. Padilla-Walker, & G. Carlo (Eds.), *Prosocial development: A multidimensional approach* (pp. 112–127). New York, NY: Oxford University Press.

Hinnant, B., & El-Sheikh, M. (2009). Children's externalizing and internalizing symptoms over time: The role of individual differences in patterns of RSA responding. *Journal of Abnormal Child Psychology*, *37*, 1049–1061. https://doi.org/10.1007/s10802-009-9341-1.

Johnson, M., Deardorff, J., Davis, E. L., Martinez, W., Eskenazi, B., & Alkon, A. (2017). The relationship between maternal responsivity, socioeconomic status, and resting autonomic nervous system functioning in Mexican American children. *International Journal of Psychophysiology*, *116*, 45–52. https://doi.org/10.1016/j.ijpsycho.2017.02.010.

Killgore, W., & Yurgelun-Todd, D. (2005). Social anxiety predicts amygdale activation in adolescents viewing fearful faces. *NeuroReport*, *16*, 1671–1675. https://doi.org/10.1097/01.wnr.0000180143.99267.bd.

Kim, J., & Deater-Deckard, K. (2011). Dynamic changes in anger linking to developmental trajectories of internalizing and externalizing problems: The moderating role of attention. *Journal of Child Psychology and Psychiatry*, *52*, 156–166. https://doi.org/10.1111/j.1469- 7610.2010.02301.x.

Kim-Spoon, J., Cicchetti, D., & Rogosch, F. A. (2013). A longitudinal study of emotion regulation, emotion lability-negativity, and internalizing symptomatology in maltreated and nonmaltreated children. *Child Development*, *84*(2), 512–527. https://doi.org/10.1111/j.1467-8624.2012.01857.x.

Obradović, J., Stamperdahl, J., Bush, N. R., Adler, N. E., & Boyce, W. T. (2010). Biological sensitivity to context: The interactive effects of stress reactivity and family adversity on socioemotional behavior and school readiness. *Child Development*, *81*(1), 270–289. https://doi.org/10.1111/j.1467-8624.2009.01394.x.

Porges, S. W. (1986). Respiratory sinus arrhythmia: Physiological basis, quantitative methods, and clinical implications. In P. Grossman, K. Janssen, & D. Vaitl (Eds.), *Cardiorespiratory and cardiosomatic psychophysiology* (pp. 101–115). New York, NY: Plenum Press. https://doi.org/10.1007/978-1-4757-0360-3_7.

Porges, S. W. (1995). Orienting in a defensive world: Mammalian modification of our evolutionary heritage: A polyvagal theory. *Psychophysiology*, *32*, 301–318. https://doi.org/10.1111/j.1469-8986.1995.tb01213.x.

Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology*, *74*(2), 116–143. https://doi.org/10.1016/j.biopsycho.2006.06.009.

Porges, S. W. (2011). *The polyvagal theory: Neurophysiological foundations of emotions, attachment, communication, and self-regulation*. New York: W. W. Norton & Co.

Porges, S. W., Doussard-Roosevelt, J. A., & Maiti, A. K. (1994). Vagal tone and the physiological regulation of emotion. *Monographs of the Society for Research in Child Development*, *59*(2–3), 167–186. https://doi.org/10.1111/j.1540-5834.1994.tb01283.x.

Porges, S. W., Macellaio, M., Stanfill, S. D., McCue, K., Lewis, G. F., Harden, E. R., ... Heilman, K. J. (2013). Respiratory sinus arrhythmia and auditory processing in autism: Modifiable deficits of an integrated social engagement system? *International Journal of Psychophysiology*, *88*, 261–270. https://doi.org/10.1016/j.ijpsycho.2012.11.009.

Quas, J. A., Bauer, A., & Boyce, W. T. (2004). Physiological reactivity, social support, and memory in early childhood. *Child Development*, *75*(3), 797–814. https://doi.org/10.1111/j.1467- 8624.2004.00707.x.

Quiñones-Camacho, L. E., & Davis, E. L. (2018). Discrete emotion regulation strategy repertoires and parasympathetic physiology characterize psychopathology symptoms in childhood. *Developmental Psychology*, *54*(4), 718–730. https://doi.org/10.1037/dev0000464.

Raver, C. C., Jones, S. M., Li-Grining, C., Zhai, F., Bub, K., & Pressler, E. (2011). CSRP's impact on low-income preschoolers' preacademic skills: Self-regulation as a mediating mechanism. *Child Development*, *82*(1), 362–378. https://doi.org/10.1111/j.1467-8624.2010.01561.x.

Royston, P. (2004). Multiple imputation of missing values. *The Stata Journal*, *4*(3), 227–241.

Shields, A., & Cicchetti, D. (1997). Emotion regulation among school-age children: The development and validation of a new criterion Q-sort scale. *Developmental Psychology*, *33*(6), 906–916. https://doi.org/10.1037/0012-1649.33.6.906.

Suveg, C., & Zeman, J. (2004). Emotion regulation in children with anxiety disorders. *Journal of Clinical Child and Adolescent Psychology*, *33*, 750–759. https://doi.org/10.1207/s15374424jccp3304_10.

Thayer, J. F., & Brosschot, J. F. (2005). Psychosomatics and psychopathology: Looking up and down from the brain. *Psychoneuroendocrinology*, *30*, 1050–1058. https://doi.org/10.1016/j.psyneuen.2005.04.014.

Thayer, J. F., & Lane, R. D. (2009). Claude Bernard and the heart-brain connection: Further elaboration of a model of neurovisceral integration. *Neuroscience and Biobehavioral Reviews*, *33*, 81–88. https://doi.org/10.1016/j.neubiorev.2008.08.004.

Weems, C. F., Zakem, A., Costa, N. M., Cannon, M. F., & Watts, S. E. (2005). Physiological response and childhood anxiety: Association with symptoms of anxiety disorders and cognitive bias. *Journal of Clinical Child and Adolescent Psychology*, *34*, 712–723. https://doi.org/10.1207/s15374424jccp3404_13.

How to cite this article: Quiñones-Camacho LE, Davis EL. Parasympathetic regulation in cognitive and emotional challenge contexts differentially predicts specific aspects of children's emotional functioning. *Developmental Psychobiology*. 2019;61:275–289. https://doi.org/10.1002/dev.21812